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Caffeine and resistance exercise: the effects of two caffeine doses and the influence of individual perception of caffeine

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Abstract

Although caffeine is a widely used ergogenic resource, some information regarding its effects on resistance exercises is still lacking. The objective of the present study was to verify the acute effect of the ingestion of two different doses of caffeine on performance during a session of resistance exercises and to analyze the perception of the subjects in relation to the intake of caffeine. Following a double-blind, randomised, cross-over, controlled, and non-placebo design, 14 trained and healthy men (24.7 ± 6.8 years; 79.8 ± 9.8 kg; 177.3 ± 8.5 cm) performed a training session in chest-press, shoulder-press, and biceps curl exercises (3 sets until exhaustion; 70% 1RM; 3 min rest interval; 2 s for each concentric and eccentric phase) on three non-consecutive days after ingestion of 3 mg.kg^{-1} caffeine (CAF3), 6 mg.kg^{-1} caffeine (CAF6), or no substance (CON). Subjects were informed that one of the caffeine doses would be placebo. The total number of repetitions performed in CON (93.6 ± 22.4) was significantly lower than in CAF3 (108.0 ± 19.9, $P = 0.02$) and in CAF6 (109.3 ± 19.8, $P = 0.03$) and there were no differences between caffeine doses. Eight subjects noticed that caffeine was in CAF3 and six in CAF6 and there were no differences in the number of repetitions between sessions in which the subjects perceived and did not perceive caffeine. In conclusion, caffeine doses of 3 or 6 mg.kg^{-1} similarly increased performance in resistance upper limb exercises, independent of the subject's perception of substance ingestion.

Keywords: *resistance training, exercise, caffeine*

Highlights

- The literature is not consensual regarding the dose of caffeine to increase performance in resistance exercises.
- The studies usually use a design which can cause effects denominated response expectancy (placebo) and stimulus expectancy (caffeine).
- It is important to analyze the subject's perception on caffeine identification.

Introduction

Caffeine is an ergogenic resource, which is often used during resistance training to increase both strength (Diaz-Lara et al., 2016; Grgic & Mikulic, 2017; Warren, Park, Maresca, McKibans, & Millard-Stafford, 2010) and muscle endurance (Diaz-Lara et al., 2016; Grgic, Mikulic, Schoenfeld, Bishop, & Pedisic, 2019; Polito, Souza, Casonatto, & Farinatti, 2016; Richardson & Clarke, 2016). The hypothesis attributed to the improvement in performance with the use of caffeine during resistance exercise is stimulus to the central nervous system (Davis & Green, 2009), as well as inhibition of the effects of adenosine acting on its receptors, resulting in decreased fatigue (Davis et al., 2003), and/or decreased subjective perception of effort (Doherty & Smith, 2005).

The ideal dosage of caffeine to increase performance during resistance exercise is still controversial. For example, Astorino, Terzi, Roberson, and Burnett (2010) observed that 5 mg.kg^{-1} (but not 2 mg.kg^{-1}) was effective for acute increases in isokinetic peak torque, total work, and power. On the other hand, the meta-analysis by Warren et al. (2010) showed a linear relationship between higher doses of caffeine and muscle endurance. In general, it seems that a caffeine intake of between 3 and 9 mg.kg^{-1} can cause a significant ergogenic effect during resistance exercise (Grgic et al., 2019;

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Richardson & Clarke, 2016). However, the scientific literature is still not consensual regarding the optimal dose of caffeine to increase performance in resistance exercises due to the small number of studies using multiple doses of caffeine.

Independent of the dose of caffeine used in studies on performance in resistance exercises, studies investigating this topic usually use a double-blind, placebo-controlled design; a design which can cause effects denominated response expectancy and stimulus expectancy (Kirsch, 2018). Response expectancy is associated with the placebo effect when the subject believes they have ingested a substance with some active principle and this produces motivation for a result to be achieved. Stimulus expectancy is associated with the intervention, i.e. when the ingested substance acts on specific physiological mechanisms, causing the result independent of the individual motivation. In this context, if the subject ingests placebo, believing it to be caffeine, a voluntary stimulus may occur to increase performance (Saunders et al., 2017). In addition, if this substance was the first to be ingested during the experiment, the second substance may not generate the same motivation, even if it really is caffeine.

Therefore, it is important to analyze the subject's perception on caffeine identification at the end of the experiment. Subjects who correctly identified caffeine in a study involving resistance exercise with blood flow restriction experienced greater improvements in exercise performance than subjects who did not correctly identify the caffeine (Souza, Duncan, & Polito, 2019). Nevertheless, caffeine intake (regardless of correct identification) provided greater results than placebo. However, this study used a single dose of caffeine, and thus did not clarify the question regarding the effects of different caffeine dosages on performance in resistance exercises.

