Journal of Human Kinetics volume 78/2021, 219-228 DOI: 10.2478/hukin-2021-0044

Section III – Sports Training

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Effects of Acute Caffeine Intake on Power Output and Movement Velocity During a Multiple-Set Bench Press Exercise Among Mild Caffeine Users

by

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The main goal of this study was to evaluate the effectiveness of an acute dose of caffeine (6 mg/kg body mass (b.m.)) on power output and bar velocity during a bench press multiple-set resistance training session in participants with mild daily caffeine consumption (in the range of 1 to 3 mg/kg/b.m). Thirteen recreationally active male participants (age: 21.9 ± 1.2 years, body mass: 74.4 ± 5.3 kg, body mass index: 23.1 ± 1.6 kg/m², bench press one-repetition maximum (1RM): 79.2 ± 14.9 kg), with daily caffeine ingestion of 1.56 ± 0.56 mg/kg/b.m., participated in the study with a randomized double-blind experimental design. Each participant performed two identical experimental sessions, 60 min after the intake of a placebo (PLAC) or 6 mg/kg/b.m. of caffeine (CAF-6). In each experimental session, participants performed 5 sets of 5 repetitions of the bench press exercise with a load equivalent to 70% 1RM. The eccentric and concentric phases of the bench press exercise were performed at maximal possible velocity in each repetition. Bar velocity was recorded with a linear position transducer and power output was calculated using velocity and load data. A two-way repeated measures ANOVA indicated no significant substance x set interaction for mean power output (MP), mean bar velocity (MV), peak power output (PP) and peak bar velocity (PV). However, there was a significant main effect of substance on MP ($p < 0.01$; $\eta^2 = 0.47$) and MV ($p < 0.01$; $\eta^2 = 0.45$). Post hoc analysis for main effect revealed that MP and MV values in the CAF-6 group were higher than in the PLAC group in all 5 sets of the exercise ($p < 0.05$). In conclusion, this study demonstrated that an acute dose of caffeine before resistance exercise increased mean power output and mean bar velocity during a multiple-set bench press exercise protocol among mild caffeine users.

***Key words**: caffeine tolerance; ergogenic aids; resistance exercise; sport performance; upper limbs.*

Introduction

Caffeine is the most popular psychoactive substance in the world, probably because of the numerous benefits, including increased wakefulness and alertness as well as reduced fatigue, obtained with oral ingestion of this substance (Burke, 2008). Generally, acute caffeine intake, in doses between 3 and 9 mg/kg/ of body mass (b.m.), has been shown as an effective supplementation strategy for increased physical performance during resistance exercise (Grgic et al., 2019; Raya-González et al., 2020; Wilk et al., 2019a; 2019b; 2019c; 2019d; 2020a). However, the optimal dose of caffeine to enhance resistance exercise may depend on the training goals, the muscle area involved in exercise, the type of muscle contraction and the duration of the physical effort (Grgic et al., 2019). Mechanisms responsible for the ergogenic effect of caffeine are various, but mainly related to its antagonistic effect on adenosine receptors, which alters arousal and results in reducing pain, diminishing

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Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 78/2021 in April 2021.

perceived exertion, and delaying fatigue (Goldstein et al., 2010b). These properties suggest that the positive effect of caffeine supplementation may be accentuated during resistance exercise under fatigued conditions (i.e., higher volume due to a higher number of sets or repetitions). However, most previous research assessing the effect of caffeine on resistance exercise performance used test procedures consisting of a single set of exercise to assess maximal muscle strength or muscular strength-endurance. Considering that a typical resistance training session entails several sets of the same exercise, current results of caffeine effects on resistance exercise testing cannot be satisfactorily translated into meaningful conclusions for resistance training (Burke, 2017; Wilk et al., 2020a).

