EFFECTS OF CAFFEINE SUPPLEMENTATION ON CROSSFIT PERFORMANCE IN TRAINED ATHLETES

EFECTOS DE LA SUPLEMENTACIÓN DE CAFEÍNA EN DEPORTISTAS ENTRENADOS EN EL RENDIMIENTO EN CROSSFIT

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ABSTRACT

Objective: This study aimed to compare the effects of caffeine supplementation (CAFF) on specific CrossFit performance, rate of perceived exertion (RPE), delayed-onset muscle soreness, and loss of jump ability in trained athletes. **Methods:** Eighteen participants (12 males and 6 females), all trained CrossFit athletes, were assigned to a specific CrossFit performance (Protocol Training "Diane") following a blinded and randomized consumption of caffeine. The RPE after exercise, countermovement jump, delayed-onset muscle soreness, and muscle thickness were assessed both before and after exercise. **Results:** An enhancement in CrossFit performance was reported after CAFF compared to baseline (BA) (p = 0.001), with a trend towards a decreased RPE (p = 0.056). Furthermore, higher delayed-onset muscle soreness was observed in the BA group compared to the CAFF group (p = 0.010) and the placebo group (p = 0.011). Regarding jump ability, increased performance was noted in the placebo after exercise (p < 0.001). **Conclusions:** CAFF did not improve CrossFit performance, RPE, delayed-onset muscle soreness, or jump ability compared to placebo. Although both caffeine and placebo improved performance relative to baseline, this pattern is likely due to learning or expectancy effects rather than a true ergogenic effect of caffeine.

Keywords: caffeine, functional training, ergogenic aids, nutrition.

RESUMEN

Objetivo: El estudio tuvo como objetivo comparar los efectos de la suplementación con cafeína (CAFF) sobre el rendimiento específico en CrossFit, la percepción subjetiva del esfuerzo (RPE), el dolor muscular de aparición tardía (DOMS) y la pérdida de capacidad de salto en atletas entrenados. **Métodos:** Dieciocho participantes (12 hombres y 6 mujeres), todos atletas entrenados en CrossFit® realizaron un protocolo específico de rendimiento en CrossFit® ("Diane") tras el consumo ciego y aleatorizado de cafeína. La RPE después del ejercicio, el salto con contramovimiento, el dolor muscular de aparición tardía y el grosor muscular se evaluaron antes y después del ejercicio. **Resultados:** Se observó una mejora en el rendimiento en CrossFit® después de la suplementación con CAFF en comparación con el control (CON) ($p = 0.001$), con una tendencia a una disminución de la RPE ($p = 0.056$). Además, se registró un mayor dolor muscular de aparición tardía en el grupo CON en comparación con el grupo CAFF ($p = 0.010$) y el grupo placebo ($p = 0.011$). En cuanto a la capacidad de salto, se observó un aumento del rendimiento en el grupo placebo después del ejercicio ($p < 0.001$). **Conclusiones:** La suplementación con CAFF no mejoró el rendimiento en CrossFit, el RPE, el dolor muscular de aparición tardía ni la capacidad de salto en comparación con el placebo. Si bien tanto la CAFF como el PLA mejoraron el rendimiento con respecto a la BA, es probable que este patrón se deba a efectos de aprendizaje o expectativas, más que a un verdadero efecto ergogénico de la cafeína.

Palabras clave: cafeína, entrenamiento funcional, sustancias ergogénicas, nutrición.

INTRODUCTION

CrossFit has emerged as one of the fastest-growing exercise modalities worldwide in recent years (Oliver-Lopez et al., 2022). This sport modality comprises training routines known as the workout of the day (WOD), which include various exercise modes such as weightlifting (e.g., Olympic lifting, squats, deadlifts, bench press), gymnastics (e.g., knees to elbows, lunges, pull-ups, push-ups, and handstand push-ups), and endurance exercises (e.g., rowing, running, swimming) (Claudino et al., 2018). In addition to the functional exercises employed, WODs are characterized by high intensity, often executed quickly with little to no recovery periods between sets (Sprey et al., 2016). Consequently, WODs are performed according to predefined criteria, including the load used, working time or completion, and the number of movements (De Souza et al., 2021a).

Various studies have reported that during WODs, the average heart rate exceeds 90% of the maximum heart rate, blood lactate concentrations surpass 14 mmol/L, and the rate of perceived exertion (RPE) is above 9.0 (on a 0–10 scale) at the conclusion of a training session (Tibana et al., 2018). Mechanical fatigue, quantified as the reduction in height achieved in a countermovement jump (CMJ) at the end of a training session (Claudino et al., 2012; Nájera et al., 2022), has been observed following diverse WODs (Nájera et al., 2022). Additionally, delayed onset muscle soreness has been recognized after a CrossFit session (De Oliveira et al., 2023). When comparing different types of WODs, it has been found that sessions focused on completing a set of tasks in the shortest time, referred to as "for time," increase training load, blood lactate concentrations, and RPE more significantly than sessions performed "as many repetitions as possible" (Tibana et al., 2018).