Thus, the objective of the present study was to compare two doses of caffeine on performance in resistance exercises and the perception of the subjects on the effect of caffeine.

Material and methods

Subjects

A total of 14 men (24.7 ± 6.8 years, 79.8 ± 9.8 kg, 177.3 ± 8.5 cm), healthy and trained in resistance exercises for more than one year, participated in the study. The habitual average caffeine intake of the participants was assessed through a questionnaire (Landrum, 1992) and all participants were considered low habitual caffeine users (83.4 ± 9.2 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 h before the experimental sessions and, on the days of data collection, not to perform physical activities and not to intake caffeinated substances. All participants were informed about the study procedures and possible effects of caffeine intake and provided informed consent to participate. The study was approved by the institutional ethics committee of the State University of Londrina (application number 1.141.230/2015).

Experimental design

Following a double-blind, randomised, cross-over, controlled, and non-placebo design, the data collection took place over four days with intervals of 48 h (Figure 1). The trials were conducted at the same time of the day (9–11:00 am) and the subjects were instructed to maintain their eating habits during the experiment and their physical training during the days between the trials. On the first day, the subjects were submitted to a maximal repetition test (1RM) in the chest-press, shoulder-press, and biceps curl exercises. The exercises were performed with bar and free weights. On the other days, exercise sessions were randomised to one session without any substance ingestion (CON), one session with an intake of 3 mg.kg^{-1} caffeine (CAF3), and one session with an intake of 6 mg.kg^{-1} caffeine (CAF6). To avoid any risk of bias during data collection, both the team of researchers and the sample were informed that the study would involve placebo and caffeine. The caffeine capsules were ingested 1 h before the exercise sessions with 200 ml of water. During this time, the subjects remained seated (talking or reading). In all sessions, the subjects performed a prior warm-up in each exercise (10 repetitions, 50% of 1RM). Subsequently, the subjects performed 3 sets until exhaustion in the chest-press, shoulder-press and biceps curl exercises at 70% 1RM, with a recovery interval of 3 min and 2 s cadence for each of the concentric and eccentric phases. Exhaustion was considered when the subject could not maintain the stipulated cadence. Subjects were verbally stimulated by the same researcher to complete as many valid repetitions as possible. After the end of the final experimental session, the subjects were asked which of the capsules ingested actually contained caffeine.

One maximal repetition test (1RM)

Initially, the subjects performed a warm-up with 10 repetitions in each exercise with 50% of the estimated

