ORIGINAL ARTICLE

Ergogenic response to caffeine in resistance performance, perceived pain, and female sex hormones following muscular endurance in strength-trained eumenorrheic females during early follicular phase

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ABSTRACT

This study investigates the ergogenic response to caffeine, in terms of repetitions to failure, time under tension, perceived pain, and female sex hormones (oestradiol and progesterone), following muscular endurance during the early follicular phase. Eleven strength-trained eumenorrheic females performed two consecutive trials (48 h apart). Using a double-blind crossover design, participants were randomly assigned to receive either caffeine (4 mg/kg) 1 h before exercise or a placebo. In each trial, participants performed as many repetitions of leg extension and hip adduction as possible at 65% of 1-RM. Two minutes of recovery were allocated between each exercise. Each repetition was performed at maximal velocity. Perceived pain was rated on an 11-point scale immediately after each exercise, and blood samples were drawn from each participant 30 min after completing the test. Data revealed a significant ergogenic response to caffeine in repetitions to failure for leg extension and hip adduction (p = .003 and p = .043, respectively); meanwhile, caffeine led to a significantly longer time under tension in leg extension (p = .001), with no differences in hip adduction (p = .053). In terms of perceived pain, no differences between trials were found for hip adduction (p = .724), but it was rated higher after leg extension in the caffeine trial, when compared to the placebo (p = .011). No differences were observed between trials regarding oestradiol and progesterone levels (p = .138 and p = .350, respectively). In conclusion, ingestion of 4 mg/kg of caffeine increased leg extension and hip adduction repetitions to failure, without main effects on perceived pain and sex hormones, in strength-trained eumenorrheic females during the early follicular phase.
Keywords: Sport medicine, Muscular endurance, CYP1A2, Menstrual cycle, Ergogenic, Theobromine.

INTRODUCTION

Caffeine (1,3,7-Trimethyxanthine) is one of the most widely used legal psychoactive substances in the world, consumed by both general and athletic populations (Norum et al., 2020; Del Coso et al., 2011; Mitchell et al., 2014; Sampaio-Jorge et al., 2021). It has been well-documented that caffeine improves endurance and anaerobic-based exercise (Grgic et al., 2021; Grgic et al., 2020; Aguiar et al., 2020; Graham & Spriet, 1995; Davis & Green, 2009; Mohr et al., 2011). In recent years, the consumption of anhydrous caffeine has been popularized as an ergogenic resource by athletes before resistance training (Polito et al., 2019; Grgic et al., 2021), in order to increase muscle strength and endurance (Grgic et al., 2020; Richardson & Clarke, 2016; Diaz-Lara et al., 2016; Aguiar et al., 2020; Grgic & Mikulic, 2017). The primary purpose of caffeine ingestion before muscular endurance training has been suggested not to increase muscle mass, but actually to tolerate more repetitions before reaching momentary muscle failure.

It is well-known that elevation of adenosine in the central nervous system (CNS) and peripheral tissues can induce drowsiness, tiredness, and mood swings (Adan et al., 2008). Caffeine can pass through the cerebral capillary endothelial cells, which make up blood–brain barrier (BBB), due to its high degree of lipophilicity and hydrophilicity (McCall et al., 1982; Bowtell et al., 2018; Davis & Green, 2009; Grgic & Mikulic, 2017; Polito et al., 2019; Duncan et al., 2013). The ingestion of caffeine before resistance exercise has been reported to reduce the sensation of pain and rating of perceived exertion (RPE) (Filip-Stanchik et al., 2021; Goldstein et al., 2010; Norum et al., 2020) through blocking selective adenosine A_1 and A_2a receptors in the CNS (Sampaio-Jorge et al., 2021; Norum et al., 2020; Sabblah et al., 2015; Adan et al., 2008; Ferré, 2016), thus delaying the onset of fatigue and improving performance.

