Effects of acute caffeine ingestion on muscle strength, muscular endurance, rating of perceived exertion, and pain perception during strength exercise until the failure

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Abstract

Purpose

We aimed to examine the effects of acute caffeine ingestion on muscular strength, muscular endurance, rating of perceived exertion (RPE) and pain perception (PP) during strength exercise to failure.

Methods

Thirteen subjects (6 males, 7 females, 21.30 ± 0.71 years) participated in this randomized, double-blind, controlled experimental study. Participants ingested caffeine capsules (5 $mg \cdot kg^{-1}$) or placebo one hour before a resistance exercise session at 90% 1RM and 50% 1RM, separated by at least 48 hours.

Results

The number of repetitions performed in the first and second series at 90% of 1RM of the bench press was significantly higher ($p < 0.05$) in the caffeine condition than the placebo. In the back squat, the first set in the caffeine condition was significantly greater ($p < 0.05$) in comparison to placebo. At 50% 1RM, the number of repetitions was higher in the caffeine session than the placebo in the bench press, back squat and leg press exercises ($p < 0.05$). RPE at 50% 1RM was lower ($p < 0.05$) in the caffeine session compared to the placebo session in the bench press, back squat, and supine row. The PP at 90% of 1RM was lower ($p < 0.05$) in the bench press in the first and second series about the placebo session.

Conclusion

In conclusion, caffeine intake can be used to obtain greater performance in strength training with lower PP and muscular endurance with lower RPE.

INTRODUCTION

Caffeine (1, 3, 7-trimethylxanthine) is one of the most widely consumed psychoactive substances worldwide, being found in many popular food products, such as coffee, tea leaves, energy drinks, and chocolate [1]. Besides being present in products for food consumption, caffeine is a common component in some medications as an antagonizing agent of the calming effect in widely circulated drugs [2], being a substance of fast and efficient absorption by the gastrointestinal tract, and reaches its peak concentration in the bloodstream between 15 and 60 minutes after its ingestion [3]. Caffeine dosages close to 5 $mg \cdot kg^{-1}$ [4] appears to exert effects on increased wakefulness, diuresis, heart rate and metabolic function, and decreased sleepiness, fatigue, perceived exertion, and pain perception (PP) [5], with no apparent adverse effects in healthy adults [6].

The fatigue process is associated with a higher rating of perceived exertion (RPE) and PP, considered a high limiting factor for physical performance [7]. Thus, several studies [4, 8–10] have provided evidence of the acute ergogenic effects of caffeine on muscle strength, muscular endurance, RPE and PP in trained [11], untrained [12] and athletes [13]. However, the results are not overall consistent. For instance, [4] reported a lower RPE and PP and increase in repetitions to failure at 60% of 1 repetition maximum (1RM) in the bench press after caffeine ingestion (5 $mg \cdot kg^{-1}$) in moderately trained men. Similarly, [8] demonstrated an increase in strength (1RM) in the bench press after acute caffeine ingestion (5 $mg \cdot kg^{-1}$) compared to the placebo group. On the other hand, [9] showed that caffeine intake (6 $mg \cdot kg^{-1}$) do not have any ergogenic effect on repetitions to failure at 60% of 1RM in the bench press. Likewise, [10] did not report positive effects of 3 $mg \cdot kg^{-1}$ of caffeine to perform leg extension during a 10RM test in men and women. The resistance exercise protocol seems to be a cause for heterogenous results regarding the effect of caffeine. Indeed, resistance exercise can be designed to focus on different physical attributes, such as muscular strength (high load, less repetitions) or muscular endurance (moderate load, more repetitions). Recent systematic reviews have compared various training protocols [14, 15], which have shown that caffeine intake can increase performance in both muscular endurance and strength training. However, the gains in muscular endurance are comparatively greater, and there may be differences in the specific exercises and muscle groups targeted.

