Effects of acute caffeine ingestion on resistance training performance and perceptual responses during repeated sets to failure

Vitor L. da Silva[1,*], Felipe R. Messias[1,*], Nelo E. Zanchi[2], Frederico Gerlinger-Romero[2], Michael J. Duncan[3], Lucas Guimarães-Ferreira[1,2,†]

[1]Exercise Metabolism Research Group, Center of Physical Education and Sports, Federal University of Espirito Santo, Vitória/ES, Brazil.
[2]Department of Physiology and Biophysics, Institute of Biomedical Sciences, University of São Paulo, São Paulo/SP, Brazil.
[3]Human Performance Laboratory, Department of Biomolecular and Sports Sciences, Coventry University, Coventry, United Kingdom.

* These authors contributed equally to this work.

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† Corresponding author:

Lucas Guimarães-Ferreira

Universidade Federal do Espírito Santo, Centro de Educação Física e Desportos. Av. Fernando Ferrari, 514, Campus Universitário, Goiabeiras – Vitória – ES. CEP: 29075810. Phone: (+55 27) 4009-7678; Fax: (+55 27) 4009-2624; e-mail: lucas.ferreira@ufes.br

ABSTRACT

Aim: The aim of the present study was to evaluate the effect of oral caffeine ingestion during repeated sets of resistance.

Methods: Fourteen moderately resistance-trained men (20.9 ± 0.36 years and 77.62 ± 2.07 kg of body weight) ingested a dose of caffeine (5 $mg.kg^{-1}$) or placebo prior to 3 sets of bench press and 3 sets of leg press exercises, respectively. The study used a double-blind, counterbalanced, crossover design. Repetitions completed and total weight lifted were recorded in each set. Readiness to invest in both physical (RTIPE) and mental (RTIME) effort were assessed prior each set, and rating of perceived exertion (RPE) was recorded after each set. Rest and peak heart rates were determined via telemetry.

Results: Caffeine ingestion result in increased number of repetitions to failure in bench press ($F[1,13] = 6.16$, $p = 0.027$) and leg press ($F[1,13] = 9.33$, $p = 0.009$) compared to placebo. The sum of repetitions performed in the 3 sets was 11.60% higher in bench press (26.86 ± 1.74; Caffeine: 30.00 ± 1.87; P=0.027) and 19.10% in leg press (Placebo: 40.0 ± 4.22; Caffeine: 47.64 ± 4.69; P=0.009). Also, RTIME was increased in the caffeine condition both in bench press ($F[1,13] = 7.02$, $p = 0.02$) and in leg press ($F[1,13] = 5.41$, $p = 0.03$). There were no differences in RPE, RTIPE and HR ($P>0.05$) across conditions.

Conclusions: Acute caffeine ingestion can improve performance in repeated sets to failure and increase RTIME in resistance-trained men.

Key words: caffeine, resistance training, dietary supplements.

INTRODUCTION

Caffeine, a 1,3,7 trimethylxanthine, is one of the most consumed supplements in the world and is also commonly found in food and medications. Caffeine appears to exert effects in various tissues, as muscle, adipose tissue and central nervous system[1] with no apparent adverse effects to healthy adults[2]. Athletes consume caffeine as an ergogenic aid to enhance performance. Investigations on the effects of acute caffeine ingestion on athletic performance have been focused on aerobic endurance exercise (reviewed by Ganio et al[3]), since the report of its glycogen sparing effect in the 70's[4]. However, the effects of caffeine ingestion on high-intensity anaerobic performance have only recently been subject to research scrutiny with the results of such studies being equivocal (reviewed by Davis and Green[5]).