Among numerous resistance exercises, the bench press is one of the most popular for developing upper-body strength and power (Golas et al., 2018; Wilk et al., 2020b; 2020e). To date, there are several studies that investigated the acute effects of caffeine on bench press performance (Arazi et al., 2016; Diaz-Lara et al., 2016; Goldstein et al., 2010a; Grgic and Mikulic, 2017; Wilk et al., 2019d, 2020a). However, only five studies included protocols with multiple-set in the bench press exercise (Giráldez Costas et al., 2020; Lane et al., 2019; Lane and Byrd, 2018; Wilk et al., 2019b, 2020a). Additionally, the outcomes of these investigations are contradictory. Lane et al. (2019) found no ergogenic effect of acute caffeine intake (150 mg) on mean and peak bar velocity during a multiple-set bench press exercise (10 sets × 3 repetitions at 80% of one-repetition maximum (1RM)). On the contrary, the study by Lane and Byrd (2018) showed improved peak bar velocity (with no significant differences in mean bar velocity) after ingestion of 300 mg of caffeine during a similar experimental protocol. Differences in these two investigations may be due the differences in the dose of caffeine administered (150 vs. 300 mg) and the lack of individual dose adjustments with regard to body mass. The normalization of caffeine doses based on body mass was performed in the research conducted by Wilk et al. (2020a) and Giráldez Costas et al. (2020). In the study by Wilk et al. (2020a), the ingestion of 3 and 6 mg/kg/b.m. of caffeine increased mean power output and mean bar velocity during a multiple-set bench press throw exercise (5 sets × 2 repetitions at 30% 1RM), without affecting peak values of power and velocity. Interestingly, results of the study by Giráldez Costas et al. (2020) showed that ingestion of 3 mg/kg/b.m. of caffeine improved mean and peak values of bar velocity and power output during a bench press training session (4 sets × 8 repetitions at 70% 1RM). Overall, it seems that at least 3 mg/kg/b.m. of caffeine are necessary to enhance muscle performance during multiple-set resistance exercise training although this finding is confirmed by limited evidence.

In addition to the dosage and normalization of the dose to body mass, the level of habituation to caffeine in the participants used for the investigation may modify the ergogenic effect of caffeine (Fredholm et al., 1999; Svenningson et al., 1999). It has been shown that chronic caffeine administration may change the physiological and performance effect of acute caffeine intake (Beaumont et al., 2017; Lara et al., 2019; Van Soerenet al., 1993; Wilk et al., 2019b). However, studies conducted on participants habituated to caffeine are also inconclusive (Beaumont et al., 2017; de Souza Gonçalves et al., 2017; Dodd et al., 1991; Lara et al., 2019; Sabol et al., 2019) with some investigations suggesting tolerance to caffeine's ergogenic effect with chronic ingestion, while others have found that individuals habituated to caffeine still obtain ergogenic benefits from acute caffeine intake. The differences in the results of previous investigations with participants habitually using caffeine may be related to the ratio of the dose of caffeine acutely ingested in respect to the level of habitual consumption. According to Pickering and Kiely (2019) habitual caffeine users should intake doses greater than their mean daily intake of caffeine to maintain the ergogenic effect of acute caffeine intake.

Since 6 mg/kg/b.m. caffeine is the most commonly used dose for sports performance (Grgic et al., 2020), the main objective of this study was to evaluate the effectiveness of this dose to increase bench press power output and velocity during a simulated workout that included several sets of resistance exercise in participants with mild daily caffeine consumption (in the range of 1 to 3 mg/kg/b.m.). This daily consumption of dietary sources of caffeine represents the typical level of caffeine intake for many populations

(Temple et al., 2017). It was hypothesized that an acute intake of 6 mg/kg/b.m. of caffeine would increase power output and bar velocity during a training session consisting of 5 sets of 5 repetitions with a load equivalent to 70% of participant's 1RM.