Several prior studies have investigated the ergogenic effect of caffeine in the context of resistance exercise (Bowtell et al., 2018; Davis et al., 2012; Grgic & Mikulic, 2017; Polito et al., 2019; Raastad et al., 2000; Smilios et al., 2014; Wilk et al., 2019). Despite their findings, most of these studies have been primarily conducted only in men. A review by Salinero et al. (2019) revealed that only 13% of the experimental participants in research focused on ergogenic caffeine between 1978 and 2018 were women and, so, the number of females participating voluntarily in investigations examining caffeine ergogenicity on muscle strength and endurance remains very scarce (Filip-Stanchnik et al., 2021; Davis et al., 2012; Ferré, 2016; Salinero et al., 2019). The exclusion of females from caffeine-based research refers to changes in female sex hormones between phases of the menstrual cycle and the use of oral contraceptive pills (OCPs). Variations in female sex hormones can affect neuromuscular function (Norum et al., 2020), attenuating the ergogenic effect of caffeine. A few prior studies have been carried out only in women; however, improvement in resistance performance after caffeine ingestion was only demonstrated during the early follicular phase (Romero-Moraleda et al., 2019; Lara et al., 2020), or without determining the phase of the menstrual cycle (Goldstein et al., 2010; Filip-Stachnik et al., 2021). The effects of caffeine on resistance performance throughout the menstrual cycle remain unclear (Romero-Moraleda et al., 2019; Wilk et al., 2019). To the best of our knowledge, no prior study has investigated the ergogenic effect of caffeine on female sex hormones during any phase of the menstrual cycle. Therefore, it seems important to conduct research related to the effects of caffeine on muscular endurance in females during the early follicular phase.

During the early follicular phase of the menstrual cycle, oestradiol and progesterone are at low levels, but they gradually increase during the late follicular phase and reach a peak in the ovulation and luteal phases (Norum et al., 2020; Notbohm et al., 2023; Elliott et al., 2004). As the early follicular phase is characterized by the lowest concentration of catabolic progesterone (Elliott et al., 2004; Norum et al., 2020), it has been speculated that resistance training could be more comfortable in eumenorrheic athletes (Romero-Moraleda

et al., 2019; Lara et al., 2020; Norum et al., 2020). The intake of ethinylestradiol, a substance included in OCPs, inhibits cytochrome P450 1A2 (CYP1A2) (Banks et al., 2019; Lara et al., 2020; Arnaud, 2014), an enzyme responsible for caffeine metabolism (Grgic et al., 2021; Martins et al., 2020), thus altering the ergogenic effect of caffeine. However, the remaining caffeine metabolites—namely, theobromine—can still induce ergogenic benefits. In addition, numerous eumenorrheic female athletes practice resistance training during menses. This discrepancy warrants further investigation to unveil the ergogenic effect of caffeine on strength in eumenorrheic females during the early follicular phase.

Consequently, the aim of the present study is to investigate the ergogenic response to caffeine on performance outcomes, perceived pain, and female sex hormone levels following muscular endurance exercise in strength eumenorrheic females during the early follicular phase for the first time. We hypothesized that caffeine could be helpful to eumenorrheic female athletes when the use of OCPs is excluded.

MATERIAL AND METHODS

Participants
Healthy strength-trained eumenorrheic females volunteered to participate in this investigation. The study sample included 11 females (age: 26.22 ± 4.27 years, height: 165.87 ± 4.11 cm, body mass: 53.33 ± 4.26 kg, BMI: 20.98 ± 2.44 kg/m^2, training experience: 5.41 ± 2.66 years). All participants were over 18 years old and familiar with the resistance exercises. The inclusion criteria of the participants were as follows: a) to be aged between 20–30 years; b) to have been engaged in resistance training for ≥ 1 h/day, at least 3 days/week, for the previous four years; c) to have had a low daily caffeine intake (i.e., ≤ 100 mg/day); and d) to have steady duration of menstrual cycle for the previous six months (i.e., 21–35 days in length). Females taking oral contraceptive pills in the previous month; having a menstrual disorder such as amenorrhea, dysmenorrhea, or acute symptoms linked to premenstrual syndrome; having musculoskeletal injures in the previous 3 months; or who smoked were excluded from the investigation. Before the beginning of the experimental protocol, participants were fully informed of the study procedures, especially the potential side effects of caffeine consumption (e.g., temporary tachycardia and numbness), and then signed an informed written consent to participate in the study. Participants were allowed to withdraw from the study at any time. The study was approved by the Ethics Committee of Al-Ahliyya Amman University (FES-18G-31/2023). All of the study protocols were in accordance with the latest version of the Declaration of Helsinki.