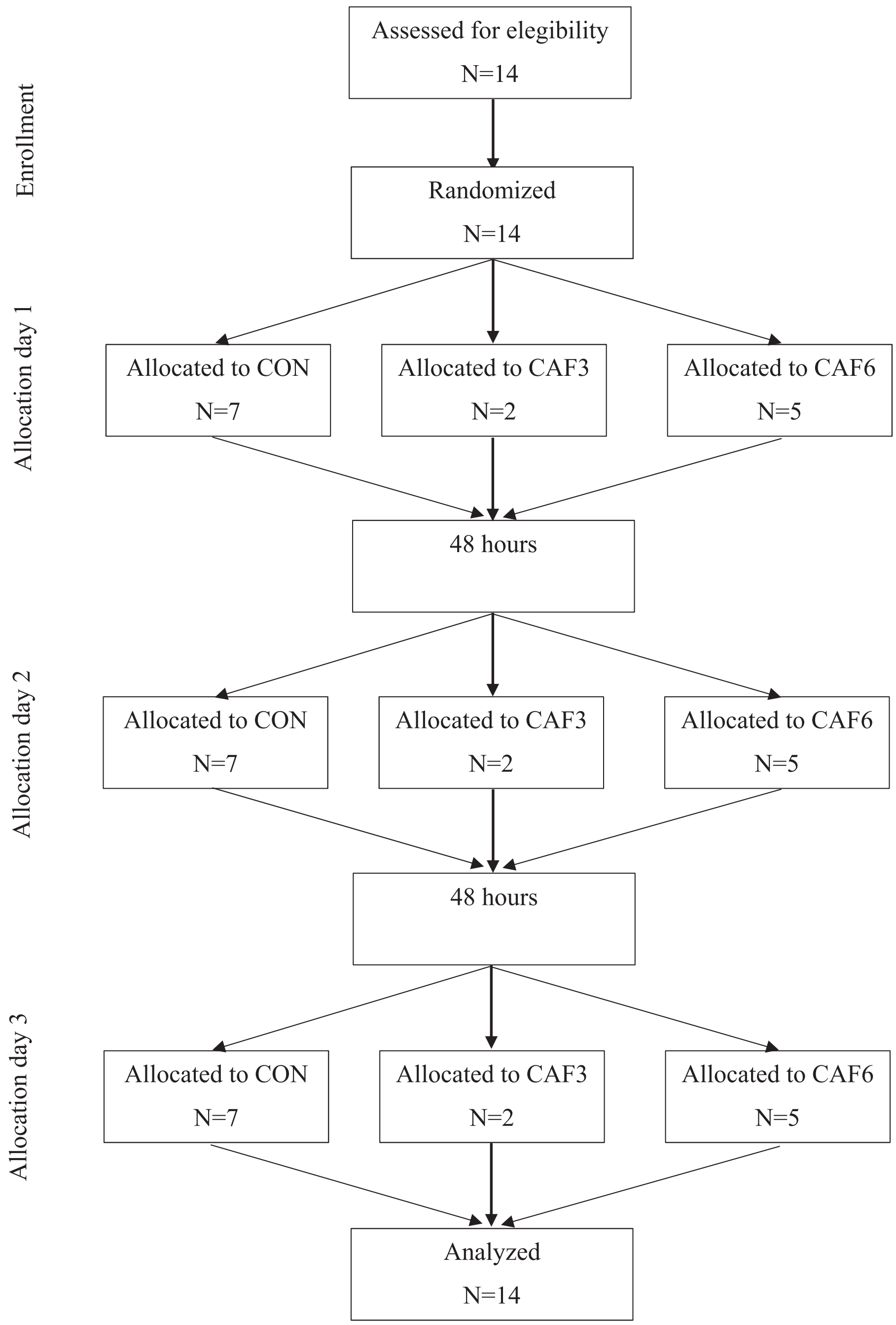

Figure 1. CONSORT diagram showing the flow of participants through each day of the randomised crossover design. CON = control session; CAF3 = session with intake of 3 $mg.kg^{-1}$; CAF6 = session with intake of 6 $mg.kg^{-1}$.

1RM load. After an interval of at least 3 min, 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 min. If the 1RM load was not determined, subjects were required to retake the test within 48 h. Test/retest reliability for the 1RM has previously been performed and a high intraclass correlation coefficient (ICC) was found, $R = 0.89$.

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. Considering the sphericity criteria, two-way ANOVA (CON/CAF3/CAF6 x number of sets) with repeated measures was used to test differences between the sets of each exercise in relation to the different sessions. One-way ANOVA was used to test intra-group differences

Table 1. Number of repetitions performed in each set in different conditions.

	Chest-press			Shoulder-press			Biceps curl		
	Set 1	Set 2	Set 3	Set 1	Set 2	Set 3	Set 1	Set 2	Set 3
CON	12.8 ± 2.1[2,3]	10.2 ± 1.9	8.3 ± 2.3	9.8 ± 3.0	8.5 ± 3.1	7.4 ± 2.9	14.6 ± 5.2[3]	12.1 ± 4.0	9.9 ± 3.6
CAF3	15.0 ± 2.4[2,3]	11.6 ± 2.3	9.3 ± 2.3	11.2 ± 2.1	10.1 ± 2.3	9.9 ± 2.5	15.2 ± 3.8	14.2 ± 5.8	11.6 ± 4.1
CAF6	15.5 ± 2.9[2.3]	11.8 ± 2.5	10.4 ± 2.2	10.1 ± 2.0	9.9 ± 2.9	9.7 ± 2.8	15.0 ± 3.5[3]	13.2 ± 3.9	11.7 ± 3.5

CON = control session; CAF3 = session with intake of 3 $mg.kg^{-1}$; CAF6 = session with intake of 6 $mg.kg^{-1}$; 2 = Significant difference to 2nd set; 3 = Significant difference to 3rd set; all sets of each exercise were performed until exhaustion (70% of one-maximal repetition test; 3 min rest interval; 2 s for each concentric and eccentric phase).

between the sets of each exercises, and to test differences between the total number of repetitions in each exercise and in the different sessions. In all cases, the Tukey post-hoc test was used to identify significant results. The level of significance adopted was $P < 0.05$. The data were analyzed using the programme Statistica 10 (Statsoft, Tulsa, OK, USA).

Results

Data are presented as mean and standard deviation.