Thus, this study aimed to examine the effects of acute caffeine ingestion (5 mg·kg^{-1}) on two resistance exercise intensity zones, one closer to muscular strength (90% 1RM), and another close to muscular endurance (50% 1RM). Performance, RPE, and PP were assessed in physically active young men and women. We hypothesize that acute caffeine ingestion could reduce RPE and PP on both intensity zones (strength and endurance) leading to a performance increase.

METHODS

Participants

All procedures were carried out according to resolution 466/2012 of the National Health Council and to the Declaration of Helsinki for experiments to be conducted on humans. After approval by the local Ethics Committee for Research on Human Subjects (protocol number: 3.951.491), the subjects were informed about the study procedures and possible effects of caffeine intake and gave written informed consent.

A total of 13 volunteers (6 males, 7 females, 21.30 ± 0.71 years), healthy and physically active, participated in the study (Table 1). The habitual average caffeine intake of the participants was assessed through a questionnaire [16] and all participants were considered low habitual caffeine users (89.56 ± 7.1 mg·day^{-1}). The following exclusion criteria were considered: use of ergogenic substances or anabolic steroids, smoking, alcohol use, and any type of injury that made it difficult to perform the exercises. The subjects were instructed not to eat food for 2 hours before the experimental sessions and, on the days of data collection, not to perform physical activities and not to intake caffeinated substances.

Table 1
General subject's characteristics and resistance exercise loads in the 1 repetition maximum test. Data expressed as mean and (±) standard deviation.

	Mean ± SD **(n = 13)**
Age (years)	21.30 ± 0.71
Body mass (kg)	71.96 ± 2.97
Height (m)	1.68 ± 0.02
BMI (kg·m^{-2})	25.29 ± 0.57
Body fat (%)	22.86 ± 1.28
Bench press 1RM (kg)	59.53 ± 7.03
Supine row 1RM (kg)	67.07 ± 6.21
Back squat 1RM (kg)	96.15 ± 8.63
Leg press 1RM (kg)	245.77 ± 22.95
BMI = body mass index; 1RM = 1 repetition maximum	

General procedures

This study was conducted in a double-blind, randomized, cross-over and controlled design. Data collection took place over five days, with intervals of at least 48 hours between sessions. All testing took place between 9.00 am and 11.00 am with each condition taking place at the same time for each participant to avoid circadian variation and the subjects were instructed to maintain their eating habits during the experiment and their exercise training during the days between the tests. On the first visit, subjects were submitted to a demographic data questionnaire, body composition measurements, a maximum repetition test (1RM) in the bench press, back squat, supine row, and leg press exercises, and familiarization with the rating of perceived exertion and pain perception scales. At the other visits, exercise sessions were randomized as follows: (i) one session without caffeine intake at 50% of 1RM (PLA50%), (ii) one session without caffeine intake at 90% of 1RM (PLA90%), (iii) a session with ingestion of 5 mg·kg^{-1} caffeine at 50% of 1RM (CAF50%) and (iv) a session with ingestion of 5 mg·kg^{-1} caffeine at 90% of 1RM (CAF90%). Caffeine capsules were ingested 1 hour before each exercise session with 200ml of water, as plasma caffeine concentration is maximal 60 minutes after ingestion of caffeine [17]. During this period, the subjects remained seated (talking or reading). In all sessions, the participants warmed up for 5 minutes by cycling on a stationary bicycle. Subsequently, the subjects performed three sets until exhaustion in the bench press, back squat, supine row, and leg press exercises at 50% 1RM or 90% 1RM, with a 3 minutes recovery interval and 2 seconds cadence for each of the concentric and eccentric phases. Exhaustion was considered when the subject could not maintain the stipulated cadence. Subjects were verbally encouraged by the same researcher to complete as many valid repetitions as possible. The number of repetitions per set was recorded. After each set, RPE was assessed using the OMNI-RES scale [18] and PP was assessed using the scale described by Cook et al. [19].

