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Jozo Grgic,[1] Pavle Mikulic,[2]

[1]Institute for Health and Sport (IHES), Victoria University, Melbourne, Australia

[2]Faculty of Kinesiology, University of Zagreb, Zagreb, Croatia

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Corresponding author

Jozo Grgic

Institute for Health and Sport (IHES), Victoria University, Melbourne, Australia

jozo.grgic@live.vu.edu.au

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Abstract

This study explored the influence of habitual caffeine intake on the acute effects of caffeine ingestion on resistance exercise, jumping, and Wingate performance. Twenty-four resistance-trained males were tested following the ingestion of caffeine (3 mg/kg) and placebo (3 mg/kg of dextrose). Participants were classified as low caffeine users (n = 13; habitual caffeine intake: 65 ± 46 mg/day) and as moderate-to-high caffeine users (n = 11; habitual caffeine intake: 235 ± 82 mg/day). Exercise performance was evaluated by measuring: (a) movement velocity, power, and muscular endurance in the bench press; (b) countermovement jump; and, (c) a Wingate test, performed in that order. Two-way repeated-measures ANOVA revealed a significant main effect (p<0.05) for condition in the majority of analyzed exercise outcomes. In all cases, effect sizes for condition favored caffeine and ranged from 0.14–0.97. Mean increases in velocity and power in resistance exercise ranged from 0.02–0.08 m/s and 42–156 W, respectively. The number of performed repetitions increased by 1.2 and jump height by 0.9 cm. Increases in power in the Wingate test ranged from 31–75 W. We did not find significant group × condition interaction effect (p>0.05) in any of the analyzed exercise outcomes. Additionally, there were no significant correlations (p>0.05; r ranged from –0.29 to 0.32) between habitual caffeine intake and the absolute change in exercise performance. These results suggest that habitual caffeine intake might not moderate the ergogenic effects of acute caffeine supplementation on resistance exercise, jumping, and Wingate performance.

Keywords: supplements; ergogenic aid; performance; sprint; resistance exercise; CMJ

Introduction

Caffeine is one of the most commonly consumed psychoactive substances in the world (1). A national survey indicated that 85% of the population in the USA consumes at least one caffeinated beverage on most days of the week (1). The effects of caffeine on exercise performance have received considerable attention in the literature (2). It is well-established that caffeine ingestion may acutely enhance aerobic endurance, muscular strength and endurance, power, jumping performance, and speed (2). Researchers also commonly acknowledge that the effects of caffeine on exercise performance may vary between individuals, as studies that present individual responses show that caffeine's effects range from ergogenic to ergolytic (3, 4).

Caffeine's ergogenic effects are generally explained by its ability to act as an adenosine A_1 and A_{2A} receptor antagonist (5). Caffeine's molecular structure is similar to that of adenosine, and therefore after ingestion, caffeine binds to adenosine receptors. After binding to these receptors, caffeine promotes wakefulness, reduces perceived exertion, and ultimately enhances performance (5). Fredholm (6) demonstrated that consuming high doses of caffeine (20 mg/kg) for seven days increased the number of adenosine receptors in rat cerebral cortical membranes by 25%. These findings suggest that short-term regular consumption of caffeine upregulates the number of adenosine receptors, subsequently attenuating the effects of caffeine at a given dose (7, 8). Theoretically, over time, habitual caffeine users would need higher doses of caffeine to experience the same effects as previously with lower doses. Therefore, it has been suggested that habitual caffeine intake might moderate the acute effects of caffeine supplementation on exercise performance (9). In support of this hypothesis, one study (10) demonstrated that ingesting a daily caffeine dose of 3 mg/kg for 20 days attenuated acute caffeine's effects on performance.

Seven studies explored the influence of habitual caffeine intake on the acute effects of caffeine supplementation on exercise performance (4, 11-16). These studies, however, presented inconsistent findings. For example, two studies (11, 13) suggested that habitual intake influences caffeine's ergogenic effects, with 'low' (<50 mg/day or <40 mg/day) users experiencing greater improvements than 'high' (≥300 mg/day or >130 mg/day) habitual caffeine users. In contrast, other studies did not find significant differences between groups stratified according to their habitual caffeine intake (12, 14-16). Most of the studies published on this topic used cycling time to exhaustion or time trials for evaluating exercise performance (11, 12, 14). Therefore, the influence of habitual caffeine intake on the acute effects of caffeine supplementation on other forms of exercise is less clear.