Experimental design
To investigate the ergogenic response to caffeine in terms of resistance performance, perceived pain, and sex hormones in eumenorrheic females during the early follicular phase, a randomized, double-blind, placebo-controlled crossover design was used. After enrolment, participants completed two trials. They ingested opaque and unidentifiable capsules containing either caffeine or a placebo. The experimental trials were separated by 48 h, in order to ensure that they occurred during the early follicular phase. The study trials were performed in a laboratory with controlled temperature (22–24 °C) and a relative humidity of 41–47%.

Pre-experimental standardization
Participants attended four laboratory visits. The first visit involved defining and approving the procedure and then signing the informed consent. The second visit focused on collecting demographic data and determining the one-repetition maximum (1-RM). Baseline measurements (oestradiol: 63.45 ± 8.76 pg/ml; progesterone: 2.14 ± 1.24 nmol/L) were conducted during the third visit (3 days prior to commencement of the main trials). On the day of each trial, participants arrived at the laboratory between 8.00 and 11.00 a.m. in a fasting state.

The day before each experimental trial, participants were asked to avoid strenuous exercise and/or physical stress and were encouraged to refrain from the ingestion of caffeine or ergogenic aids. All participants routinely consumed three main meals during the days between trials. Additionally, they were instructed not to consume breakfast or morning coffee on the days of the trials. Participants were asked to drink 500 ml of water 2 h before each trial, in order to avoid the sensation of thirst.

One repetition maximum
One week before the commencement of the trials, each participant underwent a 1-RM test for each exercise. First, participants performed their routine 10-minute warm-up on a treadmill (Technogym, Smart Code Program, A01, Italy) at 6.5 km/h, followed by 10 repetitions of the selected exercises using 40% loads of their estimated 1-RM, with a 60 s recovery interval. After 3 minutes of passive recovery, the 1-RM test commenced, following the method described by Filip-Stachnik et al. (2021). The 1-RM test constituted the maximum weight lifted once, encompassing concentric and eccentric phases, with a 5 minute passive recovery allowed between successful attempts. A pilot test indicated no significant difference in the 1-RM values for leg extension ($t = 1.11$, $p = .62$) or hip adduction ($t = 0.82$, $p = .58$).

Intervention intake
Two trials were performed under two consecutive conditions: one involving caffeine and the other a placebo. In the experimental trial, participants received 4 mg/kg of caffeine in a capsule form (Florida Supplement Caffeine Capsule, Nutrix Research, USA) and swallowed it with 250 ml of water (18 °C) 1 h before the trial began. In the placebo trial, participants ingested an empty capsule (dextrose, CapsuleB13, China) of similar shape using the same procedure. The capsules were coded and provided by an independent nutritionist, and neither the participants nor the assistants were aware of their content.