Body composition

Body mass and height measurements were obtained using a scale (Toledo®) and a stadiometer (Sanny®). The body mass index (BMI) was calculated as weight (kg)/height (m)^2. The percentage of relative body fat was estimated using the skinfold technique, in which body density was calculated using the seven-fold protocol proposed by Jackson and Pollock [20] and Jackson and Pollock [21] collected at each point in a rotational sequence on the right side of the body, being recorded the average value of three measures. The measurements were performed by a single evaluator, using a skinfold caliper (Lange®, Cambridge Scientific Instruments, Cambridge, Maryland, USA). After calculating the body density, it was converted to percentage of body fat using the equation proposed by Siri [22].

One maximal repetition test (1RM)

Initially, the subjects performed a warm-up with 8–10 repetitions in each exercise with 50% of the estimated 1RM load. After 1–2 minutes, the subjects performed 4–6 repetitions with 80% of the estimated 1RM load. After at least 3 minutes, the 1RM test was started. Participants were allowed up to five attempts to reach the value of 1RM in each exercise, with a recovery interval of at least 3 minutes. If the 1RM load was not determined, subjects were required to retake the test within 48 hours. The reliability of the 1RM protocol has been tested elsewhere [23],[24].

Rating of perceived exertion (RPE) and pain perception (PP)

After each set of each exercise, RPE was evaluated using the OMNI-RES scale [18] ranging from 0 to 10, with 0 being "extremely easy" and 10 "extremely difficult". For PP, the scale described by COOK et al. [19] ranged from 0 to 10, with 0 marking "no pain at all" and 10 marking "extremely intense pain".

Supplementation protocol

During the caffeine ingestion sessions, subjects ingested a capsule containing 5 mg·kg^{-1} of pure caffeine (*Dias da Cruz Farmácia de Manipulação*, Brasília, Distrito Federal, Brazil), with 200 ml of water. Based on previous findings [25], this dose can lead to plasma concentrations of caffeine ranging from approximately 30 to 40 µM·L^{-1}. During the placebo sessions, subjects ingested a capsule containing dextrose, with the same amount of water ingested under caffeine conditions. Caffeine and placebo were manipulated into capsules of the same size, color, and smell so that the subjects and the researcher directly involved in the data sampling were unaware of the substance ingested. All capsules were ingested 1 hour before the test to allow sufficient time to increase blood caffeine levels [26]. Caffeine dosages for each subject were prescribed by a nutritionist.

Statistical analysis

The Shapiro–Wilk test was used to verify the distribution of the data and the Levene's test to verify the homogeneity of the variances. Data were expressed as mean ± standard deviation (SD) and relative difference (%). Two-way ANOVA (PLA/CAF x number of sets) with repeated measures was used to test differences between the sets of each exercise in relation to the different sessions and Tukey's post-hoc test was used to identify significant results. Furthermore, Cohen's d was used to verify the effect size (ES) of the comparisons [27]. The following classification to measure the magnitude of effect size was used: small, $d = 0.2$ to 0.49, moderate, $d = 0.5$ to 0.79, and large, $d > 0.8$. The significance level was set at $p < 0.05$. The level of significance adopted was $p < 0.05$. All procedures were performed using SPSS 26 (IBM Corporation, New York, NY, USA)

RESULTS

According to the study findings, consuming caffeine led to an overall improvement in performance by 9%. Specifically, at 90% of 1RM the performance increased by 6%, while at 50% of 1RM, the performance increased by 10%.

Repetitions at 90% of 1RM

According to the results in Table 2, the number of repetitions in series 1 and 2 of the caffeine condition in bench press was higher than the placebo condition (p = 0.0.35; 0.005, respectively). Further, in sets 1 and 2 of the caffeine condition, the number of repetitions was higher than in set 3 (p = 0.016; 0.002, respectively). In set 1 of the back squat, the number of repetitions was higher compared to the placebo condition (p = 0.004). In the supine row, fewer repetitions were performed in set 3 compared to set 1 in the placebo condition (p = 0.001). In the leg press, set 2 of the caffeine condition in bench press was lower than the placebo condition (p = 0.001).