This study aimed to explore the influence of habitual caffeine intake on the acute effects of caffeine ingestion on resistance exercise, jumping, and Wingate test performance. We hypothesized that individuals with low habitual caffeine intake would experience greater improvements in exercise performance following caffeine ingestion compared to those with high habitual caffeine intake.

Methods

Experimental design

This study utilized a randomized, double-blind, counterbalanced design. The participants were tested on four occasions. The first two sessions served as familiarization with the exercise tests (explained in the "Exercise protocol" section). The test-retest reliability of all exercise

tests was previously reported as good-to-excellent (17-19). The third and fourth sessions were experimental sessions consisting of caffeine and placebo supplementation. Caffeine supplementation was provided 60 minutes before the start of the exercise session, at a dose of 3 mg/kg. We used a caffeine dose of 3 mg/kg, given that this dose might produce comparable ergogenic effects as higher doses of caffeine (5). Placebo was provided using the same protocol, with the exception that the placebo contained 3 mg/kg of dextrose. Using a high precision electronic digital scale (Precisa, XT 120A, Dietikon, Switzerland), caffeine and placebo powders were weighed and then packaged into capsules. Both treatments were provided in a single capsule. The experimental sessions were performed on different days, with 4-7 days between them. The time of day for the experimental sessions was standardized for each participant, and all sessions were conducted in the morning hours, between 07:00 and 12:00 h. The participants attended these sessions in a fasted state (overnight fast). One day before the experimental sessions, the participants were required: (a) not to do any form of exercise; (b) to track their food intake and to replicate it on the days before the subsequent session; and (c) to refrain from any caffeine intake after 18:00 h. All participants were provided with a list of the most common foods and beverages that contain caffeine to aid in the process of caffeine restriction. Habitual caffeine intake of the participants was determined using a validated Food Frequency Questionnaire (FFQ) (20). Ethical approval for this study was requested and granted from Victoria University Human Research Ethics Committee (21, 22); the participants were informed about the nature of the study, and all participants signed informed consent.

Participants

An a priori power analysis for repeated-measures Analysis of Variance (ANOVA) for within-between interaction, with an expected effect size (ES) *f* of 0.20, alpha of 0.05, *r* between

repeated measures of 0.80, and statistical power of 80%, indicated that the required sample size was *n*=22. Power analysis was performed using *G*Power* (version 3.1; Germany, Dusseldorf). Effect size *f* of 0.20 was chosen given that this value was similar to the differences in caffeine's ergogenic effects between "non-users" and "users" in the study by Bell and McLellan (11). Twenty-four resistance-trained males were included (Table 1). "Resistance-trained" was defined as having a minimum of six months of resistance training experience with a minimum weekly training frequency of two times per week (on most weeks). All participants completed all testing sessions; there were no dropouts and no adverse event occurred during the testing.

Habitual intake

Habitual caffeine intake was assessed using a validated FFQ (20). This questionnaire explores the frequency of consumption and portion sizes of the most common foods and drinks that contain caffeine, including: coffee; decaffeinated coffee; espresso; black, green, white, mate tea; cocoa drink; iced tea, drinks with tea extract; cola, mixed cola beverages; energy drink; energy shot; alcopops with energy drink; and chocolate. In line with the validation study, the participants used the FFQ for 24-hour recall of caffeine intake on workdays (i.e., days during which the participants had their usual caffeine intake). Where possible, the participants specified exact brands of foods or drinks consumed. Estimation of the habitual caffeine intake was performed using freely-available nutritional tables (https://www.caffeineinformer.com/). The average intake of caffeine in the population in the USA is suggested to be 165 mg/day (1). Therefore, participants with a daily habitual intake of <165 mg, were classified as low users (*n*=13; habitual caffeine intake=65±46 mg/day; range=0–145 mg/day; 10/13 participants consumed <100 mg/day). Participants with a daily habitual intake of ≥165 mg were classified

as moderate-to-high users (*n*=11; habitual caffeine intake=235±82 mg/day; range=167–447 mg/day; 8/11 participants consumed >200 mg/day).