CrossFit athletes often adhere to diets such as the Paleo and Zone diets and exhibit a high prevalence of caffeine supplementation intake (De Souza et al., 2021a; Maxwell et al., 2017). While analyzing supplementation consumption patterns in CrossFit athletes, evidence has shown that the prevalence of caffeine supplementation (Fogaça et al., 2020a), is very low, lower than that observed in other sports involving weightlifting, endurance, or repeated sprints (Günalan et al., 2022; Sánchez-Oliver et al., 2019). Caffeine (1,3,7-trimethylxanthine) shares a chemical structure similar to that of adenosine. Consequently, caffeine blocks adenosine receptors A_1, A_{2A}, and A_{2B}, acting as a modulator of central nervous system activity by inhibiting parasympathetic nervous system activity (López-González et al., 2018).

At the level of the central nervous system, by blocking adenosine receptors, caffeine supplementation (CAFF) could release excitatory neurotransmitters (e.g., noradrenaline and dopamine) while at the neuromuscular level could enhance neuromuscular recruitment, potentiate the Na^+-K^+ pump, increase Ca^{2+} bioavailability in the myoplasm, and augment glycolytic activity (Burke, 2008). Based on scientific evidence, CAFF extends the time to fatigue at submaximal intensity, improves the time to cover a distance in both endurance and high-intensity events, and enhances performance in high-intensity intermittent efforts (Maughan et al., 2018). The optimal doses proposed to elicit positive effects related to physical exercise range from 3 to 6 $mg \cdot kg^{-1}$, without completely excluding the use of higher doses (9 $mg \cdot kg^{-1}$), depending on the characteristics of the individual and the type of exercise performed (Guest et al., 2021).

Currently, only one study has examined the potential ergogenic effect of CAFF in CrossFit, utilizing a training protocol consisting of a 10-minute "as many rounds as possible" session of 30 double-unders and 15 power snatches (34 kg) with 6 mg/kg of CAFF (Fogaça et al., 2020a). Given the higher fatigue levels and training load associated with "for time" WODs (Sánchez-Oliver et al., 2019), CAFF can be a vital ally in intense training, positively influencing performance completion time and fatigue in such workouts. Therefore, this study aims to be a pioneer in assessing the effects of CAFF on the performance of “for time” WODs (“Diane”), RPE, delayed-onset muscle soreness, mechanical fatigue (as assessed by CMJ), and muscle thickness.

MATERIALS AND METHODS

Participants

Trained CrossFit athletes of both sexes were recruited, with the following inclusion criteria: i) experience in CrossFit training of at least one year in the modality and mastery of the technique of all exercises used in the study, (more than three sessions per week);ii) age range (18–40 years); iii) absence of musculoskeletal injuries and/or chronic noncommunicable diseases such as cardiovascular or respiratory diseases, diabetes, or obesity; iv) non-pregnant status (for female athletes); v) non-smoker; vi) non-user of anabolic steroids; vii) no intake of anti-inflammatory drugs; viii) non-intake of sports supplements in the six months preceding the start of the study. Signed informed consent was obtained from all participants prior to data collection and after the study protocol was reviewed by the Research Ethics Committee of the Federal University of Lavras (CAAE: 20221419.7.0000.5148) and was registered and approved at ClinicalTrials (ID: 14005).

Sample size calculation

A total of 26 volunteers were initially recruited (15 men and 11 women). Following six dropouts (2 men, 4 women) and two non-completions of the WOD (1 man, 1 woman), the final sample for analysis consisted of 18 participants (12 men and 6 women). To confirm the adequacy of this sample size, a power analysis was conducted using G*Power software. Given our final sample of 18 participants and an alpha level of 0.05, the statistical analysis yielded a strong mean effect size of 0.902 ($d \geq 0.8$). Notably, previous studies investigating CrossFit and supplementation have employed sample sizes of similar magnitude, supporting the adequacy of the sample used in the present study (De Souza et al., 2021a; Fogaça et al., 2020b; Silva de Souza et al., 2024).

Experimental design

This study was a double-blind, randomized clinical trial with a placebo (PLAC)-controlled, counterbalanced, crossover design. A preliminary familiarization session was conducted, the data from which were not included in the study with familiarization of participants. The experimental protocol commenced one week following this familiarization, with the first session (Session 1) serving as the baseline condition. Randomization (www.randomizer.org), blinding, and balancing of the groups were conducted by a professor who did not participate in the study, ensuring that researchers had no access to the data until collection was complete. Therefore, after the first experimental session, where participants did not take any supplementation, 50% (n = 9) of the participants ingested either CAFF or PLAC during the second and third experimental sessions. A 72-hour washout period was implemented between all experimental sessions to minimize residual fatigue and ensure adequate recovery. All collections took place in the same environment at a Functional Box Training Gym, ensuring consistent conditions and timing for each participant to minimize potential interactions with their circadian rhythms (Drust et al., 2005). During each experimental session, nutritional intake, body composition, and physical parameters, including vertical jump ability and a specific CrossFit test, RPE, and delayed-onset muscle soreness, were assessed (Figure 1).