Compared to aerobically based studies comparatively fewer studies have investigated the effects of caffeine ingestion on strength and muscular endurance (i.e. maximal strength and/or repetitions to failure in resistance training exercises). Some studies have provided evidence to an ergogenic effect of caffeine. For example, Duncan and Oxford[6,7] reported an increase in repetitions to failure at 60% 1RM in bench press following ingestion of caffeine (5 $mg.kg^{-1}$) in moderately trained men. Hudson et al[8] and Green et al[9] also demonstrated an increased number of repetitions following caffeine ingestion (6 $mg.kg^{-1}$) at 12RM and 10RM, respectively. Conversely, some studies have failed in demonstrate any ergogenic effect of caffeine ingestion on strength and muscular endurance. Goldstein et al [10] reported that ingestion of caffeine (6 $mg.kg^{-1}$) did not result in any ergogenic effect in repetitions to failure at 60% of 1 repetition maximum (1RM) in bench press, similar to results reported by Astorino et al[11]. Beck et al[12] also reported no effects of a caffeine-containing supplement ingestion (201mg) on bench press and leg extension total weight lifted during an endurance test at 80% 1RM following two Wingate anaerobic tests. Likewise, Williams et al[13] reported no effect of 300mg caffeine and ephedra ingestion on 1RM bench press and *latissimus dorsi* pull down performance, as well as on Wingate test performance.

It has been speculated that part of the effects of caffeine ingestion on strength and power performance could be due to attenuation of perceived effort during exercise. In this respect, Duncan and Oxford[7] reported a lower rating of perceived effort (RPE) and pain perception in response to caffeine ingestion compared to placebo during one set of bench press to failure at 60% 1RM. Conversely, Astorino et al[11] did not find differences in RPE among groups using a similar protocol, but in the presence of caffeine, participants performed 11 and 12% more repetitions to failure in bench press and leg press, respectively. This result indicates that caffeine may blunt RPE response to resistance exercise. Other perceptual responses could be affected by caffeine ingestion during exercise. For example, Duncan et al[14] reported increases in readiness to invest physical and mental effort in individuals that ingested a caffeinated energy drink prior to a bout of resistance exercise comprising bench press, deadlift, prone row, and back squat exercise to failure at 60% 1RM.

The effect of acute caffeine ingestion on strength and power performance is equivocal. To our knowledge, the effects of caffeine upon total volume (i.e. total number of repetitions or weight lifted) during multiple sets at 80% 1RM have not yet been studied. Therefore, the aims of this study are to evaluate the effect of acute caffeine ingestion on multiple sets of bench press and leg press exercises performed to failure at 80% 1RM, evaluating total volume, RPE and readiness to invest effort in moderately resistance trained men. We hypothesize that caffeine ingestion will result in acute increases in upper- and lower-body muscular performance during repeated sets to failure.

MATERIALS AND METHODS

Experimental Approach to the Problem

This study used within-subjects, repeated-measures, and double-blinded controlled design. The investigation employed 14 moderately resistance trained men with at least 1 year of previous experience in resistance training. Participants were informed they were participating in a study examining the effects of acute caffeine ingestion on repeated sets of resistance exercise to failure. On the first visit to laboratory, participants executed 1RM testing on bench press and leg press and were familiarized with the RPE, RTIPE and RTIME scales. In two subsequent visits they performed 3 sets of each exercise to failure at an intensity of 80% 1RM in two conditions: after ingestion of caffeine solution (5 mg kg^{-1}) or placebo. The aims of this study were to examine the effect of the independent variable (Caffeine vs. Placebo ingestion) on repetitions to failure and total weight lifted, RPE, RTIPE, RTIME and HRpeak.

Subjects

Fourteen men between 18 and 25 years of age were recruited from a university following written informed consent. The procedures used in this study were approved by the institution's Human Research Ethics Committee. Inclusion criteria included previous experience in resistance exercise and exclusion criteria included obesity and cardiovascular, musculoskeletal or metabolic diseases. The characteristics of the subjects are presented in Table 1. Participants were asked to abstain from foods and liquids containing caffeine, as well as any alcoholic products and intense exercise for at least 24 h prior to test sessions. Habitual caffeine consumption was determined through a questionnaire and to control individual differences in reactivity to caffeine from caffeine habituation, only moderate caffeine users were included (max 250 $mg.d^{-1}$).