Exercise protocol

One repetition maximum testing

In the first two sessions, the participants were familiarized with the exercise protocol. All sessions—including the caffeine and placebo trials—were the same with one exception: in the first familiarization session, the participants also performed a one-repetition maximum (1RM) test in the bench press. The 1RM testing protocol consisted of sets performed for one repetition with progressive increases in load until the participants reached their 1RM. Three minutes of rest was provided between the 1RM attempts. In the first set, the load was set to 20 kg. For the next sets, the load was increased by 10, 5, or 2.5 kg, depending on the mean concentric velocity of the previous set. If the mean concentric velocity of the repetition was ≥0.4 m/s, the load was increased by 10 kg (23). If the mean concentric velocity of the repetition was <0.4 m/s, the load was increased by 5 or 2.5 kg, determined in consultation with the participant (23). 1RM attempts were performed until the mean concentric velocity was ≤0.2 m/s, which is considered the velocity required for a valid estimate of the 1RM in the bench press (23). Movement velocity was assessed using the GymAware PowerTool linear position transducer (Kinetic Performance Technologies, Canberra, Australia) that was attached to the barbell.

Movement velocity and power in the bench press

Movement velocity and power in the bench press were assessed with loads of 25%, 50%, 75%, and 90% 1RM. In the first session, the assessment of movement velocity and power was performed after the 1RM test; all other sessions started with the assessment of movement velocity and power. At each load, the participants performed two sets of one repetition, whereby they were required to perform the repetition with maximum concentric velocity. The eccentric phase lasted two seconds (self-estimated by the participants), and there was no pause at the bottom phase. The rest interval between sets/repetitions was three minutes. The load was initially set at 25% 1RM and was progressively increased to 90% 1RM. Mean concentric velocity (m/s), mean power (W), peak concentric velocity (m/s), and peak power (W) data were collected using a GymAware linear position transducer.

Muscular endurance assessment

After the final repetition with 90% of 1RM, the participants passively rested for five minutes. Next, muscular endurance was assessed using a test that involved a performance of one set to momentary muscular failure in the bench press with 85% 1RM. In each repetition, the eccentric phase lasted for two seconds, there was no pause at the bottom position, and the concentric phase was performed with maximum intended velocity. During this test, the GymAware linear position transducer was attached to the barbell and measured movement velocity and power of each repetition. One of the analyzed outcomes in this test was the number of performed repetitions between the placebo and caffeine trials. Using the movement velocity and power data, we also explored if the ‘quality’ of repetitions (in the context of higher velocity and power) differed between the two main trials. This was performed by matching the number of repetitions between the placebo and caffeine trials for each participant.

Jumping performance assessment

Following the muscular endurance test, the participants were provided with another three-minute rest interval. After the rest interval, the participants performed a standardized warm-up that consisted of one minute of light running and ten bodyweight squats. After the warm-up, the participants performed three countermovement jumps (CMJ) without an arm swing, with one minute of rest between attempts. The best jump of the three was used for the analysis. This test was performed on a force platform (400S Isotronic Fitness Technology, Skye, South Australia, Australia). The participants started by standing upright on the force platform. A computer screen associated with the force platform was set in front of the platform. This software provided commands (displayed on the screen) for the jump; initially, it counted down "3, 2, 1," followed by "Set" and "Go" commands. After the "Go" command, the participants were provided with five seconds to complete the jump. The jump was completed by performing a downward countermovement (i.e., a fast knee flexion) with the lowest position being a semi-squat. After reaching the desired depth, the participants jumped as high as possible by performing an 'explosive' extension of the legs. The outcome of this test was jump height.

Wingate test

After the third CMJ attempt, the participants rested for another three minutes. Then, the participants performed a short warm-up followed by a 30-second cycling sprint. In the first session, saddle and handlebar height and length were determined and recorded for every participant. The same setup was in all subsequent trials. Before starting the Wingate test, the participants performed a 5-minute warm-up (cycling at 100 W and 60-80 rpm (24)). After the

warm-up, participants performed a 30-second 'all-out' sprint with a torque factor set at 0.75 Nm/kg. The participants remained seated during the 30-second sprint. The test was performed using a Lode Excalibur Sport Cycle Ergometer (The Netherlands, Groningen); the data output was extracted using the associated Lode Ergometry Manager 10 software. Outcomes in this test include peak, mean, and minimum power.