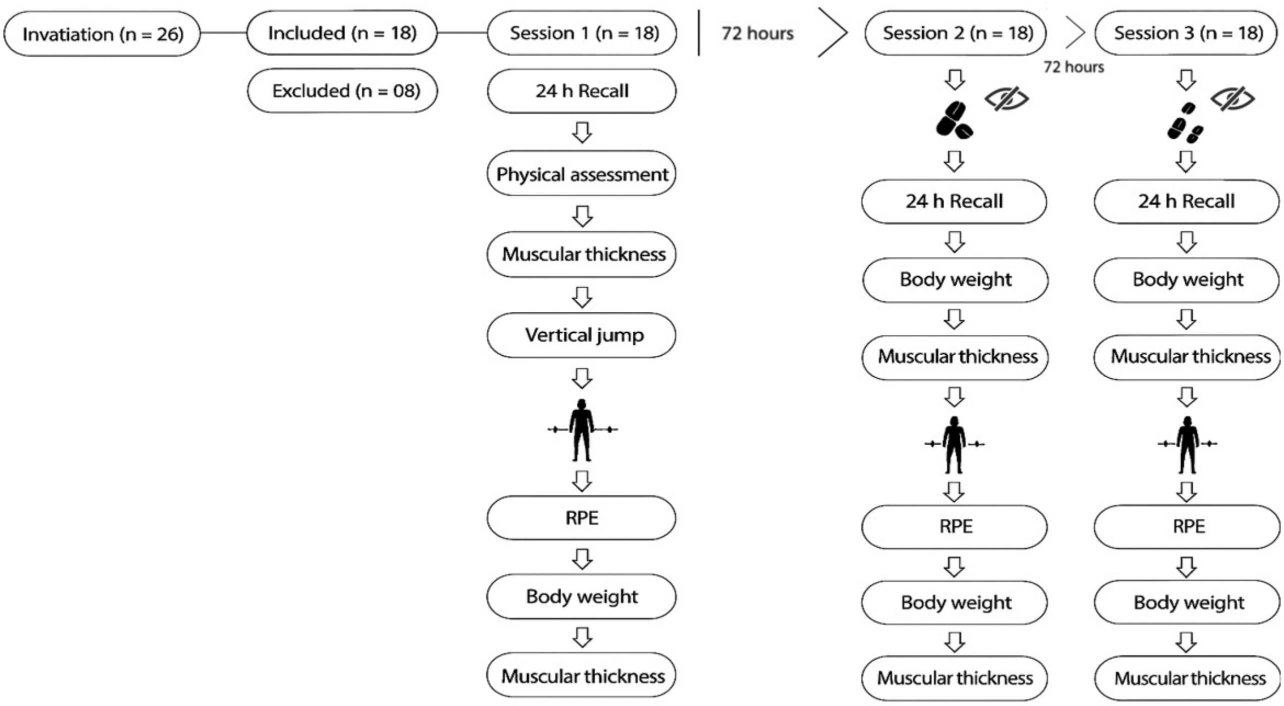

Figure 1. Experimental design of research and procedures. Source: the authors

Anthropometry and body composition assessment

To characterize the volunteers, an anthropometric evaluation was performed. Weight was measured using a digital scale with ±0.1 kg precision (Welmy Instruments, Brazil), and height was measured using a vertical stadiometer (Sanny Instruments, Brazil) with participants barefoot and their heads positioned in the Frankfurt plane. Body mass index was calculated as $\text{weight (kg)}/\text{height (m}^2)$.

In addition, subcutaneous fat and muscular thickness were assessed using the BodyMetrix BX-2000 A-mode ultrasound (Intelametrix, USA) and the BodyView Professional software. Measurements were taken on the right side of the body while the subject was standing using three-site skinfold locations according to Jackson and Pollock (Jackson & Pollock, 1978), and as instructed by the image on the computer screen. Measurements were taken from multiple sites (pectoral, abdominal, and thigh) for males and (triceps, suprailiac, and thigh) and for females. Measurements were conducted by applying transmission gel to the probe and gently placing the probe perpendicular to the site.

Measurements were taken at each location with minimal movement of the probe across the skin (± 25 mm), and care was exercised to control the probe's pressure on the skin to minimize tissue deformation. The subcutaneous fat thickness was calculated by the device software using a linear relationship between ultrasound propagation velocity and the time of flight. Each site was measured approximately two to three times, based on the software's agreement between measurements, and the average of these trials was used to represent the final thickness measurement. These site-specific subcutaneous fat thickness values were utilized to calculate %BF using the Jackson Pollock 3-site skinfold equation. Fat mass and Fat-Free Mass (FFM) were calculated from body mass and fat mass.

Supplementation protocol

During the first experimental session, participants did not take supplements to establish baseline (BA) results. In the second and third experimental sessions, 50% of the participants ingested 3 mg/kg of CAFF (± 210 mg) or maltodextrin as PLAC with water, 60 minutes after exercise, following the guidelines described by Graham (Graham, 2001). Between supplementation and exercise, participants rested until the start of the exercise. The second third experimental sessions were spaced 7 days apart to mitigate any effects from the previous supplementation (Fogaça et al., 2020a). All participants completed the sessions under BA conditions, and subsequently with CAFF and PLAC.