Table 2

Number of repetitions to failure performed in each set at 90% 1RM in placebo and caffeine (5 mg·kg^{-1}) conditions. Data expressed as mean and (±) standard deviation.

	Bench press			**Back squat**			**Supine row**			**Leg press**		
	PLA	CAF	ES	PLA	CAF	ES	PLA	CAF	ES	PLA	CAF	ES
Set 1	4.92 ± 0.52	6.30 ± 0.67*	2.30	4.84 ± 0.47	8.46 ± 1.16*	4.09	6.61 ± 0.47	5.92 ± 0.52	1.39	7.23 ± 0.60	5.92 ± 0.68	2.04
Set 2	4.23 ± 0.44	6.15 ± 0.43*[1]	4.41	4.69 ± 0.85	5.61 ± 0.34	1.42	6.07 ± 0.52	5.46 ± 0.48	1.21	6.69 ± 0.75	4.61 ± 0.79*	2.70
Set 3	4.69 ± 0.51	4.23 ± 0.16[1]	1.21	3.53 ± 0.58	5.07 ± 0.53	2.77	5.30 ± 0.47[1]	4.84 ± 0.49	0.95	5.76 ± 0.80	5.61 ± 0.71	0.19

PLA = placebo session; CAF = caffeine session; ES = effect size; *=significant difference to PLA; [1]= significant difference to set 1.

Repetitions at 50% of 1RM

For the exercises performed at 50% of 1RM, the number of repetitions in the bench press in sets 2 and 3 were lower than in set 1 in both conditions (p = 0.001; 0.004, respectively). Furthermore, in the third set of the caffeine condition, more repetitions were performed compared to the placebo condition (p = 0.040). In the back squat, the number of repetitions was lower in sets 2 and 3 than in set 1 in the placebo condition (p = 0.005; 0.001, respectively) and set 3 compared to set 1 in the caffeine condition (p = 0.016). In condition comparisons, participants who ingested caffeine did more repetitions in sets 2 and 3 compared to placebo (p = 0.036; 0.021, respectively). In the supine row, have no significant difference between conditions ($p > 0.05$), but the number of repetitions in set 1 was lower than in sets 2 and 3 in both conditions (p = 0.001 for all). In the leg press, the repetitions in set 3 in the caffeine condition were significantly higher compared to the placebo condition (p = 0.039). The repetitions in set 3 of the placebo condition were lower than in set 1 (p = 0.010). See Table 3.

Table 3

Number of repetitions to failure performed in each set at 50% 1RM in placebo and caffeine (5 mg·kg^{-1}) conditions. Data expressed as mean and (±) standard deviation.

	Bench press			Back squat			Supine row			Leg press		
	PLA	CAF	ES	PLA	CAF	ES	PLA	CAF	ES	PLA	CAF	ES
Set 1	20.23 ± 2.05	21.15 ± 1.24	0.54	19.84 ± 1.33	20.69 ± 1.45	0.61	19.23 ± 1.61	17.92 ± 1.07	0.95	14.00 ± 1.57	15.92 ± 1.25	1.35
Set 2	14.30 ± 1.50[1]	14.92 ± 0.82[1]	0.51	14.30 ± 1.49[1]	17.15 ± 1.12*	2.16	13.07 ± 1.01[1]	14.15 ± 0.83[1]	1.16	12.38 ± 1.05	15.00 ± 1.13	2.40
Set 3	11.53 ± 1.06[1]	13.53 ± 1.02*[1]	2.88	12.53 ± 1.15[1]	15.00 ± 1.56*[1]	1.80	12.46 ± 1.04[1]	13.84 ± 0.96[1]	1.37	11.15 ± 1.06[1]	13.84 ± 1.14*	2.44

PLA = placebo session; CAF = caffeine session; ES = effect size; *=significant difference to PLA; [1]= significant difference to set 1.