Evaluation of blinding

The effectiveness of blinding was explored by asking the participants the following question: "Which supplement do you think you have ingested?" (25). This question had three possible responses: (a) "caffeine", (b) "placebo" and (c) "I do not know".

Statistical analysis

A two-way, repeated-measures ANOVA for group (low users vs. moderate-to-high users) × condition (placebo vs. caffeine) was used to analyze each performance outcome. ESs were calculated using Hedge's *g* for repeated measures. ESs of 0.00–0.19, 0.20–0.49, 0.50–0.79, and ≥0.80 represented trivial, small, moderate, and large effects, respectively. Mean differences and their 95% confidence intervals were also calculated. Pearson's correlation was performed between habitual caffeine intake (data from both groups) and the absolute change in performance outcome (caffeine – placebo), analyzed for each outcome separately. The effectiveness of the blinding was explored using the Bang's Blinding Index (26). The values in this index range from −1.0 (opposite guessing) to 1.0 (complete unblinding); we reported these data as a percentage of individuals who identified the correct condition beyond random chance. All analyses were performed using the Statistica software (version 13.4.0.14; TIBCO Software Inc., Palo Alto, CA, USA). The significance level was set at $p<0.05$.

Results

Movement velocity and power in the bench press

We found a significant main effect (p<0.05) for group in peak power at 25% and 50% 1RM, and mean power at 50% 1RM and 75% 1RM, with moderate-to-high users having higher power values in these outcomes than low users (Table 2). There was a significant main effect for condition (p<0.05) for all variables, except for peak power at 50% 1RM (p=0.060). ESs for condition favored caffeine and ranged from 0.20–0.64. We did not find significant group × condition interaction effect (p>0.05) in any of the analyzed outcomes. We did not find significant correlation coefficients (p>0.05; r = –0.29 to 0.18) between habitual caffeine intake and the absolute change in any of the analyzed outcomes.

Muscular endurance

We did not find a significant main effect for group or group × condition interaction effect (p>0.05 for all) in any of the analyzed outcomes for muscular endurance. For all outcomes, there was a significant main effect for condition (p<0.001 for all). ESs for condition favored caffeine and ranged from 0.28–0.97. We did not find significant correlation coefficients (p>0.05; r = –0.19 to 0.27) between habitual caffeine intake and the absolute change in any of the analyzed outcomes.

Countermovement jump

For CMJ height, we did not find a significant main effect for group (p=0.356) or group × condition interaction effect (p=0.151). There was a significant main effect for condition (p=

0.012; ES=0.14). We did not find a significant correlation coefficient (p=0.378; r = –0.18) between habitual caffeine intake and the absolute change in CMJ height.

Wingate test

For peak power, we did not find a significant main effect for group (p=0.180), or group × condition interaction effect (p=0.937). There was a significant main effect for condition (p<0.001; ES=0.34) that favored caffeine. For mean power, we did not find a significant group × condition interaction effect (p=0.866). There was a significant main effect for group (p=0.008; with moderate-to-higher users producing greater power than low users; Table 3) and a significant main effect for condition (p<0.001; ES=0.31; Table 4) that favored caffeine. For minimum power, we did not find a significant main effect for group (p=0.515), or group × condition interaction effect (p=0.177). There was a significant main effect for condition (p=0.012; ES=0.41) that favored caffeine. We did not find significant correlation coefficients (p>0.05; r = –0.12 to 0.32) between habitual caffeine intake and the absolute change in peak, mean, or minimal power.

Assessment of blinding

In the pre-exercise assessment, 61% and 69% of the low users correctly identified the placebo and caffeine conditions beyond random chance, respectively. In the post-exercise assessment, 77% and 85% of the low users correctly identified the placebo and caffeine conditions beyond random chance, respectively.

In the pre-exercise assessment, 27% and 70% of the moderate-to-high users correctly identified the placebo and caffeine conditions beyond random chance, respectively. In the post-exercise assessment, 55% and 73% of the moderate-to-high users correctly identified the placebo and caffeine conditions beyond random chance, respectively.