Experimental protocol
Upon arrival at the laboratory, participants were provided with the capsule to be ingested and then rested for 60 minutes. During this time, participants were seated in the Gym room (talking or reviewing social media). They subsequently performed an adapted warm-up, which consisted of 10 minutes on the treadmill at 7 km/h and a single set of 10 repetitions for each exercise at 50% 1-RM, with a 60 s recovery interval. After a 3-minute break, participants performed as many repetitions as possible for leg extension and hip adduction at 65% of 1-RM. Two minutes of recovery were allocated between each exercise. During the test, each repetition was performed at maximal velocity, and the examiner observed and counted the number of repetitions in each exercise during both trials. Failure was defined as an inability to tolerate full repetition. All exercises were performed according to the American College of Sports Medicine guidelines (ACSM, 2010). Both experimental trials were recorded using a camera (Sony, FDR, AX43), and total repetitions were confirmed according to the footage obtained with the camera. Time under tension was obtained manually from the recorded data through the camera (using slow-speed playback). To ensure the reliability of manual data collection, three independent persons conducted the analysis from the camera footage. There were no differences between the analysis data of these three reviewers. Perceived pain was rated on the 11-point numerical received pain (NRS) scale (0—no pain to 10—worst imaginable pain) immediately after the muscular endurance test for each exercise in each trial. Blood samples (4 ml) were drawn from the left antecubital vein of each participant 30 min after the completion of each trial. Serum samples were used for all parameter analyses of oestradiol and progesterone, and they were centrifuged at 3500 rpm for 10 minutes. These hormones were analysed through immunochromatography (lateral flow assay, Japan). The reference ranges of hormones during the early follicular phase were as follows: 19.0–140 pg/ml for oestradiol and 0.181–2.84 nmol/L for progesterone.

Statistical analysis

The normal distribution of the data was verified using the Shapiro–Wilk test, and both analysed variables (female sex hormones) adhered to normal distributions ($p > .05$). Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) software (version 18.0). Between-group differences in performance outcomes and female sex hormone responses were determined using paired-sample t-tests. Cohen's effect size (d) was calculated for all statistically significant pairwise comparisons, with the magnitude of effect size interpreted as follows: ≤0.2 (trivial), >0.2–0.6 (small), >0.6–1.2 (moderate), >1.2–2.0 (large), >2.0 (very large) (Lara et al., 2020). Descriptive statistics are presented as the mean ± standard deviation. Statistical significance was set at $p < .05$.

RESULTS

Table 1 presents information about the effect of caffeine on repetitions until momentary muscle failure, time under tension, and perceived pain. Briefly, main effects of caffeine on repetitions to failure in leg extension ($p = .003$) and hip adduction ($p = .043$) were observed; furthermore, caffeine led to a significantly longer time under tension for leg extension ($p = .001$), with no differences between trials for hip adduction ($p = .053$). No differences between trials were observed in the NRS pain scale results obtained immediately after hip adduction repetitions to failure ($p = .724$), while the perceived pain was rated higher immediately after leg extension in the caffeine trial, when compared to the placebo ($p = .011$).

Table 1. Effect of caffeine and placebo on performance outcomes.

Performance outcomes	Caffeine	Placebo	Mean of Δ ± SD	95% CI	Effect size
RTF Leg extension (n)	31.7 ± 2.1	26.9 ± 1.8	2.8 ± 1.9	1.5, 4.1	0.36
TUT Leg extension (s)	32.5 ± 2.0	29.5 ±2.3	3.1 ± 1.8	1.9, 4.3	0.37
PP Leg extension	7.5 ± 0.8	6.8 ± 0.8	0.6 ± 0.7	0.2, 1.1	0.15
RTF Hip adduction (n)	34.3 ± 3.5	32.8 ± 3.7	1.5 ± 1.5	0.4, 2.5	0.04
TUT Hip adduction (s)	35.5 ± 4.1	35.0 ± 3.8	0.5 ± 0.7	0, 0.9	0.04
PP Hip adduction	6.1 ± 0.8	6.0 ± 0.8	0.1 ± 0.8	-0.5, 0.6	0.05

Note: Values are presented as mean ± SD, median, and 95% confidence intervals. Abbreviations: CI, confidence interval; RTF, repetition to failure; TUT, time under tension; PP, perceived pain.
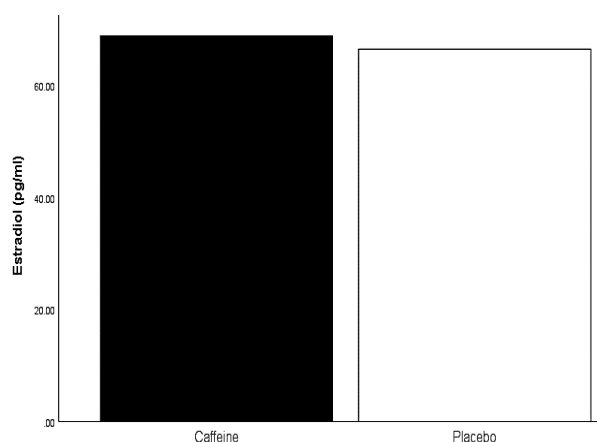