Methods

Study Participants

Thirteen recreationally active male individuals (mean ± standard deviation = age: 21.9 ± 1.2 years, body mass: 74.4 ± 5.3 kg, height: 179.3 ± 5.3 cm, body mass index (BMI): 23.1 ± 1.6 kg/m^2, bench press 1RM: 79.2 ± 14.9 kg) volunteered to participate in the study. All participants were classified as mild habitual caffeine consumers according to the classification recently proposed by Filip et al. (2020). The participants self-reported their daily ingestion of caffeine (1.56 ± 0.56 mg/kg/b.m., 114.63 ± 40.92 mg of caffeine per day) and it was obtained using a Food Frequency Questionnaire (FFQ) that assessed the participants' average consumption of caffeine for four weeks before the start of the experiment. The inclusion criteria were as follows: (a) free from neuromuscular and musculoskeletal disorders, (b) previous resistance exercise training experience of at least 2 years, (c) mild habitual caffeine intake as per previous proposed thresholds for classifying individuals in sport performance research according to their habitual caffeine consumption (Filip et al., 2020), (d) no medication nor dietary supplements usage within the 3 previous months, which could potentially affect the study outcomes (e.g., beta-alanine, creatine, multi-ingredient pre-workout supplements, etc.) (e) self-described satisfactory health status. Participants were excluded if they reported a) a positive smoking status, b) potential allergy to caffeine. The study protocol was approved by the Bioethics Committee for Scientific Research, at the Academy of Physical Education in Katowice, Poland (3/2019), according to the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All participants gave their informed written consent prior to their inclusion in the study.

Habitual Caffeine Intake Assessment

Habitual caffeine intake was assessed by an adapted version of the FFQ proposed by Bühler et al. (2014). The FFQ was completed individually with the supervision of a qualified nutritionist. The FFQ was employed to assess the habitual consumption of dietary products containing caffeine. Portions, in household measures, were used to assess the amount of food consumed during a day, a week and a month. The list was composed of dietary products with moderate to high caffeine content including different types of coffee, tea, energy drinks, cocoa products, popular beverages, medications, and caffeine supplements. Previously published information and nutritional tables were used for database construction (Frankowski et al., 2008; SelfNutrition Data, 2020). Based on the answers in the FFQ, a qualified nutritionist estimated the habitual caffeine intake for each participant.

Experimental Design

This study used a randomized, double-blind, placebo-controlled crossover design where each participant acted as his own control. Participants performed a familiarization session with a pre-experimental 1RM test, followed by two experimental sessions. There was a one-week interval between the sessions to allow complete recovery and substance wash-out. The blinding and randomization of the sessions was conducted by a member of the research team who was not directly involved in data collection. The two experimental sessions were identical, and they only differed in the substance ingested before exercise: participants either ingested a placebo (PLAC) or 6 mg/kg/b.m. of caffeine (CAF-6). After resting for 60 min for substance absorption, participants performed 5 sets of 5 repetitions of the bench press exercise with a load equivalent to 70%1RM, as measured in the pre-experimental trial. There was a 4-min rest interval between sets to allow for recovery. Participants were encouraged to execute each repetition at the highest velocity during concentric and eccentric phase. The trials were performed at the Strength and Power Laboratory at the Academy of Physical Education in Katowice (Poland), at the same time of the day and in a laboratory room with controlled ambient temperature (~21ºC). Both, caffeine and the placebo, were administered orally 60 min before the onset of the exercise protocol to allow peak blood caffeine concentration and at least 2 hours after their last meal to avoid the influence of feeding on absorption rates. Caffeine was provided in the form of commercially available capsules (Caffeine Kick®, Olimp Laboratories, Dębica, Poland). The manufacturer of the caffeine capsules also prepared identical PLAC capsules filled with an inert substance (all-purpose flour). Participants refrained from physical activity the day before testing and they kept their habitual training routines during the study period. Participants were also asked to refrain from caffeine intake 12 hours before each trial. In addition, participants were instructed to maintain their usual hydration and dietary habits during the study period and register their calorie intake using "MyfitnessPal" software (Teixeira et al., 2018) every 24 hours before the testing procedure. The average calorie intake was ~3000 kcal/day and it was similar before the two experimental trials.