Table 1: Subjects' characteristics and resistance exercise loads in the 1RM* test.

	Mean ± SE
Age (years)	20.9 ± 0.36
Body weight (Kg)	77.62 ± 2.07
Bench Press 1RM (Kg)	84.71 ± 3.80
Leg Press 1RM (Kg)	194.3 ± 20.93

* 1RM: 1 repetition maximum

Maximal Strength Assessment

Maximal dynamic strength was evaluated using the 1RM test, according to methods described by Baechle and Earle[15]. All participants had experience performing bench press and leg press exercises. However, before commencing the 1RM, the proper technique was demonstrated to each participant. The 1RM test was preceded by a warm-up set (10 repetitions) with approximately 50% of the maximal load used in the first attempt in each exercise. Two experienced researchers subjectively determined the load that would be used in each attempt. After 2 minutes, the subjects were instructed to try to accomplish 2 repetitions with the imposed load, 3 such attempts were made for each exercise. The rest period between each attempt was 5 minutes. The 1RM was recorded as the weight that the subject was able to complete during a single execution and was used to set the 80% 1RM intensity undertaken during the proceeding experimental trials.

Procedures

The number of repetitions per set was recorded and total weight lifted was calculated by multiplying the mass lifted by the number of repetitions performed. After each set, RPE was assessed using the OMNI-RES RPE scale. The OMNI-RES was validated in young adults to access the RPE during resistance exercise[16] and presents intraclass reliability coefficient ranging from 0.69 to 0.95[17]. Readiness to invest in both physical and mental effort was accessed prior each set. Participants were asked to rate how physically and mentally ready they were to invest effort using visual scales ranging from 0 to 10, with higher scores reflecting greater readiness to invest effort, as used before[18]. Resting and peak heart rate (HR) was assessed using telemetry (Polar Electro Oy, Kempele, Finland). One hour before testing, participants ingested 5 mg kg^{-1} of caffeine (Sigma-Aldrich, Sydney, USA) diluted in 250 mL of artificially sweetened water or a placebo, consisting of 250 mL of artificially sweetened water, in a double-blinded and randomized manner.

Statistical Analysis

Repetitions, RPE, RTIPE, RTIME and HR per set were assessed using a series of 2 (condition: placebo vs. caffeine) x 3 (sets) ways repeated measures analysis of variance (ANOVA). Post Hoc analysis using Bonferroni adjustments were performed where any significant interactions and main effects were found. Total repetitions and weight lifted were analyzed using paired samples t-tests for each variable. Intraclass correlation coefficients (ICC Rs) were 0.792 for repetitions, 0.853 for total weight lifted, 0.925 for RPE, 0.954 for RTIPE and 0.891 from RTIME in bench press exercise. In leg press, ICC Rs were 0.901 for repetitions, 0.950 for total weight lifted, 0.930 for RPE, 0.925 for RTIPE and 0.865 for RTIME. These ICC Rs indicate good reliability across experimental conditions. A p value of 0.05 was used to establish statistical significance. The statistical software SigmaPlot for Windows (Systat Software Inc. CA, USA) version 12.5 was used for all analysis.

RESULTS

Results indicated that participants performed more repetitions to failure in bench press ($F[1,13] = 6.16$, $p = 0.027$; figure 1A and table 2) and leg press ($F[1,13] = 9.33$, $p = 0.009$; figure 1C and table 3) exercises in the caffeine condition compared to placebo. Post hoc analysis indicated that the number of repetitions performed in the first set was greater in caffeine condition compared to placebo in bench press (Placebo: 13.00 ± 0.93; Caffeine: 14.93 ± 1.14; a 14.84% increase) and leg press (Placebo: 16.86 ± 2.56; Caffeine: 20.07 ± 2.01; a 19.03% increase). Likewise, main effect for total weight lifted was statistically different in bench press (F[1,13] = 5.05, p = 0.042; table 2) and leg press (F[1,13] = 6.94, p = 0.021; table 3) exercises. The increase in total number of repetitions to failure during three sets was 11.60% in bench press (26.86 ± 1.74; Caffeine: 30.00 ± 1.87; P=0.027; figure 1B) and 19.10% in leg press (Placebo: 40.0 ± 4.22; Caffeine: 47.64 ± 4.69; P=0.009; figure 1D).