Nutritional intake assessment

To monitor dietary intake and its potential impact on results, a professional nutritionist interviewed participants during each experimental session. Nutritional intake was assessed using 24-hour food recalls. Using Dietbox® software and caffeine intake quantification guidelines (Heckman et al., 2010), daily energy intake, carbohydrates, lipids, proteins, and caffeine consumption by participants were calculated.

Physical performance assessment

Specific physical performance was evaluated using the benchmark "Diane," standardized according to the CrossFit brand, with the same number of repetitions and specified loads for both males and females. This benchmark comprises two distinct exercises: the deadlift, where the barbell must be lifted from the ground, extending the trunk fully until the shoulders surpass the barbell, and the handstand push-up, where participants position themselves upside down, supporting their backs against a wall. When the head touches the floor, the elbows should form a 90-degree angle relative to the floor, and the movement is completed with full arm extension, without any added weight. The loads were set at 100 kg for males and 60 kg for females. The test was concluded after performing consecutive sets of 21, 15, and 9 repetitions for each exercise, starting with the deadlift and followed by the handstand push-up. Participants were encouraged to complete the test as quickly as possible. The time to completion was recorded as a measure of specific CrossFit performance.

Before the specific CrossFit test and five minutes after its conclusion, a CMJ was conducted on a jumping platform (Jump System Pro, Cefise Biotecnologia Instruments, Brazil). Participants began with arms on their hips and legs extended, then bent their knees (to approximately 90 degrees) to initiate an explosive jump, aiming for maximum height. During the flight phase, knees were fully extended, and hands rested on the hips to minimize backward or forward movement. Jump height (cm) and power output (W/kg) were measured and analyzed.

Upon completing the CrossFit test, the Borg CR10 scale was employed to assess participants' RPE. Delayed-onset muscle soreness was gauged using a visual analog scale, where 0 represents no pain and 10 indicates maximum pain, allowing participants to quantify perceived pain in the posterior thigh muscles. Delayed-onset muscle soreness was obtained at three intervals: 24-, 48-, and 72-hours post-benchmark.

Statistical treatment

Data are presented as the mean ± standard deviation. The Shapiro-Wilk and Levene tests were applied to verify normal distribution and homogeneity of variances, respectively. A Student" t-test was used for descriptive variables, while a repeated measures analysis of variance (ANOVA-RM) was conducted to evaluate differences in nutritional intake and body composition variables. For the time in the specific CrossFit test and RPE, a generalized estimating equation model was used, which accommodates non-normal distributions (Gamma distribution with an identity link function) and accounts for correlation among repeated measures within the same participants. For CMJ variables, muscular thickness and delayed-onset muscle soreness, a two-way ANOVA-RM with the factors supplementation and time was performed. If significant differences were detected concerning time, supplementation, or the time x supplementation interaction, a Holm-Bonferroni test was performed. Additionally, the effect size of ANOVAs was calculated using partial eta squared (η_p^2), and values below 0.25 were considered small, 0.26–0.63 were considered medium, and above 0.63 were considered large. The significance level was set at $p < 0.05$. All statistical analyses were conducted using the IBM SPSS Statistics (v. 24.0, IBM Corp., USA) and Jamovi software (v. 2.6).

RESULTS

Descriptive data

Table 1 presents the sample characteristics. Significant differences between men and women were observed for the anthropometric variables: body mass, height, BMI, and body fat percentage. In contrast, no significant differences were found for age, training frequency, or habitual caffeine intake (Moreira et al., 2026).

Table 1.

Characterization of the sample.

Variable	**Total (n=18)**	**Men (n=12)**	**Women (n=6)**	***p-value***
Age (years)	28 ± 6	27 ± 5	30 ± 8	0.393
Weight (kg)	77.48 ± 13.99	83.83 ± 12.63	64.78 ± 4.90	0.003
Height (m)	1.74 ± 0.10	1.79 ± 0.09	1.66 ± 0.05	0.003
BMI (kg/m^2)	25.33 ± 2.51	26.18 ± 2.62	23.63 ± 1.09	0.003
Body fat (%)	14.38 ± 7.41	9.88 ± 3.96	23.47 ± 1.58	0.001
Workout frequency (days/weekly)	5.75 ± 0,46	5.66 ± 0.49	5.55 ± 0.54	0.317
Caffeine intake (mg/day)	41.31 ± 47.65	49.00 ± 49.69	24.63 ± 21.59	0.333

Note. * Data presented as mean ± standard deviation. Source: the authors.

Nutritional intake

Table 2 summarizes the nutritional intake of the participants across the three experimental sessions. In comparing the nutritional intake parameters among the three experimental conditions, no statistical differences were detected for any nutritional variable ($p > 0.05$).

Table 2.

Nutritional intake on the three experimental conditions.