Table 1 presents the values in each of the sets performed in the different sessions. There were no significant differences between sessions. On the other hand, there was a progressive reduction throughout the sets, mainly in the chest-press exercise. In this sense, in all sessions, there was a significant difference in the chest-press exercise between the 1st and 2nd sets ($P < 0.05$) and between the 1st and 3rd sets ($P < 0.01$). There was no difference in the shoulder-press and in the biceps curl exercise a difference was observed only between the 1st and 3rd sets in the CON ($P = 0.02$) and CAF6 ($P = 0.01$).

Table 2 shows the total repetition values for each exercise and each session. There was no significant difference in the sum of repetitions of each exercise between sessions. However, in the total repetitions in each session, there was a difference between the CON and CAF3 ($P = 0.02$); and CON and CAF6 ($P = 0.03$).

Table 3 shows the division of the sample on different days of data collection. On the 1st day, seven subjects started with the CON session, two with the CAF3, and five with the CAF6; on the 2nd day, one subject with the CON, eight with the CAF3, and five with the CAF6; and on the 3rd day, six subjects with the CON, four with the CAF3, and four with the CAF6. At the end of the data collection, eight subjects stated that caffeine was in the CAF3 session and six subjects stated that caffeine was in the CAF6 session. The comparison between these subjects did not demonstrate any significant difference between the sets or the total number of repetitions performed. No subjects reported side effects from caffeine use.

Discussion

The main findings of the present study were: 1) caffeine dosages of 3 $mg.kg^{-1}$ or 6 $mg.kg^{-1}$ similarly increased the performance of total repetitions performed until exhaustion in resistance exercises; 2) performance was not altered regardless of caffeine identification.

There is still little consensus regarding information on the optimal caffeine dosage for increased performance in resistance exercises. The pharmacokinetics of caffeine suggests that higher dosages are related to a higher peak plasma concentration of caffeine (Graham & Spriet, 1995). In this context, apparently higher doses of caffeine could be associated with higher performance in resistance exercise. In fact,

Table 2. Total number of repetitions performed in 3 sets until exhaustion in each exercise in difference conditions.

	Chest-press	Shoulder-press	Biceps curl	Total
CON	31.3 ± 5.5	25.7 ± 8.8	36.6 ± 12.6	93.6 ± 22.4*
CAF3	35.8 ± 6.4	31.2 ± 6.3	41.0 ± 13.1	108.0 ± 19.9
CAF6	37.7 ± 6.6	29.7 ± 7.0	39.9 ± 10.3	109.3 ± 19.8

CON = control session; CAF3 = session with intake of 3 $mg.kg^{-1}$; CAF6 = session with intake of 6 $mg.kg^{-1}$; * Significant difference to CAF3 and CAF6; each exercise was performed in 3 sets until exhaustion (70% of one-maximal repetition test; 3 min rest interval; 2 s for each concentric and eccentric phase).

Table 3. Individual identification of caffeine on different days.

Subject	Day 1	Day 2	Day 3	Identification of caffeine
1	CON	CAF6	CAF3	CAF6
2	CAF6	CAF3	CON	CAF6
3	CON	CAF3	CAF6	CAF6
4	CAF6	CAF3	CON	CAF6
5	CON	CAF3	CAF6	CAF3
6	CAF6	CAF3	CON	CAF3
7	CAF3	CAF6	CON	CAF3
8	CON	CAF6	CAF3	CAF3
9	CAF6	CON	CAF3	CAF3
10	CON	CAF3	CAF6	CAF6
11	CAF3	CAF6	CON	CAF3
12	CON	CAF3	CAF6	CAF3
13	CON	CAF6	CAF3	CAF6
14	CAF6	CAF3	CON	CAF3

CON = control session; CAF3 = session with intake of 3 $mg.kg^{-1}$; CAF6 = session with intake of 6 $mg.kg^{-1}$.

this information was reported in the meta-analysis of Warren et al. (2010) and some studies have concluded that doses above 6 $mg.kg^{-1}$ may increase performance. For example, Fett et al. (2018) found that 6 mg of caffeine per kg of body weight increased the number of repetitions performed by women in upper and lower limb exercises. Similarly, Salatto, Arevalo, Brown, Wiersma, and Coburn (2018 *in press*) showed that the intake of 800 mg of caffeine increased performance in 3 resistance exercises for upper limbs. Considering the mean body weight in this study, the caffeine intake was between 8 and 9 $mg.kg^{-1}$. However, a recent review of the literature (Grgic et al., 2019) suggests that performance improvement in resistance training occurs similarly with caffeine doses between 3 and 9 $mg.kg^{-1}$. On the other hand, Pallarés et al. (2013) found that 3 $mg.kg^{-1}$ of caffeine was enough to improve high-velocity muscle actions against low loads (25–50%1RM), whereas a higher caffeine dose (9 $mg.kg^{-1}$) was necessary against high loads (90% 1RM).