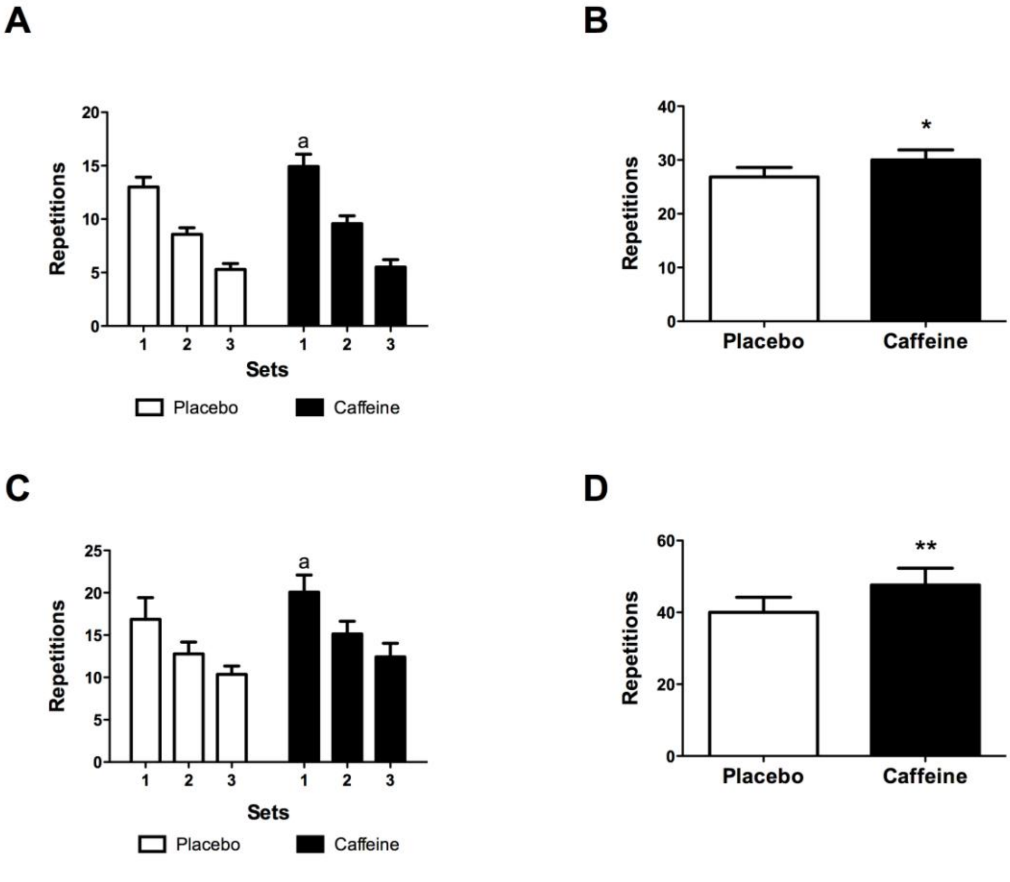

Figure 1

There were no significant differences in RPE across conditions for bench press (F[1,13] = 0.36, p = 0.55; table 2), or leg press (F[1,13] = 0.24, p = 0.62; table 3). Likewise, RTIPE was not different between conditions in bench press (F[1,13] = 0.004, p = 0.95; table 2) and leg press (F[1,13] = 3.32, p = 0.09; table 2). With respect to RTIME, there were significant main effects for condition both in bench press (F[1,13] = 7.02, p = 0.02; table 2) and in leg press (F[1,13] = 5.41, p = 0.03; table 2). Rest and peak HR were not different across conditions.