Figure 1. Ergogenic response to caffeine on oestradiol level 30 min after completion the test. No differences between trials were found in oestradiol levels ($p > .05$).
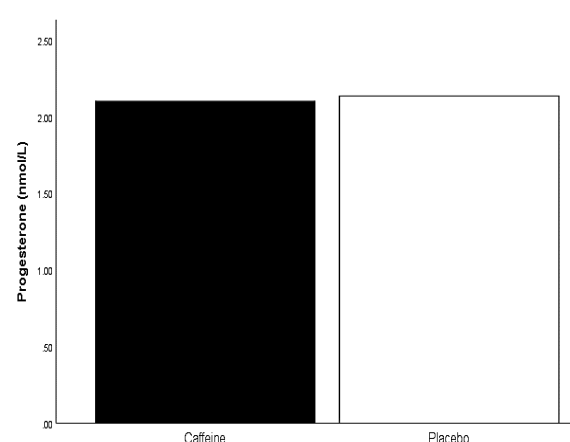

Figure 2. Ergogenic response to caffeine on progesterone level 30 min after completion the test. No differences between trials were found in oestradiol levels ($p > .05$).

In regard to female sex hormone levels (Figures 1 and 2), the paired sample t-test revealed that no differences existed between trials for oestradiol and progesterone levels (t = −1.01, *p* = 0.138; t = 0.62, *p* = .350, respectively).

DISCUSSION

This study investigated the ergogenic response to caffeine in terms of resistance performance, perceived pain, and female sex hormones following muscular endurance training through leg extension and hip adduction in strength eumenorrheic females during the early follicular phase. The main findings of this investigation were as follows: a) repetitions to failure increased after caffeine ingestion for both exercises, b) caffeine led to longer time under tension only in leg extension, with no differences between trials focused on hip adduction, c) perceived pain was rated higher only immediately after leg extension repetitions to failure in the caffeine trial, compared to the placebo, and d) no differences between trials were observed for oestradiol and progesterone levels.

With regard to momentary muscle failure, caffeine induced performance improvements through increased repetitions to failure in both leg extension and hip adduction. This result may be attributed to the ability of caffeine to boost energy expenditure (Goldstein et al., 2010; Warren et al., 2010), altering sodium/potassium ATP_{ase} pump activity (Mohr et al., 2011), and inhibiting adenosine acting on its receptors. This, in turn, delays the feeling of fatigue and stimulates the CNS (Davis & Green, 2009; Mohr et al., 2011), resulting in activation of motor unit recruitment (Warren et al., 2010). This result is in agreement with Norum et al. (2020), who found that 4 mg/kg caffeine increased the number of repetitions to failure at 60% of 1-RM during squat (45 ± 17 rep) and bench press (23 ± 6 rep), compared to placebo (39 ± 17 and 21 ± 6 rep, respectively) in Caucasian female volunteers. They reported that volunteers who performed three familiarization sessions exceeded a coefficient of variation of 10%. In the present study, the participants did not perform familiarization sessions, due to their acclimatization to resistance exercise for at least the four years prior. On the other hand, this result is in disagreement with other prior studies (Filip-Stachnik et al., 2021; Goldstein et al., 2010; Arazi et al., 2016; Sabblah et al., 2015) that did not confirm the ergogenic effects of caffeine on muscular endurance in females. For example, Filip-Stachnik et al. (2021) found no differences between 3 mg/kg or 6 mg/kg of caffeine and placebo on bench press endurance at 50% of 1-RM (33.81 ± 5.46; 35.29 ± 6.99; and 33.05 ± 6.59 rep, respectively) in 21 resistance-trained female university students (23.0 ± 0.9 years age). They suggested that females have a greater proportion of slow oxidative fibres, facilitating beneficial effects for muscular endurance using caffeine in long-term training. Goldstein et al. (2010) showed that bench press repetitions to failure was similar in placebo and 6 mg/kg caffeine groups (23.0 ± 7.1 vs. 23.1 ± 6.2 rep, respectively) in resistance-trained females. They concluded that caffeine habituation may induce intense emotional responses, affecting performance. Sabblah et al. (2015) found no difference (*p* = .059) in bench press endurance performance after ingestion of 5 mg/kg of caffeine, compared to placebo, in eight moderately active resistance females. They suggested that further research should be explored using trained participants. Arazi et al. (2016) also demonstrated no differences between 5 mg/kg or 2 mg/kg of caffeine and placebo in leg press repetitions to failure (39 ± 26.5; 47 ± 22.6; and 46 ± 15.7 reps, respectively) in female karate athletes. They suggested that the type of muscle action performed and volunteer's fitness level leads to a greater variation than the standard deviation, thus affecting the significance level.