Rating of perceived exertion

Table 4 shows the RPE in the exercises at 90% of 1RM. No significant differences between caffeine and placebo conditions ($p > 0.05$). However, there were differences in all sets of all exercises in the caffeine condition. In the bench press and supine row, the RPE was significantly higher in sets 2 and 3 about set 1 ($p = 0.023$; 0.034, respectively). In the back squat ($p = 0.006$) and leg press (0.018), the RPE was higher in set 3 than the set 1. The placebo condition only differed in sets 2 and 3 in the back squat exercise compared to set 1 ($p = 0.007$; 0.044).

Table 4

Rating of perceived exertion in each set at 90% 1RM in placebo and caffeine (5 mg·kg^{-1}) conditions. Data expressed as mean and (±) standard deviation.

	Bench press			Back squat			Supine row			Leg press		
	PLA	CAF	ES	PLA	CAF	ES	PLA	CAF	ES	PLA	CAF	ES
Set 1	5.84 ± 0.55	5.30 ± 0.62	0.92	6.46 ± 0.58	6.53 ± 0.63	0.11	6.38 ± 0.53	6.07 ± 0.62	0.53	7.46 ± 0.61	7.07 ± 0.51	0.69
Set 2	6.15 ± 0.37	6.23 ± 0.57[1]	0.14	7.23 ± 0.57[1]	7.46 ± 0.62	0.38	6.61 ± 0.51	7.15 ± 0.50[1]	1.06	7.84 ± 0.52	7.76 ± 0.55	0.14
Set 3	6.61 ± 0.50	6.23 ± 0.54[1]	0.73	7.61 ± 0.47[1]	7.23 ± 0.65[1]	0.67	6.76 ± 0.65	7.15 ± 0.57[1]	0.63	8.38 ± 0.26	7.76 ± 0.50[1]	1.55

PLA = placebo session; CAF = caffeine session; ES = effect size; [1]= significant difference to set 1.

At 50% of 1RM, the RPE was significantly lower in the caffeine condition compared to the placebo in the last set of the bench press ($p = 0.028$) and supine row ($p = 0.027$) and the second set of the back squat ($p = 0.041$). In the placebo condition, RPE was higher in sets 2 and 3 of the bench press ($p = 0.002$; 0.001) and supine row ($p = 0.020$), set 2 in the back squat ($p = 0.005$), and set 3 of the leg press (0.XX) than the set 1. In the caffeine condition, RPE was increased in set 3 of the bench press ($p = 0.015$) and back squat ($p = 0.007$), sets 2 and 3 of the supine row ($p = 0.007$; 0.018, respectively) compared to set 1. See Table 5.

Table 5

Rating of perceived exertion in each set at 50% 1RM in placebo and caffeine (5 mg·kg^{-1}) conditions. Data expressed as mean and (±) standard deviation.

	Bench press			**Back squat**			**Supine row**			**Leg press**		
	PLA	CAF	ES	PLA	CAF	ES	PLA	CAF	ES	PLA	CAF	ES
Set 1	5.46 ± 0.56	5.23 ± 0.50	0.43	6.61 ± 0.51	5.69 ± 0.53	1.76	6.00 ± 0.45	5.23 ± 0.45	1.55	6.38 ± 0.52	6.30 ± 0.57	0.14
Set 2	6.61 ± 0.53^1	5.69 ± 0.59	1.64	7.84 ± 0.38^1	6.69 ± 0.49*	2.62	6.76 ± 0.52^1	6.15 ± 0.56^1	1.12	7.23 ± 0.57	6.69 ± 0.57	0.94
Set 3	6.92 ± 0.51^1	5.84 ± 0.43^1*	2.29	7.53 ± 0.48	6.92 ± 0.60^1	1.12	7.07 ± 0.45^1	6.23 ± 0.61^1*	1.56	7.61 ± 0.47^1	6.84 ± 0.61	1.41

PLA = placebo session; CAF = caffeine session; ES = effect size; *=significant difference to PLA; [1]= significant difference to set 1.