Table 2: Mean ± SEM for repetitions, weight lifted, RPE, RTIPE, RTIME, and HRpeak after 3 sets of bench press repetitions to failure at 80% 1RM in caffeine (5 mg.kg^{-1}) and placebo conditions.*

	Placebo			**Caffeine**		
	Set 1	**Set 2**	**Set 3**	**Set 1**	**Set 2**	**Set 3**
Repetitions	13.00 ± 0.93[a]	8.57 ± 0.62	5.28 ± 0.55	14.93 ± 1.14[a]	9.57 ± 0.73	5.5 ± 0.70
Weight Lifted (Kg)	868.0 ± 55.1[a]	578.7 ± 45.2	370.3 ± 49.8	1014 ± 55.5[a]	651 ± 55.5	376 ± 49.9
RPE	7.14 ± 0.52	7.57 ± 0.57	7.85 ± 0.63	6.64 ± 0.46	8.07 ± 0.48	8.57 ± 0.46
RTIPE	7.42 ± 0.53	7.07 ± 0.49	5.92 ± 0.58	7.28 ± 0.72	6.85 ± 0.67	6.21 ± 0.77
RTIME	6.78 ± 0.67[a]	6.57 ± 0.66	5.78 ± 0.73[c]	8.21 ± 0.50[a]	7.71 ± 0.47	7.42 ± 0.58[c]
Hrpeak	117.2 ± 6.63	119.4 ± 6.08	119.7 ± 7.12	114.1 ± 6.59	129.3 ± 7.12	117.4 ± 9.74

* RPE: Rating of perceived effort; RTIPE: readiness to invest in physical effort; RTIME: readiness to invest in mental effort; HRpeak: Peak Heart Rate.

Table 3: Mean ± SEM for repetitions, weight lifted, RPE, RTIPE, RTIME, and HRpeak after 3 sets of leg press repetitions to failure at 80% 1RM in caffeine (5 mg.kg^{-1}) and placebo conditions.*

	Placebo			**Caffeine**		
	Set 1	**Set 2**	**Set 3**	**Set 1**	**Set 2**	**Set 3**
Repetitions	16.86 ± 2.56[a]	12.79 ± 1.38	10.36 ± 0.99	20.07 ± 2.01[a]	15.14 ± 1.49	12.43 ± 1.59
Weight Lifted (Kg)	2583 ± 435.5	1882 ± 206.8	1527 ± 158.4	3058 ± 414.1[a]	2187 ± 221.0	1769 ± 200.0
RPE	7.85 ± 0.55	8.42 ± 0.52	8.57 ± 9.65	7.57 ± 0.52	8.78 ± 0.35	9.00 ± 0.27
RTIPE	5.78 ± 0.73	5.21 ± 0.78	4.85 ± 0.88	7.07 ± 0.61	6.50 ± 0.70	5.21 ± 0.79
RTIME	6.28 ± 0.66[a]	5.71 ± 0.80[b]	5.14 ± 0.94	8.00 ± 0.43[a]	7.42 ± 0.53[b]	6.14 ± 0.83
Hrpeak	131.9 ± 5.23	136.4 ± 5.33	139.9 ± 3.88	135.3 ± 4.99	143.1 ± 4.31	142.9 ± 3.82

* RPE: Rating of perceived effort; RTIPE: readiness to invest in physical effort; RTIME: readiness to invest in mental effort; HRpeak: Peak Heart Rate.