Variable	**BA**	**CAFF**	**PLAC**	***p-value* Anova**
Daily energy intake	2082.78 ± 660.98	2099.91 ± 683.91	1961.88 ± 737.99	0.811
Carbohydrates (g)	248.91 ± 117.21	258.54 ± 106.15	243.86 ± 126.41	0.929
Carbohydrates (g/kg)	3.28 ± 1.62	3.43 ± 1.53	3.14 ± 1.69	0.822
Lipid (g)	63.06 ± 23.60	66.34 ± 34.55	56.43 ± 20.89	0.537
Lipid (g/kg)	0.83 ± 0.32	0.86 ± 0.43	0.71 ± 0.29	0.400
Protein (g)	125.23 ± 49.42	122.30 ± 48.62	123.81 ± 47.41	0.986
Protein (g/kg)	1.66 ± 0.73	1.60 ± 0.65	1.57 ± 0.61	0.904

Note. Data presented as mean ± standard deviation. Source: the authors.

Physical performance

The specific performance, assessed by the time to completion of “Diane,” indicated a statistical effect of the supplementation ($X^2 = 30.1$; $p < 0.001$), with a reduction in time (ΔTime = 62.5 s) in CAFF compared to BA ($p < 0.001$), but no differences were found in the comparison between CAFF and PLAC ($p = 0.080$). The PLAC condition resulted in a significant reduction of 43.7 s compared to BA ($p < 0.001$) (Figure 2).

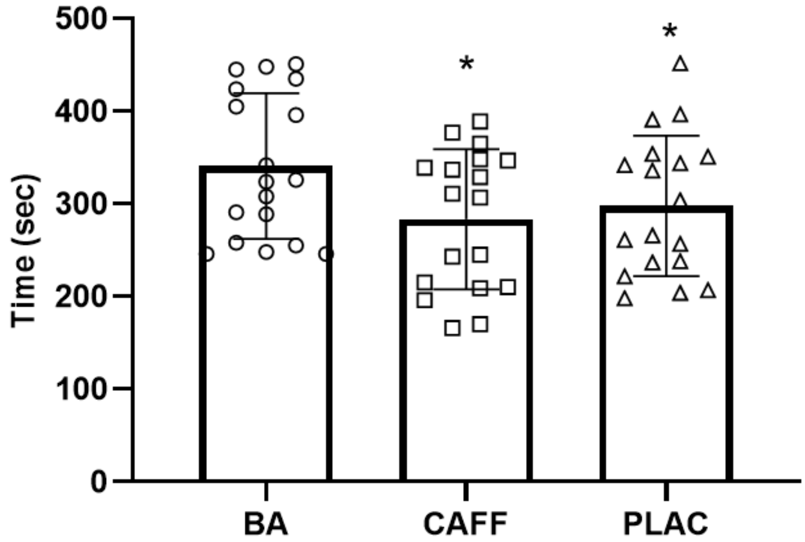

Figure 2. Time of completion of the benchmark “Diane” under the three experimental conditions. Note. *:Significantly difference compared CAFF to BA; **: Significantly difference compared PLAC to BA. Source: the authors.

Following the CrossFit test, a significant effect was observed ($X^2 = 10.2$; $p = 0{,}006$) for supplementation on RPE. Comparison of CAFF with BA showed a reduction (ΔRPE = -0.804 points; $p = 0.003$); however, there were no statistical differences in PLAC compared to BA (ΔRPE = -0.554 points; $p = 0.038$) (Figure 3).

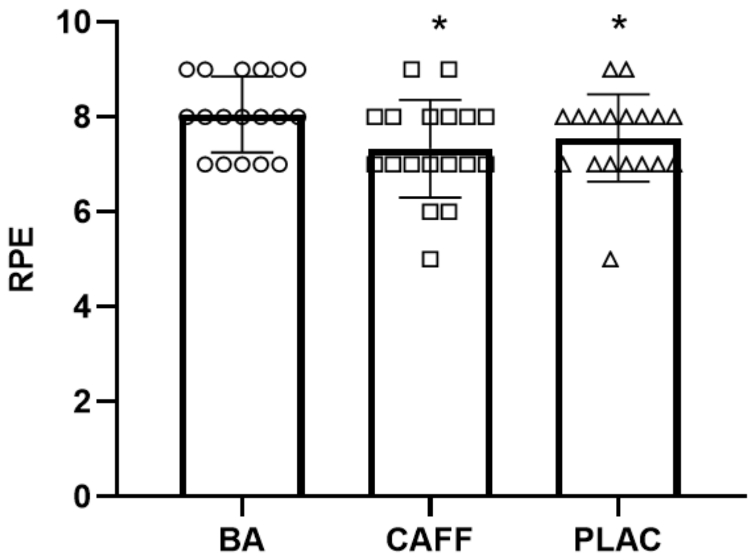

Figure 3. Rate of perceived exertion (RPE) after finishing the benchmark "Diane" under the three experimental conditions. Note. *:Significantly difference compared CAFF to BA; **:Significantly difference compared PLAC to BA. Source: the authors.