Discussion

Despite these general ergogenic effects of caffeine, comparisons of caffeine's effects on exercise performance between a group of low and a group of moderate-to-high habitual caffeine users did not find significant differences. Habitual caffeine intake also did not correlate with the absolute change in exercise performance in any of the analyzed outcomes. Overall, these results suggest that habitual caffeine intake might not negate the acute ergogenic effects of caffeine supplementation on exercise performance.

Habitual caffeine intake is often highlighted as a major determinant of the individual acute responses to the effects of caffeine supplementation on exercise performance (9). However, no significant differences in response to caffeine ingestion between low-users and moderate-to-high users were observed in the present study. The concept that habitual caffeine intake moderates the acute ergogenic effects of caffeine supplementation was developed using data from animal models in which regular caffeine intake upregulated adenosine receptors (6). However, caffeine supplementation in that research was very high (i.e., 20 mg/kg) and did not necessarily mirror caffeine doses typically consumed by humans. Therefore, while these studies on animal models certainly provide interesting mechanistic data, they may also be less relevant to humans. Two studies performed in humans (10, 27) reported that a daily caffeine intake of 1.5–3.0 mg/kg/day for 20–28 days attenuated caffeine's effects in previously low

habitual users (<75 mg/day). However, these studies' designs differed from the design of the present study, which prevents a direct comparison of the results.

One aspect that needs to be highlighted when interpreting the findings presented herein is the interplay between the amount of caffeine habitually ingested and the caffeine dose ingested before the start of the exercise session. Pickering and Kiely (28) speculated that individuals might need a pre-exercise caffeine dose that is above their habitual intake. For example, an individual with a habitual caffeine intake of 200 mg/day, might need an acute dose that is higher than 200 mg to experience an ergogenic effect. Even though a dose of 3 mg/kg of caffeine was used in the present study, which may be classified as a "low dose" of caffeine, this dose was equal to or greater than the amount of caffeine taken habitually for 21 out of the 24 participants. Therefore, this aspect of the study needs to be mentioned as a possible explanation for the present findings; albeit, with a need for future dose-response studies.

The findings presented in this study are generally in line with the majority of previous research on the topic. Tarnopolsky and Cupido (16) reported that caffeine supplementation (6 mg/kg) potentiated force of contraction during electrical stimulation in habitual (*n*=6; 771 mg/kg) and non-habitual (*n*=6; 14 mg/day) caffeine consumers. Jordan et al. (15) used a repeated-sprint test and reported that 6 mg/kg of caffeine produced similar improvements in performance among 8 caffeine users (>300 mg/day) and 10 non-users (≤50 mg/day). One limitation of the study by Jordan et al. (15) is that they used a questionnaire created by the authors to determine habitual caffeine. While there are limitations with FFQs (29), they likely represent a methodologically more valid solution for the estimation of habitual caffeine intake than the use of self-created questionnaires. The same FFQ that was used in this study, was also used in two other recent studies (4, 14). These studies also did not find differences in

acute responses to caffeine supplementation between groups with varying amounts of habitual caffeine intake for medicine ball throw distance, jumping height, or cycling time trial (4, 14).

While we presented data that is in agreement with previous findings, our results contrast with the findings of two other studies. Evans et al. (13) reported that ingestion of 200 mg of caffeine attenuated the decrease in repeated-sprint performance in low habitual caffeine consumers (<40 mg/day, *n*=10) but not in the moderate/high habitual caffeine consumers (>130 mg/day, *n*=6). The authors suggested that habitual caffeine intake modulates the ergogenic potential of acute caffeine supplementation. However, this study only compared the effects of caffeine vs. placebo based on within-group analysis (using a paired-sample t-test), and did not perform an analysis to explore the possibility of a significant group × condition interaction effect. Bell and McLellan (11) included 13 caffeine users (≥300 mg/day) and eight non-users (<50 mg/day). The participants ingested 5 mg/kg of caffeine or placebo 1, 3, or 6 hours before performing a cycling time to exhaustion task. The authors concluded that the duration and magnitude of the ergogenic effect are greater in non-users. Based on the ES data, the effects of caffeine differed between the groups at 1-hour post-ingestion (non-users ES=1.01; users ES=0.56), and at 6 hours post-ingestion (non-users ES=0.77; users ES=0.14) whereas performance was similar at 3 hours post-ingestion (non-users ES=0.64; users ES=0.62). A possible explanation for this variation in ES might be the use of time to exhaustion test, as these types of tests have been shown to have poor reliability (coefficient of variation>10%) (30). Another aspect that needs to be highlighted when discussing these studies (11, 13) is the use of unspecified questionnaires for estimating habitual caffeine intake.