DISCUSSION

The current study evaluates the acute effects of caffeine ingestion on repeated sets to failure at 80% 1RM in resistance exercises. Our results support the notion that acute caffeine ingestion promotes performance enhancement during short-term high intensity exercise. Specifically, caffeine promoted an increase in total repetitions to failure and total weight lifted during three consecutive sets of bench and leg press exercises. These results agree with previous investigations[6–9,14] and differ from others evaluating the effects of acute caffeine ingestion on resistance exercise performance[7,13,18,19]. Different intensities were used in these prior studies, varying from 60% to 80% 1RM. For example, Goldstein et al[10] reported that ingestion of caffeine (6 $mg.kg^{-1}$) did not result in differences between conditions at 60% 1RM in bench press repetitions to failure in trained women. Likewise, Astorino et al[11] report no effects of caffeine (6 $mg.kg^{-1}$) ingestion in bench and leg press exercise at 60% 1RM. In contrast, Duncan and Oxford[6,14] report an increase in repetitions to failure in bench press at the same intensity in resistance trained men. In the present study, the intensity used was higher, 80% 1RM. Previous studies failed in demonstrate effects of acute caffeine ingestion on the number of repetitions to failure using 70 to 80% 1RM[12,13,19,20] with caffeine dosage varying from 201 mg to 6 $mg.kg^{-1}$. These results contrast with our findings that indicate a positive effect of caffeine ingestion in the first set at 80% 1RM, as well as in total volume performed in three sets. Discrepancies between prior studies and the current study may occur because differences in gender, training status, exercise selected, dosage of caffeine used or habituation to caffeine. With respect to habituation, Bell and McLellan[21] demonstrated that effect of caffeine ingestion on exercise time to exhaustion was greater and lasting longer in nonusers (≤ 50 $mg.d^{-1}$) compared to users (≥ 300 $mg.d^{-1}$) of caffeine. To our knowledge, no study has evaluated the effects of acute ingestion of caffeine on resistance exercise performance in habituated compared to non-habituated individuals. However, previous research[20] has reported that although some individuals did not respond to caffeine ingestion, part of the sample (9 individuals) responded positively. They concluded, that because of intra-individual variation in responses of caffeine ingestion, that additional research is necessary to elucidate the differences in caffeine-mediated improvements in performance among responders and non-responders. In our study, only moderate caffeine users were used, in order to control individual differences in reactivity to caffeine. However, there may be merit in future studies stratifying caffeine use (e.g., low, moderate, high users) and assessing whether the impact of acute caffeine ingestion on exercise performance differs depending on habitual caffeine intake.

A mechanism that could explain, at least in part, the ergogenic effect of caffeine on strength performance is the modulation of perceptual responses to exercise. RPE scales have been extensively used to access perceived exertion during dynamic exercise (reviewed by Bell and McLellan[21]). More recently, these tools have also been applied to monitor resistance exercise[16,23,24]. A meta-analysis performed by Doherty and Smith[25] demonstrates that caffeine ingestion could reduces RPE during exercise by 5.6%, accounting for approximately 29% of the variance in the performance improvement in submaximal, aerobically based exercise. However, studies reporting the effects of caffeine ingestion on RPE responses during resistance exercise are equivocal. Duncan et al[7] reported lower RPE after 1 set of bench press exercise to failure at 60% 1RM in the presence of caffeine compared to placebo. In contrast, Green et al[9] reported no effect of caffeine ingestion on RPE during 3 sets to failure of bench and leg press exercises, similar to reported by others[8,11]. In agreement with previous studies using resistance training, we failed to demonstrated any difference in RPE with caffeine compared to placebo, despite the increments in performance[6,8,9,20]. The fact that there was increased muscular performance at the same rating of perceived exertion in the caffeine condition is however indicative of an ergogenic effect. Discrepancies in the RPE response between studies may be due to the different intensities used in these studies, or as pointed by Davis and Green[5], because RPE scales may be too gross to be used to detect changes in perceptual responses at high exercise intensities.