Studies that used low caffeine dosages ($\leq$ 3 $mg.kg^{-1}$) and demonstrated an increase in performance did not present alterations in non-central physiological variables, strengthening the hypothesis that the main mechanism of action of caffeine on performance is through the central nervous system (Spriet, 2014), principally through the blockade of adenosine receptors (Fredholm, 1995; Nehlig, Daval, & Debry, 1992). Thus, low amounts of caffeine intake could act to block adenosine receptors in a manner similar to higher intake. In the present study, the fact that both CAF3 and CAF6 resulted in improvement in performance compared to CON, demonstrated that the increase in performance may be independent of dose.

In addition to the dosage of caffeine ingested, factors such as motivation, habitual caffeine consumption, and believing that caffeine was ingested may affect performance positively and, in some cases, similarly to the physiological effect of caffeine (Shabir, Hooton, Tallis, & Higgins, 2018). In the present study, the sample reported relatively low consumption of caffeine. Thus, only the subject's motivation and the fact that they believed they had ingested caffeine could have affected performance. For these reasons, we used a design consisting of the intake of two substances (caffeine), but we informed the sample that one would be placebo and the other caffeine. This was justified as, if the sample realised (or believed) that their caffeine intake had been on the first day, their motivation for the second day of data collection could have been reduced. If the intake on the first day was actually caffeine, the performance of the subject could be overestimated due to the physiological action of caffeine added to the motivation. In this context, their motivation for the second day (placebo) could have been proportionally lower.

This explains why, besides the possible identification of the ergogenic substance, another factor that can contribute to better performance is performance knowledge (in the case of the present study, the number of repetitions performed). This fact may generate a response expectancy, in which the subjects feel more motivated to perform more repetitions in relation to the session in which there was no ingestion of any substance or when the subjects thought they had not ingested an ergogenic substance. This can be explained by the fact that response expectancy promotes the endogenous release of opioids and non-opioids and expectations of benefit, facilitating the activation of pain and non-pain control systems (Colloca, 2018). In this context, psychophysiological variables (such as motivation, expectancy, and conditioning) can interact significantly with physiological variables (such as muscle mass and activation of motor units), acting positively or negatively on performance (Beedie & Foad, 2009). These explanations appear to be centred on the OPTIMAL theory, i.e. *Optimising Performance through Intrinsic Motivation and Attention for Learning* (Wulf & Lewthwaite, 2016). According to this model, three lines of guidance – increased expectations, support for autonomy, and external focus – influence motor performance and learning. Thus, the putative relationship of these reward factors provides an increased dopaminergic response, triggering better performance, and building structural and functional brain connectivity. In the present study, knowledge of the previously performed repetitions could stimulate conditions to increase performance in the next sessions. On the other hand, the idea of having previously ingested caffeine may restrict the stimuli for better performance. Independent of this, the experimental model used made it impossible to hide knowledge about performance from the sample.

However, in the present study, no significant differences were observed (in the sets or total repetitions) between the subjects who reported that the presence of caffeine was in CAF3 or CAF6, regardless of the order of ingestion. In this sense, our hypothesis is that the physiological effect of caffeine to increase performance overcomes the stimulus of expectation of the subject.

Independent of the results presented, some limitations need to be described. We only use upper limb exercises and therefore we cannot confirm that the results presented here would be reproducible in other exercises. In this sense, greater effects of caffeine might have been observed if lower-body exercises were employed given that studies do suggest that the effect of caffeine may be predominantly manifested in the lower-body (Astorino, Martin, Schachtsiek, Wong, & Ng, 2011; Warren et al., 2010). Plasma caffeine concentration was not measured and thus we cannot confirm the bioavailability of this substance in all study subjects. In addition, there is the possibility that caffeine has an individualised physiological action, enabling some people to demonstrate a superior ergogenic effect to others. Finally, as this is an acute study, we cannot verify the effects of continuous use of caffeine on long-term training.

In conclusion, caffeine doses of 3 or 6 mg.kg^{-1} increase the number of repetitions performed in three resistance upper limb exercises, independent of the subject's perception of substance ingestion.

Disclosure statement

No potential conflict of interest was reported by the authors.

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