Pain Perception

Table 6 shows the PP in the exercises at 90% of 1RM. Set 2 and 3 in the bench press (p = 0.045; 0.049, respectively) and set 1 of supine row (p = 0.017) of the caffeine condition had a lower value than the placebo condition. Set 3 of the bench press was higher than set 2 (p = 0.040), whereas, set 3 of the supine row was increased compared to set 1 in the placebo condition (p = 0.023).

Table 6

Muscle pain perception in each set at 90% 1RM in placebo and caffeine (5 mg·kg^{-1}) conditions. Data expressed as mean and (±) standard deviation.

	Bench press			**Back squat**			**Supine row**			**Leg press**		
	PLA	CAF	ES	PLA	CAF	ES	PLA	CAF	ES	PLA	CAF	ES
Set 1	1.00 ± 0.32	0.46 ± 0.27*	1.82	1.84 ± 0.63	1.15 ± 0.47	1.24	0.61 ± 0.33	0.46 ± 0.24*	0.52	1.46 ± 0.46	1.61 ± 0.65	0.26
Set 2	0.96 ± 0.32	0.69 ± 0.26*	0.24	1.69 ± 0.41	1.61 ± 0.54	0.16	1.07 ± 0.41	0.92 ± 0.28^1	0.35	2.07 ± 0.43	1.76 ± 0.64	0.56
Set 3	1.15 ± 0.40^2	1.30 ± 0.71	0.26	1.76 ± 0.46	1.30 ± 0.39	1.07	1.15 ± 0.40	0.92 ± 0.32^1	0.32	1.92 ± 0.52	1.76 ± 0.65	0.27

PLA = placebo session; CAF = caffeine session; ES = effect size; *=significant difference to PLA; [1]= significant difference to set 1; [2]= significant difference to set 2.

Regarding the PP at 50% of 1RM, no differences were found between caffeine and placebo conditions (p > 0.05). In the placebo condition, sets 2 and 3 were higher than set 1 in the bench press (p = 0.003; 0.008), back squat (p = 0.039; 0.007), and supine row (p = 0.014; 0.001), already caffeine condition, sets 2 and 3 were higher than set 1 in the supine row (p = 0.039; 0.008) and set 3 compared to sets 1 and 2 in leg press (p = 0.001; 0.041). See Table 7.

Table 7

Muscle pain perception in each set at 50% 1RM in placebo and caffeine (5 mg·kg^{-1}) conditions. Data expressed as mean and (±) standard deviation.

	Bench press			**Back squat**			**Supine row**			**Leg press**		
	PLA	CAF	ES	PLA	CAF	ES	PLA	CAF	ES	PLA	CAF	ES
Set 1	1.46 ± 0.46	1.92 ± 0.38	1.09	3.15 ± 0.60	2.76 ± 0.65	0.62	1.76 ± 0.46	2.38 ± 0.64	1.11	3.69 ± 0.63	3.07 ± 0.68	0.94
Set 2	3.00 ± 0.48[1]	2.61 ± 0.62	0.70	3.84 ± 0.63[1]	3.00 ± 0.69	1.27	4.00 ± 0.73[1]	3.07 ± 0.66[1]	1.33	4.38 ± 0.67	3.69 ± 0.51	1.15
Set 3	3.30 ± 0.65[1]	2.92 ± 0.61	0.60	4.00 ± 0.72[1]	3.07 ± 0.67	1.33	4.15 ± 0.65[1]	3.46 ± 0.69[1]	1.02	4.15 ± 0.64	4.30 ± 0.64[1,2]	0.23

PLA = placebo session; CAF = caffeine session; ES = effect size; [1]= significant difference to set 1; [2]= significant difference to set 2.