Utilization of RPE scales as the only psychophysiological assessment tool during exercise has been criticized, and the readiness to invest effort was assessed in this study as has been recommended[26]. We demonstrate a significant main effect for the RTIME across conditions, with no differences in RTIPE. These results contrast with previous findings. For example, Duncan et al[14] using an multi exercise protocol in a sample of 13 resistance-trained men demonstrated that ingestion of caffeinated (179 mg) energy drink resulted in increased RTIME before and after exercise. RTIPE increased pre-ingestion to pre-exercise in greater magnitude in energy drink condition compared to placebo, as well as in the post exercise period. Also, caffeine ingestion before hockey skill performance test following high-intensity fatigue results in significantly higher scores of RTIPE and RTIME in caffeine condition compared to placebo[18]. Is important to highlight that in the present study the main effect in RTIPE for condition was close to statistical significance (P=0.09) in leg press exercise.

It's possible that pain could reduce muscle voluntary contraction. According to the pain adaptation model, proposed by Lund et al[27], exercise-induced pain reduces muscle force production when they act as agonists, impairing muscle contraction. Adenosine binding to A2 receptors could lead to pain sensation[28] and caffeine has been show to act as a antagonist of adenosine receptors[29], which could result in reduction in pain sensation[30,31]. A possible mechanism of the effects of caffeine ingestion on anaerobic performance is its action in blunt exercise-induced pain sensation[5]. Prior studies, however, provide equivocal results[7,32–35]. Discrepancies among studies may be due to exercise protocol employed or gender used. In our study we did not measure pain sensation during or after the exercise protocol, but this mechanism could not be discarded. Future investigations should be conducted in order to elucidate the role of caffeine in pain sensation during exercise and its role on performance enhancement.

In summary, the results of the present study indicate that acute caffeine ingestion could lead to increased numbers of repetitions to failure performed at 80% 1RM in resistance-trained men. RTIME was also improved, which may explain, at least in part, the ergogenic effects of caffeine ingestion documented in this study. Despite increases in volume performed, RPE and RTIPE were not different across conditions, indicating that these psychological variables may be blunted during exercise in response to caffeine ingestion. These findings are in agreement with previous studies indicating positive effects of caffeine ingestion during resistance training[6–9,20]. Future studies should examine the effects of various dosages of caffeine, as well as its effects in habituated vs. non-habituated individuals during resistance training.

CONCLUSIONS

The results of this study indicated that caffeine ingestion prior to repeated bouts of resistance exercise resulted in increased performance in resistance-trained men. Specifically, acute caffeine ingestion resulted in greater repetitions performed and weight lifted and increased RTIME when compared to placebo. RPE and RTIPE were not different across conditions, indicating that these psychological variables may be blunted during exercise in response to caffeine. Therefore, acute caffeine ingestion 1 hour prior to resistance training bouts may be beneficial for enhancing performance and favorably influencing perceptual responses to exercise.

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Table 1: Subjects' characteristics and resistance exercise loads in the 1RM* test.

Table 2: Mean ± SEM for repetitions, weight lifted, RPE, RTIPE, RTIME, and HRpeak after 3 sets of bench press repetitions to failure at 80% 1RM in caffeine (5 mg.kg-1) and placebo conditions.*

Table 3: Mean ± SEM for repetitions, weight lifted, RPE, RTIPE, RTIME, and HRpeak after 3 sets of leg press repetitions to failure at 80% 1RM in caffeine (5 mg.kg-1) and placebo conditions.*

TITLES OF FIGURES

Figure 1: Total repetitions to failure performed three sets at 80% 1RM of bench press and leg press exercises in placebo and caffeine (5 $mg.kg^{-1}$) conditions.

FIGURE LEGENDS

Figure 1: Values expressed as Mean ± SEM. (A) Number of repetition per set in bench press; (B) total repetitions performed in bench press; (C) number of repetition per set in leg press; and (D) total repetitions performed in leg press. a = $p < 0.05$ vs Set 1 of Placebo condition (Bonferroni Post Hoc analysis). *$p < 0.05$ and **$p < 0.01$ vs Placebo condition (paired t test analysis).