Habitual caffeine intake of 165 mg/day was used as the cut-off to classify participants into their respective groups. This is a limitation given that habitual caffeine intake exists on a continuum. However, no significant correlation was found between the absolute change in performance and habitual caffeine intake, reinforcing the results of the primary analysis. We used an FFQ to assess habitual caffeine intake and such questionnaires might be affected by recall bias (30). Furthermore, caffeine content in drinks can vary between/within caffeine sources (31, 32), making it challenging to estimate habitual caffeine intake using questionnaires. However, this is not specific to the present study, as all other studies on this topic used questionnaires or food records. Depending on the group and treatment, the percentage of those that correctly identified the conditions beyond random chance ranged from 27%–85%. Another potential limitation is that correct supplement identification may influence the outcome of a given exercise task and possibly lead to bias in the findings (25). However, it is questionable if the effectiveness of the blinding affected the findings as Gonçalves et al. (14) also did not find differences in responses to acute caffeine ingestion between low, moderate, and high habitual caffeine users, even though only 17/40 participants were able to identify the placebo and caffeine conditions.

One important aspect of this study is that the participants refrained from caffeine intake after 18:00 h on the days before the caffeine and placebo trials. Not allowing caffeine intake for the moderate-to-high group might have reduced performance from refraining caffeine alone. However, all testing was performed in the morning hours after waking up, which likely prevented strong withdrawal side effects as peak intensity of withdrawal symptoms tends to occur at 20–51 h after abstinence (33). Nevertheless, future studies might explore this topic while allowing all participants to continue their usual caffeine consumption habits. The participants were aware of their performance values in some (e.g., muscle endurance test), but

not all tests (e.g., Wingate). This might be a limitation of the study since knowledge of the performance values in one trial might influence the participants' performance in another. However, the findings were similar in all tests—regardless of participants' knowledge of their performance level—suggesting that this aspect might not have influenced the overall results. Finally, the sample of this study was comprised of young men, and the results cannot necessarily be generalized to older adults and women.

Conclusion

Despite the general ergogenic effects of caffeine on resistance exercise, jumping, and Wingate test, the comparisons of the effects of caffeine on exercise performance between low and moderate-to-high habitual caffeine users did not find significant differences. Furthermore, there was no significant correlation between habitual caffeine intake and changes in exercise performance outcomes. These results suggest that habitual caffeine intake might not negate the acute ergogenic effects of caffeine supplementation on resistance exercise, jumping, and Wingate performance.

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Table 1. Characteristics of the participants

Variable	Low users (*n* = 13)	Moderate-to-high users (*n* = 11)
Age (years)	29 ± 5	28 ± 5
Body mass (kg)	75.9 ± 9.0	85.2 ± 9.8
Height (cm)	183.4 ± 5.0	183.4 ± 6.9
1RM in the bench press (relative to body mass)	1.1 ± 0.1	1.1 ± 0.2
Habitual caffeine intake (mg/day)	65 ± 123	235 ± 82
Data reported as mean ± standard deviation; 1RM: one repetition maximum		

Table 2. Movement velocity and power exercise performance data following placebo and caffeine ingestion in the low and moderate-to-high users