One Repetition Maximum Test and Familiarization Session

During the pre-experimental day, the participants underwent a 1RM test followed by familiarization with the study protocol. On this day, participants arrived at the laboratory at the same time of the day as in the upcoming experimental sessions (in the morning, between 9:00 and 11:00). Upon arrival, they cycled on an ergometer for 5 minutes at an exercise intensity that induced a heart rate of~130 bpm, followed by a general upper-body warm-up. Then, participants performed 15, 10, 5, 3 bench press repetitions using 20, 40, 60 and 80% of their estimated 1RM, respectively. There was a 3-min rest interval between sets. Once the warm-up was completed, participants executed single repetitions of the bench press exercise with a 5-min rest interval between successful trials. The load for each subsequent attempt was increased by 2.5 to 5 kg, and the process was repeated until failure. The load was calculated to produce 1RM within a maximum of five attempts. The 1RM was identified as the last successful lift with a correct technique and this value was used to standardize the load in subsequent experimental trials. Hand placement on the barbell was individually selected with a grip width on the barbell of 150% individual bi-acromial distance. After completing the 1RM test, participants performed the familiarization session. The familiarization session consisted of 5 sets of 5 repetitions with 50% of the 1RM, as previously measured. The load used in the familiarization was lower than in the experimental trials to allow participants to learn how to execute repetitions at high velocity with a proper technique. A 4-min rest interval between sets was adopted. All sets were performed with a maximal movement tempo (Wilk et al., 2020c; 2020d).

Experimental Protocol

The two experimental sessions were identical, and all testing took place between 9.00 and 11.00 am to avoid the effect of circadian variation on the study outcomes. The general warm-up for the experimental sessions was identical to the one used for the familiarization session. After the warm-up, participants began the simulated training session, consisting of 5 sets of 5 repetitions at 70%1RM for the bench press exercise. The rest interval between sets equaled 4 min. The eccentric and concentric phases of the bench press exercise were performed at maximal possible velocity in each repetition. Execution technique and motivation were standardized and monitored by two experienced researchers. A linear position transducer system (Tendo Power Analyzer, Tendo Sport Machines, Trencin, Slovakia) was used for the measurement of bar velocity (García-Ramos et al., 2018). Power output was calculated using velocity and load data. During each repetition, peak power output (PP, in W), mean power output (MP, in W); peak bar velocity (PV, in m/s); and mean bar velocity (MV, in m/s) were registered. MP and MV were obtained as the mean of the five repetitions, while PP and PV were obtained from the best repetition in each set.

Statistical analysis

Data are presented as the mean ± standard deviation. All variables presented a normal distribution according to the Shapiro-Wilk test. Verification of differences in PP, MP, PV, MP was performed using a two-way (substance x set) analysis of variance (ANOVA) with repeated measures. Effect sizes for main effects and interactions were determined by partial eta squared ($\eta2$). Partial eta squared values were classified as small (0.01 to 0.059), moderate (0.06 to 0.137) and large (>0.137). In the event of a significant main effect, post-hoc comparisons were conducted using the Tukey's test. Percentage changes were assessed with 95% confidence intervals (95CI). For pair wise comparisons, effect sizes were determined by

Cohen's d and were characterized as large (d> 0.8), moderate (d between 0.79 and 0.5), small (d between 0.49 and 0.20) and trivial (d<0.2) (Cohen, 2013).

Results

The two-way repeated measures ANOVA indicated no significant substance x set interaction for MP (p = 0.72; η2 =0.04); MV (p = 0.73; η2 =0.04); PP (p = 0.54; η2 = 0.06); PV (p = 0.51; η2 = 0.06). However, there was a significant main effect of substance on MP (p = 0.01; η2 = 0.47; Table 1) and MV (p = 0.02; η2 = 0.45). No statistically significant main effect of substance was revealed on PP (p = 0.10; η2 = 0.20) and PV (p = 0.06; η2 = 0.27).

The post hoc analysis for the main effect revealed that MP and MV values in CAF-6 were higher than in PLAC in all 5 sets of exercise (p < 0.05; Table 2).

Table 1

The main effect of caffeine on performance variables measured during a bench press exercise consisting of 5 sets of 5 repetitions at 70% 1RM with the ingestion of 6 mg/kg/b.m. of caffeine (CAF-6) or a placebo (PLAC).

Bench Press	Conditions			
	PLAC	CAF-6	*p*	η^2
Mean Power Output (W)	326 ± 61	352 ± 76	0.01*	0.47
Peak Power Output (W)	575 ± 118	601 ± 122	0.10	0.20
Mean Bar Velocity (m/s)	0.62 ± 0.06	0.66 ± 0.08	0.02*	0.45
Peak Bar Velocity (m/s)	0.95 ± 0.11	0.98± 0.11	0.06	0.27

All data are presented as mean ± standard deviation. These data represent the mean values of the 5 sets.