A significant main effect was found for time (F = 9.485; $p < 0.001$; $\eta^2 = 0.110$) and supplementation (F = 14.85; $p < 0.001$; $\eta^2 = 0.163$) for DOMS, with no significant time × supplementation interaction (F = 0.979; $p = 0.421$; $\eta^2 = 0.025$). DOMS was higher at 24 h for BA compared with CAFF ($p = 0.012$) and PLAC ($p = 0.016$), with no difference between CAFF and PLAC ($p = 0.918$). At 48 h, no difference was observed between BA and CAFF ($p = 0.556$), while BA remained higher than PLAC ($p = 0.021$); CAFF and PLAC did not differ ($p = 0.918$). At 72 h, no significant differences were detected among conditions (BA vs CAFF, $p = 0.987$; BA vs PLAC, $p = 0.946$; CAFF vs PLAC, $p = 0.991$) (Table 3).

Table 3.

Delayed-onset muscle soreness (DOMS) 24, 48, and 72 hours after the specific CrossFit test.

	DOMS (points)		
	24h	48h	72h
BA	3.94 ± 2.36	3.22 ± 2.73	1.33 ± 2.57
CAFF	1.44 ± 2.25*	1.56 ± 2.56	0.33 ± 0.76
PLA	1.50 ± 1.62**	0.83 ± 1.65***	0.27 ± 0.66

Note. * Statistical differences ($p < 0.05$) compared to BA vs CAFF (24h); ** Statistical differences ($p < 0.05$) compared to BA vs PLA (24h); *** Statistical differences ($p < 0.05$) compared to BA vs PLA (48h). Source: the authors.

In assessing jump ability, no statistical differences were reported in the height (cm) on CMJ for supplementation (F = 0.746; $p = 0.483$; $\eta_p^2 = 0.051$), time (F = 3.896; $p = 0.068$; $\eta_p^2 = 0.218$) or time supplementation (F = 0.678; $p = 0.516$; $\eta_p^2 = 0.046$) (Figure 4A). However, a higher jump height was observed in CMJ_{POST} compared to CMJ_{PRE} in the PLAC group ($p < 0.001$). For power on CMJ (Figure 4A), statistical differences were found for time, with an increased performance in CMJ_{POST} compared to CMJ_{PRE} (CMJ_{POST}: 47.84 ± 1.29 w/kg vs. CMJ_{PRE}: 46.40 ± 1.13 w/kg; F = 5.208; $p = 0.039$; $\eta_p^2 = 0.271$), although statistical differences in pairwise comparisons were only detected in PLAC ($p = 0.017$). No differences were detected for supplementation (F = 0.179; $p = 0.837$; $\eta_p^2 = 0.013$) or time supplementation (F = 0.699; $p = 0.506$; $\eta_p^2 = 0.048$).

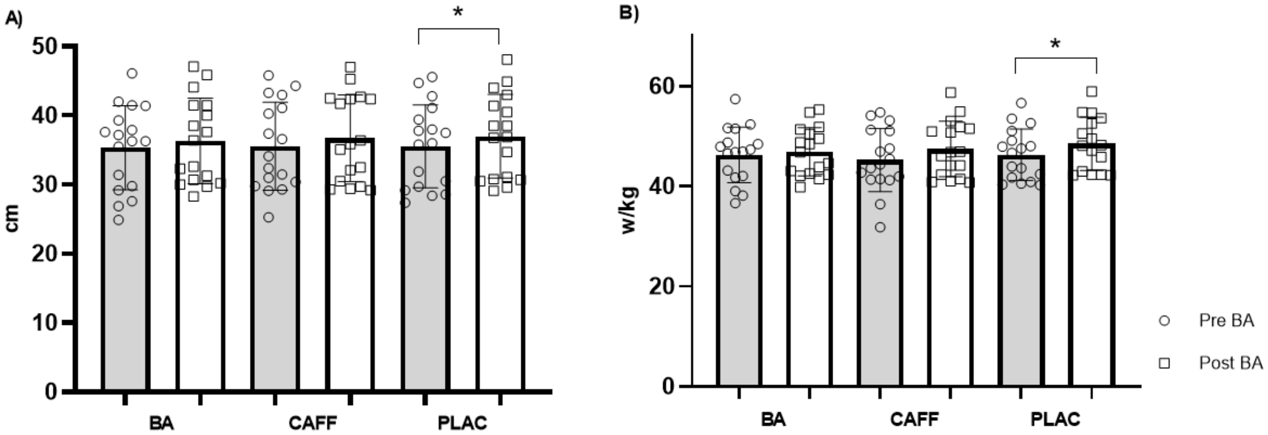

Figure 4. Vertical jump ability on the three experimental conditions. Note. *:Significantly difference compared to Pre e Post Plac (*p* < 0,001). Source: the authors.