The results of the present study indicated that 4 mg/kg caffeine led to a significantly higher time under tension during leg extension, but it had a similar effect to the placebo in hip adduction. This result could have been caused by the type of action/technique performed during leg extension and the greater number of repetitions during the muscular endurance test, increasing the period and, subsequently, the time under tension. During

leg extension, the weight is lifted reverse to gravity, whereas a participant squeezes the weight medially in hip adduction, such that gravity is ignored. Recalling the study of Filip-Stachnik et al. (2021), they showed increased time under tension during bench press after both 3 mg/kg and 6 mg/kg caffeine (57.05 ± 10.9 s and 61.76 ± 15.39 s, respectively), compared to placebo (53.52 ± 11.44 s), without any explanation of these results. Therefore, it is still necessary to unveil the ergogenic effects of caffeine on muscular endurance in females during the early follicular phase. On the other hand, Romero-Moraleda et al. (2019) demonstrated that 3 mg/kg of caffeine increased mean movement velocity during a half-squat exercise performed at maximal velocity with loads equivalent to 40%, 60%, and 80% of 1-RM, although the effect was catalogued as being of small magnitude. The authors in that study also did not determine either an explanation of the result or the mechanism through which caffeine improved movement velocity.

Caffeine had no ergogenic effects in attenuation of perceived pain immediately after leg extension repetitions to failure. The explanation of this result could refer to the greater muscular effort when muscle action potentials are activated during each contraction cycle. Motor units in the lower limbs are conditioned to slow movement and, thus, tolerant to fatigue (as occurs in long distance running). However, during muscular endurance with maximal velocity, perceived pain increases dramatically, especially when the repetitions to failure is increased. This finding is in accordance with Norum et al. (2020), who found 4 mg/kg caffeine to insignificantly decrease pain perception during squat and bench press. Similarly, Sabblah et al. (2015) showed that perceived pain during bench press and squat was unaffected by caffeine ingestion. They suggested that the light weight (40% of 1-RM) may be an important factor for failure in the reduction of perceived pain using caffeine. It has been suggested (Goldstein et al., 2010; Sabblah et al., 2015; Davis & Green, 2009; Warren et al., 2010; Sampaio-Jorge et al., 2021) that the analgesic role of caffeine is based on blocking adenosine receptors within the brain and working muscles. Caffeine acts as an adenosine antagonist, causing attenuation of muscle pain and, thus, greater time to exhaustion (Sampaio-Jorge et al, 2021; Wu & Lin, 2010). This is the available explanation for the mechanism by which caffeine enhances performance. In the present study, however, caffeine had no effect on perceived pain in leg extension. In this context, increased pain tolerance rather than a reduction in perceived pain is a governing theory linked to caffeine's effect on resistance performance (Beck et al., 2006; Warren et al., 2010).

