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Article

The effect of caffeine on countermovement jump performance in recreationally trained women habituated to caffeine

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Abstract: Introduction. The main goal of this study was to examine the effect of acute intake of 3 mg/kg/body mass (b.m.) of caffeine (CAF) on countermovement jump (CMJ) performance in recreationally trained women habituated to CAF. Material and Methods. 17 healthy recreationally trained women habitually using CAF participated in the study. The experiment followed randomized, crossover, double-blind design under three different conditions: control test (CONT) or consumed placebo (PLAC) or consumed 3 mg/kg/b.m. of CAF (CAF-3). Each participant performed 2 sets of 2 CMJ. The following variables were recorded: concentric peak velocity (PV), peak power (PP) and jump height (JH). Results. The two-way repeated measure ANOVA (substance × set) revealed no statistically significant interaction and main effects for all measured variables between conditions. In comparison to the CONT and PLAC, the intake of CAF-3 was not effective at increasing PV ($p = 0.533$), JH ($p = 0.417$) and PP ($p = 0.871$) during 2 sets of the CMJ. Conclusions. This study suggests that 3 mg/kg/b.m. of CAF did not improve CMJ height in recreationally trained women habituated to CAF. Furthermore, the level of athletic performance might be considered a factor in regard to CAF ergogenicity.

Keywords: ballistic exercise, ergogenic aid, female, sport performance.

1. Introduction

Caffeine (CAF) is a well-established ergogenic supplement, common among athletes in many sport disciplines, and among the majority of general population [1, 2]. CAF ingestion in numerous forms [2, 3] has been shown to have an impact on exercise performance and to be beneficial in various modes of exercise, such as maximal strength, endurance and power output [4, 5]. The ergogenic effect of CAF, particularly during anaerobic performance is most often attributed to its ability to act as adenosine A1 and A2A receptor antagonist [4, 6]. CAF and adenosine molecular structures are similar, hence CAF inges-

tion results in blocking adenosine and A1 and A2A receptors binding [6, 7], inducing increased arousal, motor unit firing rates, neuro-excitability and inhibited pain perception [4, 8].

The power output is known to be a significant component of athletic performance and it has been shown that CAF ingestion enhances single-bout sprinting tasks (the Wingate test), ballistic tasks (jumps and throws) or resistance exercise performance [10]. Although CAF supplementation has been shown to affect power output in both male and female subjects [8, 9, 11], it should be pointed out that the gender may be one of the factors that plays an important role in acute CAF efficiency [11–13]. Due to the differences in stages of the menstrual cycle as well as the use of oral contraceptives by females, CAF metabolization speeds and thus its ergogenic effect might be altered [13,33]. Moreover, a systematic review by Mielgo-Ayuso et al. [11] indicated a different ergogenic effect of acute CAF intake on anaerobic performance in men from that in women (greater CAF ergogenicity for males). Furthermore, in most of the studies analyzing CAF ergogenicity, the majority of subjects are male, or mixed gender populations are included, thus it is not clear whether these results translate to women or not [11–13].

Although various doses of CAF, ranging from 3 to 13 mg/kg/body mass, have been utilized in the literature [12, 14, 15], as regards the power output, most often low (3 mg/kg/body mass) to moderate (6 mg/kg/body mass) doses are used [4,9,16]. The results of several studies indicated that habitual use of CAF may reduce the ergogenic effects of such doses [12, 15, 17–19]. On the other hand, different studies (related to ballistic tasks performance) have shown that the level of daily CAF intake does not influence its ergogenicity [7, 20]. Thus, the available literature regarding the effects of habitual consumption of CAF on its ergogenicity remains inconclusive, and this issue has not been sufficiently examined, particularly in female subjects [2, 13, 20–22].

Taking into consideration that habituation to CAF may be a factor affecting its ergogenicity, and only few previous investigations included female subjects [23], the purpose of this study was to examine the effect of acute intake of 3 mg/kg/body mass of CAF on countermovement jump (CMJ) performance in recreationally trained women habituated to CAF. Given that the CAF dose of 3 mg/kg/body mass is the lowest CAF dose considered to be ergogenic [2, 12], and could be potentially used as an ergogenic aid during training by recreationally trained females, the dose of 3 mg/kg/body mass was administered. We hypothesized that acute CAF ingestion would enhance performance compared to both control and placebo conditions.