Table 2

Mean and peak values for power output and bar velocity during 5 sets of 5 repetitions of the bench press exercise at the load of 70% 1RM with the ingestion of 6 mg/kg/b.m. of caffeine (CAF-6) or a placebo (PLAC).

Conditions	Set 1 (95%CI)	Set 2 (95%CI)	Set 3 (95%CI)	Set 4 (95%CI)	Set 5 (95%CI)
			Mean Power Output (W)		
PLAC	326 ± 65	327 ± 61	325 ± 61	327 ± 65	324 ± 64
(95%CI)	(286 to 366)	(290 to 364)	(288 to 362)	(287 to 366)	(285 to 362)
CAF-6	352 ± 71	350 ± 71	350 ± 80	352 ± 85	357 ± 85
(95%CI)	(309 to 394)	(307 to 393)	(301 to 398)	(301 to 404)	(306 to 409)
ES	0.38	0.35	0.35	0.33	0.44
			Peak Power Output (W)		
PLAC	580 ± 117	575 ± 129	573 ± 132	576 ± 113	572 ± 116
(95%CI)	(509 to 651)	(497 to 653)	(493 to 653)	(508 to 644)	(502 to 642)
CAF-6	594 ± 118	592 ± 126	606 ± 131	601 ± 124	610 ± 130
(95%CI)	(523 to 666)	(516 to 668))	(527 to 685)	(525 to 676)	(531 to 689)
ES	0.12	0.13	0.25	0.21	0.31
			Mean Velocity (m/s)		
PLAC	0.62 ± 0.05	0.62 ± 0.07	0.61 ± 0.07	0.62 ± 0.06	0.61 ± 0.06
(95%CI)	(0.58 to 0.65)	(0.58 to 0.66)	(0.57 to 0.66)	(0.58 to 0.66)	(0.58 to 0.65)
CAF-6	0.65 ± 0.07	0.66 ± 0.08	0.66 ± 0.09	0.66 ± 0.09	0.67 ± 0.08
(95%CI)	(0.61 to 0.70)	(0.61 to 0.71)	(0.60 to 0.71)	(0.61 to 0.71)	(0.62 to 0.72)
ES	0.49	0.53	0.62	0.52	0.85
			Peak Velocity (m/s)		
PLAC	0.96 ± 0.10	0.96 ± 0.11	0.95 ± 0.13	0.95 ± 0.12	0.94 ± 0.12
(95%CI)	(0.90 to 1.02)	(0.89 to 1.02)	(0.87 to 1.03)	(0.88 to 1.02)	(0.87 to 1.02)
CAF-6	0.97 ± 0.11	0.97 ± 0.12	0.98 ± 0.10	0.98 ± 0.12	0.99 ± 0.11
(95%CI)	(0.91 to 1.04)	(0.90 to 1.04)	(0.92 to 1.04)	(0.91 to 1.05)	(0.92 to 1.06)
ES	0.09	0.09	0.26	0.25	0.43

All data are presented as mean ± standard deviation. CI: confidence interval. ES: effect size. The data were obtained by averaging the values obtained in each set.

Discussion

The main finding of this study is that the acute caffeine intake of 6 mg/kg/b.m. enhanced MP and MV during a multiple-set bench press exercise consisting of 5 sets of 5 repetitions at 70% 1RM in mild caffeine users. The dose of caffeine administered was ~4-fold their habitual caffeine intake, which suggests that habitual caffeine users may obtain benefits from acute caffeine intake if the dose ingested acutely is greater than their mean daily intake. Although the results did not show a statistically significant main effect of caffeine on PP and PV, the magnitude of the effect of caffeine in these variables over the placebo was from small-to-moderate. Therefore, these results suggest that 6 mg/kg/b.m. of caffeine can be an effective dose to improve power-specific training outcomes in mild caffeine consumers. Interestingly, although there was no substance x repetition interaction, the size of the ergogenic effect of caffeine on the considered variables reached their highest value in the last, fifth set, which suggests that the positive effect of caffeine increases along with the number of sets performed in the resistance-based training session.