Variable	**Low users (placebo)**	**Low users (caffeine)**	**Moderate-to-high users (placebo)**	**Moderate-to-high users (caffeine)**
Movement velocity and power (bench press exercise)				
Mean power at 25% 1RM (W)	1885 ± 335	2019 ± 375	2183 ± 414	2294 ± 426
Mean velocity at 25% 1RM (m/s)	1.43 ± 0.15	1.47 ± 0.18	1.46 ± 0.12	1.48 ± 0.10
Peak power at 25% 1RM (W)	3248 ± 408	3317 ± 435	3648 ± 565	3809 ± 633
Peak velocity at 25% 1RM (m/s)	2.27 ± 0.21	2.31 ± 0.20	2.25 ± 0.15	2.31 ± 0.14
Mean power at 50% 1RM (W)	1166 ± 144	1202 ± 164	1310 ± 184	1360 ± 207
Mean velocity at 50% 1RM (m/s)	0.96 ± 0.11	0.98 ± 0.11	0.96 ± 0.08	0.98 ± 0.07
Peak power at 50% 1RM (W)	1941 ± 162	1962 ± 165	2168 ± 360	2280 ± 354
Peak velocity at 50% 1RM (m/s)	1.45 ± 0.13	1.46 ± 0.13	1.40 ± 0.12	1.44 ± 0.11
Mean power at 75% 1RM (W)	767 ± 109	820 ± 137	888 ± 159	956 ± 190
Mean velocity at 75% 1RM (m/s)	0.57 ± 0.09	0.62 ± 0.09	0.57 ± 0.07	0.61 ± 0.07
Peak power at 75% 1RM (W)	1207 ± 167	1290 ± 188	1376 ± 287	1474 ± 359
Peak velocity at 75% 1RM (m/s)	0.84 ± 0.16	0.90 ± 0.14	0.81 ± 0.12	0.88 ± 0.13
Mean power at 90% 1RM (W)	512 ± 94	588 ± 83	591 ± 162	680 ± 191
Mean velocity at 90% 1RM (m/s)	0.36 ± 0.11	0.41 ± 0.09	0.35 ± 0.08	0.40 ± 0.08
Peak power at 90% 1RM (W)	840 ± 153	974 ± 166	981 ± 366	1162 ± 368
Peak velocity at 90% 1RM (m/s)	0.56 ± 0.15	0.64 ± 0.13	0.52 ± 0.14	0.61 ± 0.13
1RM: one repetition maximum: data are presented as mean ± standard deviation				

Table 3. Muscular endurance, jumping and Wingate test exercise performance data following placebo and caffeine ingestion in the low and moderate-to-high users

Variable	**Low users (placebo)**	**Low users (caffeine)**	**Moderate-to-high users (placebo)**	**Moderate-to-high users (caffeine)**
Muscular endurance (85% of 1RM to failure)				
Maximum repetitions at 85% 1RM	7.8 ± 2.5	8.7 ± 2.3	6.5 ± 1.8	8.1 ± 1.8
Mean power matched for repetitions (W)	384 ± 53	436 ± 73	458 ± 142	543 ± 158
Mean velocity matched for repetitions (m/s)	0.27 ± 0.04	0.31 ± 0.04	0.27 ± 0.05	0.32 ± 0.06
Peak power matched for repetitions (W)	589 ± 79	646 ± 90	754 ± 312	835 ± 311
Peak velocity matched for repetitions (m/s)	0.40 ± 0.05	0.45 ± 0.04	0.42 ± 0.10	0.46 ± 0.09
Jumping performance (CMJ)				
CMJ vertical jump height (cm)	33.9 ± 6.1	35.1 ± 6.0	36.5 ± 5.1	36.9 ± 5.4
Wingate test				
Peak power in the Wingate test (W)	822 ± 246	898 ± 215	941 ± 177	1015 ± 194
Mean power in the Wingate test (W)	557 ± 92	589 ± 83	657 ± 76	686 ± 84
Minimum power in the Wingate test (Watts)	338 ± 107	360 ± 68	340 ± 117	409 ± 115
1RM: one repetition maximum: CMJ: countermovement jump; data are presented as mean ± standard deviation				