Regarding muscle morphology, differences were detected for time (F = 55.393; $p < 0.001$; $\eta_p^2 = 0.776$), but not for supplementation (F = 1.237; $p = 0.318$; $\eta_p^2 = 0.142$) or time supplementation (F = 0.307; $p = 0.740$; $\eta_p^2 = 0.039$). Significantly greater muscle thickness was detected post-experiment compared to pre-experiment under all three conditions: BA (39.67 ± 0.84 mm vs. 37.65 ± 0.87 mm; $p < 0.001$), CAFF (40.29 ± 0.85 mm vs. 38.40 ± 0.93 mm; $p < 0.001$), and PLAC (40.09 ± 0.85 mm vs. 38.53 ± 0.85 mm; $p = 0.003$) (Figure 5).

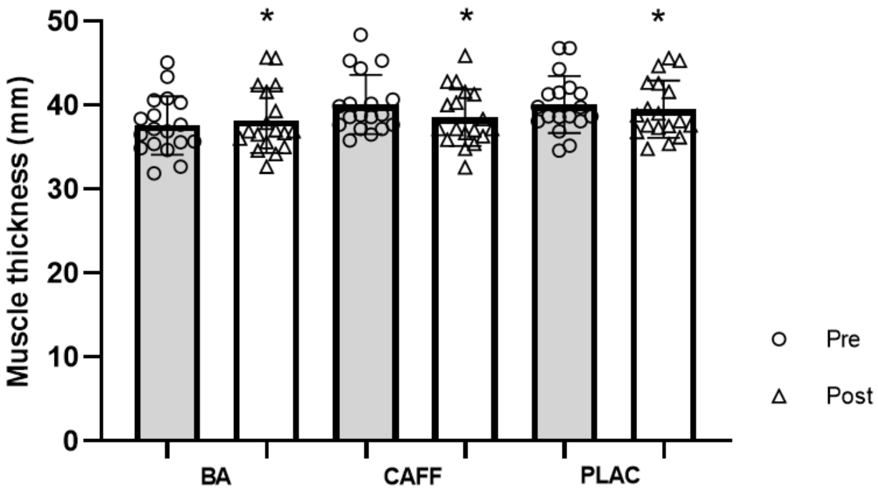

Figure 5. Muscle thickness before and after the benchmark “Diane” under the three experimental conditions. Note. *: Significantly difference compared to Pre for moments. Source: the authors.

DISCUSSION

The main findings of this study suggest that supplementation with 3 mg/kg of caffeine did not result in any increase in CrossFit performance, jumping capacity, RPE, delayed-onset muscle soreness, or muscle thickness compared to placebo. Although both CAFF and PLAC showed improvements relative to baseline, the absence of differences between the two conditions does not support an ergogenic effect of caffeine under the present experimental protocol.

The shorter time to complete the “Diane” workout after caffeine supplementation compared to BA suggests that the intake of this supplement is effective in enhancing specific CrossFit performance in trained athletes. However, this positive effect did not translate into statistically significant differences compared to PLAC, consistent with previous studies (Fogaça et al., 2020a; Stein et al., 2020). In research conducted by (Fogaça et al., 2020b),CAFF at a dosage of 6 mg/kg did not increase the number of repetitions performed over 10 minutes of rounds, consisting of 30 double-unders followed by 15 power snatches with a load of 34 kg, after a training session focused on maximal and power strength. No significant effects of 5 mg/kg CAFF and PLAC in the number of rounds completed in 20 minutes of workouts composed of 5 pull-ups, 10 push-ups, and 15 air squats compared to PLAC(Stein et al., 2020) . Nonetheless, this study reported a statistical learning effect between assessment sessions, which could affect the sensitivity to detecting the ergogenic effects of CAFF(Stein et al., 2020). In any case, the present results confirm that the protocol “for time” did not detect a statistical effect on specific CrossFit performance compared to PLAC, in accordance with specific CrossFit performance in “as many repetitions as possible” workouts (Fogaça et al., 2020a; Stein et al., 2020). However, CAFF showed an ergogenic effect compared to BA.

In the analysis of RPE, this study has reported a fastest time in the WOD used “Diane” compared to BA followed by a trend to decrease RPE (p = 0.05). Previous studies have reported a higher performance in high intensity efforts (i.e., Wingate test) with a decreased RPE and other physiological domains. For example, enhanced mood at the beginning of high-intensity exercise after CAFF, characterized by optimized tension, vigor, and subjective vitality, could predispose individuals to better performance (Domínguez et al., 2021; Jodra et al., 2020). This could be due to increased neurotransmitter synthesis(Davis et al., 2003), and the blocking of adenosine receptors in the brain after CAFF, which might limit central fatigue characterized by an accumulation of adenosine in the cortex (Pageaux et al., 2015).Therefore, the combined results on “Diane” and RPE support that CAFF alters the relationship between RPE and workload, reducing RPE at a determined load compared to BA (Tibana et al., 2018).