Finally, 4 mg/kg caffeine had no effects on both oestradiol and progesterone response during the early follicular phase, with an insignificant increase in oestradiol. To the best of our knowledge, this is only the first study on the ergogenic response to caffeine in main female sex hormones during the early follicular phase of the menstrual cycle. Norum et al. (2020) explained that the absence of consideration of these hormones in their study was due to cost- and time-based limitations, and they recommended further studies on caffeine in females during different phases of the menstrual cycle. Prior studies have not measured these sex hormones due to changes in caffeine metabolism during the phases of the menstrual cycle, along with the effect of OCPs on caffeine's ergogenicity (Arnaud, 2011). Importantly, the early follicular phase has been reported to be characterized by the lowest fluctuation in oestradiol and progesterone concentrations (Elliott et al., 2004). In a systemic review, McNulty et al. (2020) showed that the effects associated with fluctuations in oestradiol and progesterone throughout the menstrual cycle on performance are elusive and conflicting, with some studies demonstrating enhanced performance during early follicular and luteal phases, while other previous studies having reported no changes in performance between different phases. However, the findings assessed in their systemic review were carried out without a caffeine intervention. In addition, female sex hormone levels in the early follicular phase are roughly similar to the same levels in females using OCPs (Norum et al., 2020). Of relevance, females taking OCPs are predisposed to CYP1A2 inactivity (Romero-Moraleda et al., 2019; Granfors et al., 2005). Ethinylestradiol, a substrate found in OCPs, may induce inhibition of CYP1A2 activity (Granfors et al., 2005; Arnaud, 2011). This liver enzyme is responsible for 90%

of caffeine metabolism, where caffeine exerts several of its beneficial effects through antagonistically binding to adenosine A_2a receptors (Banks et al., 2019). On the other hand, some prior studies (Norum et al., 2020; Goldstein et al. 2010; Romero-Moraleda et al., 2019; Filip-Stachnik et al., 2021; Sabblah et al., 2015; Lara et al., 2020) have demonstrated the ergogenic effect of caffeine on some parameters of resistance performance in females. These studies, however, did not measure the main female sex hormone levels. It has been speculated that the pharmacokinetics of caffeine might be unaffected by the menstrual cycle (McLean & Graham, 2002; Norum et al., 2020). In the present study, all participants were in eumenorrheic state and unaffected by any menstrual disorder, making investigation of the effects of caffeine on resistance exercise in females during early the follicular phase complex. Hence, further research to establish the role of caffeine on resistance exercise in females during the early follicular phase is warranted.

The present study had two main limitations. First, blood samples were collected from the participants only one time for each trial (i.e., 30 min after completion of the muscular endurance test). This could make the explanation of findings related to female sex hormones unclear. Second, no measurements of catecholamine—precisely, dopamine—were performed, which could be a factor explaining the perceived pain.

CONCLUSION

The ingestion of 4 mg/kg of caffeine in capsule form increased leg extension and hip adduction repetitions to failure and improved, to some extent, the time under tension during the muscular endurance performance, such as hip adduction. However, caffeine had no effect on perceived pain, assessed using the NRS pain scale, immediately after the muscular endurance test. Female sex hormone levels were unaffected by caffeine, although the participants were in eumenorrheic status. These outcomes might indicate that, in trained and eumenorrheic female strength athletes who do not take oral contraceptive pills, caffeine is effective for improving muscular endurance exercise.

AUTHOR CONTRIBUTIONS

Mohammad Fayiz AbuMoh'd involved in conceptualization, methodology, investigation, resources, writing-review & editing, supervision, procedure administration, and final approval the manuscript. Hatem A. Shlool involved in selection of volunteers, validation, formal analysis, data curation and collection, writing-original draft, and final approval the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

RESEARCH ETHICS AND ATHLETE CONSENT

The study was approved by the Al-Ahliyya Amman University Ethical Committee (FES-18G- 31/2023). All study procedures and potential side effects of caffeine consumption, such as temporary tachycardia, hypertension, and numbness, were explained, and participants provided written informed consent.

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