Previous studies showed that acute caffeine ingestion increased mean power output (Giráldez Costas et al., 2020; Pallarés et al., 2013; Wilk et al., 2020a) and peak power output (Del Coso et al., 2012; Diaz-Lara et al., 2016; Giráldez Costas et al., 2020) during the bench press exercise. However, it should be noted that most previous research assessed the effects of caffeine intake in tests with a single set of exercise and to date, only five studies considered the ergogenic effect of caffeine during a multiple-set bench press training session (Giráldez Costas et al., 2020; Lane et al., 2019; Lane and Byrd, 2018; Wilk et al., 2019b, 2020a). Results of the present study show that acute caffeine intake improves mean power output and mean bar velocity during a multiple-set bench press exercise, which is consistent with the data of Wilk et al. (2020a) obtained during a multiple-set bench press-throw exercise. Similar to the results of Wilk et al. (2020a), the current study did not show any changes in peak power output and peak bar velocity after ingestion of 6 mg/kg/b.m. caffeine. Contrary to these two investigations, Giráldez Costas et al. (2020) showed that ingestion of 3 mg/kg/b.m. of caffeine before a bench press training session improved not only mean but also peak bar velocity. Furthermore, the recent meta-analysis by Raya-González et al. (2020) showed that acute caffeine intake was highly ergogenic for both, mean and peak movement velocity. It is worth noticing that the exclusion of unpublished studies in the systematic review by Raya-González et al. (2020) changed the effect of caffeine for peak velocity from being significant to non-significant. In fact, most previous research has demonstrated improvement in mean velocity during the bench press exercise after caffeine ingestion in a wide range of loads (25-100% of 1RM) (Raya-González et al., 2020), but the impact of caffeine on peak velocity is less clear. The differences between our results and those of Giráldez Costas et al. (2020) can also be related with the type of exercise used. In the study of Giráldez Costas et al. (2020), participants performed a bench press-exercise on a Smith machine, while in our study we used a free barbell bench press. Schick et al. (2010) showed that muscle activation of the medial deltoid was significantly greater during the free weight bench press exercise compared to the Smith machine bench press. The instability caused by the free weight bench press necessitates a greater response by the medial deltoid and it may be that the increased stability offered by the Smith machine decreases the need for the anterior deltoid and pectoralis major to stabilize, allowing them to produce more force (Schick et al., 2010). This factor likely leads to increased variation in exercise technique and subsequently variation in peak and mean power output variables in free-weight exercises compared to the Smith machine exercise. Further investigations are needed to confirm if some of the benefits of acute caffeine intake during resistance training may be obtained only when exercise is performed on a Smith machine.

Additionally, it should be noticed that the level of habitual caffeine consumption of study participants varied significantly, what may also explain the differences in results. The habitual ingestion of caffeine may modify the physiological response to acute ingestion of caffeine by the up-regulation of adenosine receptors (Fredholm et al., 1999; Svenningson et al., 1999). Specifically, habitual caffeine intake creates new adenosine receptors which may bind to adenosine, ultimately reducing the role of caffeine to block adenosine receptors (Fredholm et al., 1999). Several previous studies considered the impact of habituation to caffeine on the ergogenic effects of acute caffeine intake and they found a reduced or non-significant ergogenic effect of acute caffeine intake in habituated participants (Beaumont et al., 2017; Lara et al., 2019; Wilk et al., 2019a; 2019b; 2019c; 2019d; 2020a). The confirmation that habitual consumption of caffeine can reduce the acute effects of caffeine in habitual users, may result from the comparison of results presented here, those by Wilk et al. (2020a) and those of Giráldez Costas et al. (2020). Wilk et al. (2020a) showed that the intake of 3 and 6 mg/kg/b.m. of caffeine increased mean power output, but not peak power output during a multiple-set bench press throw, what was also observed in this study. Similarly, to the present results, participants in the Wilk et al.'s study (2020a) were habituated to caffeine intake. On the contrary, participants in the Giráldez Costas et al.'s (2020) study were recruited because they had caffeine intake of < 100 mg/day, which may explain the larger ergogenic effect of acute caffeine intake in that study, despite using only a dose of 3 mg/kg/b.m. of caffeine. Overall, these outcomes point towards a relationship between habitual daily caffeine consumption and the effectiveness of acute caffeine intake to enhance muscle performance during resistance-based exercise, at least in terms of magnitude. It is worth noticing that, to date, only two studies compared the effect of acute caffeine intake on power performance in groups with different levels of daily caffeine consumption (Grgic and Mikulic, 2020; Sabol et al., 2019) and showed that habitual caffeine consumption did not modify the ergogenic effects of acute caffeine supplementation. However, it has to be highlighted that in the study of Sabol et al. (2019) and Grgic and Mikulic (2020) a multiple-set exercise protocol was not investigated. Further studies are warranted to clearly unveil if individuals habituated to caffeine obtain the same ergogenic benefits from acute caffeine supplementation as unhabituated individuals, considering that habitual caffeine intake may be a modifiable variable to maximize the benefits of this stimulant to resistance exercise performance.