Table 4. Results on the effects of caffeine on the exercise performance outcomes

Variable	**Main effect for group *p*-value**	**Main effect for condition *p*-value**	**Group × condition interaction effect *p*-value**	**ES for condition and 95% CI**	**Mean diff and 95% CI***	**Correlation ****	**Correlation *p*-value**
Movement velocity and power (bench press exercise)							
Mean power at 25% 1RM (W)	0.079	< 0.001	0.703	0.29 (0.14, 0.47)	123 (66, 180)	0.02	0.926
Mean velocity at 25% 1RM (m/s)	0.697	0.024	0.251	0.21 (0.04, 0.38)	0.03 (0.01, 0.05)	–0.11	0.611
Peak power at 25% 1RM (W)	0.040	0.018	0.314	0.20 (0.04, 0.37)	111 (23, 200)	0.15	0.472
Peak velocity at 25% 1RM (m/s)	0.938	0.004	0.589	0.28 (0.08, 0.48)	0.05 (0.02, 0.08)	0.11	0.608
Mean power at 50% 1RM (W)	0.042	0.005	0.586	0.22 (0.06, 0.38)	43 (16, 71)	0.09	0.692
Mean velocity at 50% 1RM (m/s)	0.985	0.018	0.577	0.21 (0.04, 0.40)	0.02 (0.00, 0.04)	0.06	0.780
Peak power at 50% 1RM (W)	0.016	0.060	0.190	0.20 (–0.03, 0.44)	63 (–4, 130)	0.15	0.481
Peak velocity at 50% 1RM (m/s)	0.481	0.033	0.379	0.20 (0.01, 0.41)	0.03 (0.00, 0.05)	0.18	0.389
Mean power at 75% 1RM (W)	0.043	< 0.001	0.503	0.36 (0.19, 0.55)	60 (38, 83)	–0.03	0.884
Mean velocity at 75% 1RM (m/s)	0.858	< 0.001	0.646	0.60 (0.38, 0.86)	0.04 (0.03, 0.06)	–0.29	0.177
Peak power at 75% 1RM (W)	0.095	0.003	0.779	0.33 (0.12, 0.55)	89 (39, 140)	0.02	0.931
Peak velocity at 75% 1RM (m/s)	0.661	< 0.001	0.674	0.43 (0.21, 0.67)	0.07 (0.04, 0.09)	–0.07	0.730
Mean power at 90% 1RM (W)	0.125	< 0.001	0.677	0.57 (0.30, 0.85)	82 (51, 113)	0.14	0.515
Mean velocity at 90% 1RM (m/s)	0.728	< 0.001	0.907	0.57 (0.30, 0.86)	0.05 (0.03, 0.07)	0.12	0.560
Peak power at 90% 1RM (W)	0.137	< 0.001	0.516	0.53 (0.25, 0.84)	156 (87, 224)	0.04	0.865
Peak velocity at 90% 1RM (m/s)	0.559	< 0.001	0.859	0.64 (0.34, 0.98)	0.08 (0.05, 0.12)	–0.06	0.770
Muscular endurance (85% of 1RM to failure)							
Maximum repetitions at 85% 1RM	0.291	< 0.001	0.189	0.55 (0.30, 0.84)	1.2 (0.8, 1.7)	0.22	0.302
Mean power matched for repetitions (W)	0.055	< 0.001	0.135	0.54 (0.32, 0.80)	67 (47, 88)	0.27	0.195
Mean velocity matched for repetitions (m/s)	0.757	< 0.001	0.315	0.97 (0.61, 1.38)	0.04 (0.03, 0.05)	0.23	0.279
Peak power matched for repetitions (W)	0.059	< 0.001	0.313	0.28 (0.16, 0.42)	68 (45, 91)	0.14	0.511
Peak velocity matched for repetitions (m/s)	0.644	< 0.001	0.858	0.51 (0.29, 0.76)	0.04 (0.03, 0.06)	–0.19	0.380
Jumping performance (CMJ)							

CMJ vertical jump height (cm)	0.356	0.012	0.151	0.14 (0.03, 0.25)	0.9 (0.3, 1.5)	–0.18	0.378
Wingate test							
Peak power in the Wingate test (W)	0.180	< 0.001	0.937	0.34 (0.17, 0.52)	75 (45, 105)	–0.12	0.591
Mean power in the Wingate test (W)	0.008	< 0.001	0.866	0.31 (0.14, 0.49)	31 (16, 45)	0.03	0.881
Minimum power in the Wingate test (W)	0.515	0.012	0.177	0.41 (0.07, 0.77)	44 (10, 77)	0.32	0.126
1RM: one repetition maximum: CMJ: countermovement jump; CI: confidence interval; * mean difference between caffeine and placebo for the whole sample; ** correlation between habitual caffeine intake and the absolute change in performance							