DISCUSSION

The present investigation examined the effects of acute caffeine ingestion (5mg·Kg^{-1}) on muscular strength (90% 1RM), muscular endurance (50% 1RM), RPE, and PP in the bench press, back squat, supine row and leg press in young men and women physically active. The main findings were: (1) In general, consuming caffeine led to an improvement in performance by 9%. Specifically, at 90% of 1RM the performance increased by 6%, while at 50% of 1RM, the performance increased by 10%. (2) The ingestion of 5mg·kg^{-1} caffeine increases strength performance at 90% of 1RM in the first sets of bench press (sets 1 and 2) and back squat (first set); (3) Ingestion of caffeine increases muscular endurance performance at 50% of 1RM in the last sets of bench press (last set), back squat (sets 2 and 3), and leg press (last set); (4) The RPE has no considerable changes in the 90% 1RM condition, but at 50% of 1RM, it has a lower number in the third set of bench press and the second series of the back squat; (5) The PP has lower values only in the 90% 1RM (bench press) and no changes at 50% of 1RM.

Regarding the number of repetitions, the present study showed a better performance of the caffeine session in the first series in the condition of 90% of 1RM in the bench press and back squat exercises in comparison with the placebo session, and at 50% of 1RM in the last series of bench press, back squat and leg press. Indeed, caffeine ingestion blocks adenosine A1 and A2 receptors in the central nervous system (CNS) by increasing the permeability of the sarcoplasmic reticulum to calcium ions, allowing the reduction of the excitability threshold and longer duration of muscle contraction [28]. Recently, Grgic et al. [28] demonstrated that carriers of the C allele of adenosine A2a (ADOR2A C) respond better to low doses of caffeine (3mg.kg^{-1}) compared to other alleles, suggesting improved muscle performance in some individuals. In addition, Warren et al. [29] indicate that caffeine has more pronounced effects on large muscle groups, as these may contain more significant amounts of myofibrils and calcium receptors.

The results of the rating of perceived exertion (RPE) align with several studies that have found no significant difference in RPE after caffeine consumption during strength exercises [4, 11]. It's possible that the absence of a glycogen-depleting activity at 90% of 1RM could explain why caffeine doesn't seem to affect RPE during these exercises. Many studies on trained subjects[30–32] support this explanation, and it may also apply to exercises at 50% of 1RM. As for pain perception, studies have yielded similar results [7], with lower average scores reported in muscular strength but no significant results in muscular endurance. One potential explanation for this finding is that participants may have had difficulty accurately communicating their pain and exertion levels during the exercises.

Some limitations need to be taken into consideration in this study. It can be highlighted that the small sample size of the participants may result in an adverse effect on the other studies. The plasma concentration of caffeine was not measured, and therefore we cannot confirm the bioavailability of this substance in all study subjects. Furthermore, caffeine has an individualized physiological action [28], allowing some people to demonstrate a superior ergogenic effect than others. Finally, because this is an acute study, we cannot verify the influences of continuous caffeine use on long-term muscular strength or endurance. So, the traditional double-blind design used in studies evaluating the effect of ergogenic substances on performance has been critically analyzed [33]. The comparison of an active substance (such as caffeine) with a placebo assumes that the placebo is inert, and these studies, which use this design may mask the true effect of caffeine. We suggest that future research should evaluate a third condition, where no substance is consumed, which may determine a baseline from which exercise responses after caffeine ingestion can be more accurately examined.

CONCLUSIONS

In conclusion, the results suggest that caffeine intake ($5 mg \cdot kg^{-1}$) can be used to achieve higher performance in muscular strength (bench press and back squat) with lower PP and in localized muscular endurance (bench press, back squat, and leg press) with lower RPE.

Declarations

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CONFLICT OF INTEREST

No conflict of interest exists. All authors disclose any financial and personal relationships that may unfairly influence (bias) our work with other individuals or organizations.

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