It has to be taken into consideration that the ergogenic effect of caffeine ingestion occurs primarily through the central nervous system as caffeine possesses the ability to inhibit adenosine receptors. Caffeine has potential fatigue-delaying properties (Davis et al., 2003) that may be only present when exercise lasts long enough to produce moderate-to-high levels of fatigue. As the mechanism responsible for tolerance to the ergogenic effect of caffeine is associated with the up-regulation of adenosine receptors (Fredholm et al., 1999), thus it could be hypothesized that the effect of habituation to caffeine on resistance exercise could be more pronounced during fatiguing resistance training sessions. In any case, the current investigation showed a positive effect of caffeine on power output and mean bar velocity during the bench press exercise in athletes habituated to caffeine. However, it is still possible that using caffeine is more effective in unhabituated individuals or when the differences between the level of habituation and the dose of caffeine administered acutely is higher.

It should be noted that the results of the present study indicate a progressively higher magnitude of the effect of caffeine over the placebo as the session progresses in sets (Table 2). A similar trend was observed in the study of Wilk et al. (2020a) where the highest effect sizes in the caffeine-placebo pairwise comparison were mostly observed in the last, fifth set of a bench press throw session. The increasing effectiveness of caffeine along with the duration of bench press training can be related to the caffeine mechanism of action, producing better maintenance of the level of central motor drive despite biochemical disturbance of the muscle cell during exercise (Bowtell et al., 2018), at least in comparison to the placebo-control situation. Previous studies have shown that caffeine supplementation improves high-intensity exercise tolerance despite phosphocreatine depletion and H^+ accumulation (Bowtell et al., 2018). Additionally, caffeine intake reduces muscle interstitial K^+, ultimately preserving peripheral excitability and enhancing resistance to fatigue (Mohr et al., 2011). The efficacy of caffeine to preserve muscle performance even in the presence of fatigue-associated disturbances may help explain the obtained results.

In addition to its strengths, the present study has several limitations which should be addressed: (1) the study did not include any biochemical analysis, such as plasma/urinary caffeine concentrations which could help explain the obtained results; (2) there was no analysis of the genetic intolerance to caffeine in the tested participants (3); the study included only young, trained men, and the results cannot necessarily be generalized to inactive individuals and women. Finally, we analyzed only the effects of caffeine intake in mild caffeine consumers, and the generalizability of these results to the population with other levels of caffeine consumption remains unclear. More research is needed to determine an effective acute caffeine dose considering various daily levels of caffeine consumption in the population. Additionally, future studies should explore the effectiveness of acute caffeine intake in other multiple-set exercise protocols.

Conclusions

The results of the current investigation showed an ergogenic effect of 6 mg/kg/b.m. of caffeine on mean power and bar velocity during a bench press exercise routine consisting of 5 sets of 5 repetitions with a load equivalent to 70% 1RM. These results were obtained in participants with mild habituation to caffeine, potentially obtained because the dose of caffeine administered was ~4-fold their habitual caffeine intake. Although statistically significant changes were not observed for peak power output and peak bar velocity, caffeine induced an effect of small-to-moderate magnitude in all performance variables. Last, the increasing magnitude of the ergogenic effect of caffeine on muscle performance in the multiple-set resistance training session suggests that the effectiveness of caffeine to enhance bench press performance may be more pronounced with the progress of fatigue.

Acknowledgements

The study was supported and funded by the statutory research of the Jerzy Kukuczka Academy of Physical Education in Katowice, Poland.

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