Regarding delayed-onset muscle soreness, the mean values obtained 24 hours post-exercise in BA (3.94 ± 2.36) align with the literature, which reports approximately 4 points after the workout called “FRAN” (Martínez-Gómez et al., 2022). Nevertheless, this study uncovered two novel findings: (i) the intensity of delayed-onset muscle soreness decreases 72 hours post-CrossFit session, and (ii) both CAFF and PLAC effectively reduce the acute phase increase in soreness magnitude. The values of delayed-onset muscle soreness 24 hours post-exercise may be mediated by peaks in lactate dehydrogenase and creatine kinase, which are explained by their release into the bloodstream after sarcolemma disruption due to very high mechanical stress (Sousa Neto et al., 2022). Therefore, the mechanical load imposed by CrossFit could activate pain signaling pathways, as reflected in increased delayed-onset muscle soreness 24 hours post-exercise, with intensity decreasing by 72 hours, a period during which statistically significant attenuation in creatine kinase levels has been recorded post-workout (Davis et al., 2003). While blocking adenosine receptors, CAFF might attenuate delayed-onset muscle soreness. However, a similar effect was observed with PLAC, possibly due to the expectancy of CAFF consumption (Shabir et al., 2018). However, when the experimental design compares a BA situation with both a CAFF and a PLAC condition, where the PLAC condition is characterized by participants believing they are consuming a caffeine-containing supplement, it has been reported that there is an enhancement in the time taken to cover a running distance. The characteristics of the experimental design in this study could promote the emergence of the expectancy of caffeine consumption phenomenon. In fact, this phenomenon could be explained because the lower time in covering the CrossFit test did not reach statistical differences in CAFF compared to PLAC, as the similar effect of CAFF and PLAC in delayed-onset muscle soreness.

Jump height loss in a CMJ has been demonstrated as an effective measure to quantify fatigue induced during a training session (Claudino et al., 2018). Contrary to our hypothesis, there was no decrease in CMJ performance after the WOD. Previous studies have reported that a WOD consisting of 150 wall balls aimed at a 3-meter-high target using a 9 kg medicine ball significantly reduced CMJ height post-exercise, which researchers considered mechanical fatigue (De Souza et al., 2021b; Sousa Neto et al., 2022). Another study reported reduced CMJ height loss post-exercise in a session involving 5 minutes of power cleans (40% 1RM), and a WOD consisting of 20 minutes of rounds of 5 pull-ups, 10 push-ups, and 15 air squats, although not in a WOD aimed at performing the maximum number of double unders over 8 sets of 20 seconds with 10 seconds of recovery (Maté-Muñoz et al., 2017). The lower limb exercise used in this study was the deadlift; it is a resistance exercise that primarily targets the posterior muscles (e.g., biceps femoris) as opposed to the anterior muscles (e.g., rectus femoris) of the knees (Martín-Fuentes et al., 2020). The recruitment of quadriceps muscle fibers and their influence on performance is greater than that of the hamstrings (Shabir et al., 2018) It is possible that the CMJ is not a reliable indicator of neuromuscular fatigue in CrossFit; nonetheless, it may be a good indicator of neuromuscular fatigue when used for exercises that impose high mechanical stress on knee extensor muscles, as other researchers have suggested (Campos et al., 2022; Claudino et al., 2012)

This study recruited a sample of trained athletes experienced in the WOD used and familiar with the CMJ and the questionnaires. This approach minimized potential confounding variables. Furthermore, considering that dietary intake could affect metabolism, nutrition was controlled by a nutritionist. It was confirmed that there were no differences in nutritional intake (including caffeine consumption) before each of the experimental sessions. However, several factors may explain the absence of significant differences between CAFF and PLAC. First, both conditions improved relative to baseline, suggesting the presence of a learning effect inherent to repeated exposure to the "Diane" workout. Second, expectancy effects cannot be ruled out, as participants in the PLAC condition may have believed they were receiving caffeine, which has been shown to elicit performance improvements like caffeine itself. Third, the selected dose of 3 mg/kg, while ergogenic in some contexts, may not have been sufficient to elicit meaningful differences in this specific type of high-intensity functional training. While the amount of CAFF recommended for ergogenic effects ranges from 3 to 6 mg/kg (Guest et al., 2021), some studies have reported higher effects at slightly greater dosages (e.g., 9 mg/kg), in resistance exercises. (Guest et al., 2021). Additionally, individual variability in habitual caffeine consumption and genetic sensitivity could have influenced responsiveness. The performance tests used, particularly the CMJ as a marker of neuromuscular fatigue, may have limited sensitivity to detect subtle differences resulting from supplementation. Lastly, the experimental design of this study might have created an expectancy effect for CAFF, potentially affecting the relationship between CAFF and PLAC.

CONCLUSIONS

Overall, although both caffeine and placebo improved performance relative to baseline, the lack of differences between the supplemented conditions (CAFF vs. PLAC) indicates that caffeine did not exert an additional ergogenic effect in CrossFit athletes under the specific conditions of this study. Although CAFF demonstrated positive effects on delayed-onset muscle soreness (DOMS) compared to the BA, the fact that the Placebo yielded similar results suggests that the benefit in recovery may be attributed to non-pharmacological factors, such as the placebo effect. In summary, these findings reinforce the importance of including placebo and baseline comparisons when evaluating the effects of supplementation in repeated high-intensity training protocols.

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