2. Materials and Methods

This study used a randomized, cross-over, double-blind design in which initially a familiarization session was conducted, followed by three different experimental sessions with a one-week rest interval between sessions to allow for complete recovery and rinsing out the substance (Figure 1). During three experimental sessions, participants performed a control test (CONT) or consumed either placebo (PLAC) or CAF at a dose of 3 mg/kg/body mass (CAF-3). One hour after consuming CAF-3 or PLAC, the subjects performed 2 series of 2 jumps with a 3-minute rest interval between each trial. Both CAF and PLAC were administered orally one hour before each exercise protocol to ensure the maximum concentration of CAF in the blood and at least 2 hours after the last meal to maintain the same absorption time of the tested substance. The CAF supplement was in the form of capsules containing an individual dose of CAF (Caffeine Kick®, Olimp Laboratories, Dębica). The manufacturer also supplied identical PLAC capsules filled with all-purpose flour. Participants abstained from strenuous physical activity the day before each test, and they were also asked to maintain their training, eating and hydration habits, including regular CAF consumption during the study period. Participants also received a list of CAF-containing products that were prohibited for consumption 12 hours prior to each trial. In addition, participants recorded their caloric intake 24 hours prior to the start of every test procedure using the "MyfitnessPal" program to ensure that the diet was similar before each trial.

2.1. Participants

The study included 17 healthy recreationally trained women (age = 23.1 ± 1.0 years; body mass = 60.2 ± 7.6 kg; height = 166.4 ± 5.3 cm; body mass index (BMI) = 21.7 ± 2.1) with at least 2 years of strength training experience (2.9 ± 0.8 years), who volunteered to participate in the study. All participants were habitual CAF consumers (3.2 ± 1.2 mg/kg/body mass; 191.6 ± 72.9 mg of CAF per day) and their reported daily ingestion of CAF was based on the Food Frequency Questionnaire (FFQ). The inclusion criteria were as follows: (a) free from neuromuscular and musculoskeletal disorders, (b) minimum 2 years of experience in strength training, (c) at least low habitual consumption of CAF, as per previously proposed thresholds for classifying individuals in sport performance research according to their habitual caffeine consumption [24]. Participants were excluded when they suffered from any pathology or injury. Additionally, participants were required not to take any medications or supplements within the 3 previous months. 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 of the latest version of the Declaration of Helsinki, 2013.

2.2. Study Protocol

Habitual Caffeine Intake Assessment

Habitual CAF intake was measured by an adapted version of FFQ proposed by Bühler et al. [25]. Portions, in household measures, were used to assess the amount of food consumed according to the frequency of consumption during a day, week and month. The list was composed of dietary products with high CAF 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 [26–28]. Based on the answers in FFQ, a qualified nutritionist estimated the habitual CAF intake.

Familiarization Session

The familiarization session which included the same procedures used in subsequent experimental sessions was the first attempt at research. Study participants arrived at the laboratory at the same time of day as for the upcoming experimental sessions (morning, between 9:00 am and 11:00 am). Upon arrival, participants cycled on an ergometer for 5 minutes at an intensity that resulted in a heart rate of around 130 beats per minute, followed by an overall lower body warm-up containing ten bodyweight forward and lateral lunges, squats and standing calf raises. Then, the participants performed a test trial consisting of 2 sets of 2 CMJ, with a 3-minute rest between sets, which is exactly the same as in the other experimental sessions.

Experimental session

Three sessions were carried out during the experimental trials with one week between each trial, and the protocols were identical. All trials were conducted between 9.00 am and 11.00 am to avoid diurnal variability. The overall warm-up for the experimental sessions was identical to that performed in the familiarization session. After the warm-up, participants performed 2 sets of 2 CMJ, with 3 minutes' rest between the sets. Each CMJ was performed on the Force-Decks FD4000 Dual Force Platforms hardware, with a sample rate of 1000 Hz. Previous research has shown high reliability and validity of this force platform (intraclass correlation coefficient [ICC] = 0.944 to 0.975) for all variables measured in this study, with jump height showing the highest coefficient of variation (CV) (3.8%) [29]. Manufacturer's software was used for the instantaneous recording of peak velocity, height, and peak power obtained during each CMJ under three different conditions: CONT (i.e. no ingestion of the substance) or consumed PLAC or CAF-3. Each CMJ was performed from a standing position with a straight torso, knees fully extended with

hands-on-iliac crest and feet shoulder-width apart. Participants dropped into the counter-movement position to a self-selected depth and immediately jumped for maximum height without arm swing. The take-off was executed as a continuous movement with no observable pause between downward and upward phases. Participants were told that the landing must be with the same position than the take-off and it should be produced on the mid-section of the force platform. During the apex of the jump, participants kept their legs fully extended. No instructions were given as to the amplitude or speed of the counter-movement. The best jump of the two attempts was used for further analysis. The measurement was performed independently for each replicate and the following variables were recorded: concentric peak velocity (PV, in m/s), peak power (PP, in W), and jump height (JH, in cm). The jump height was calculated from the flight time. All participants completed the described test protocol, which was carefully repeated in subsequent experimental sessions.

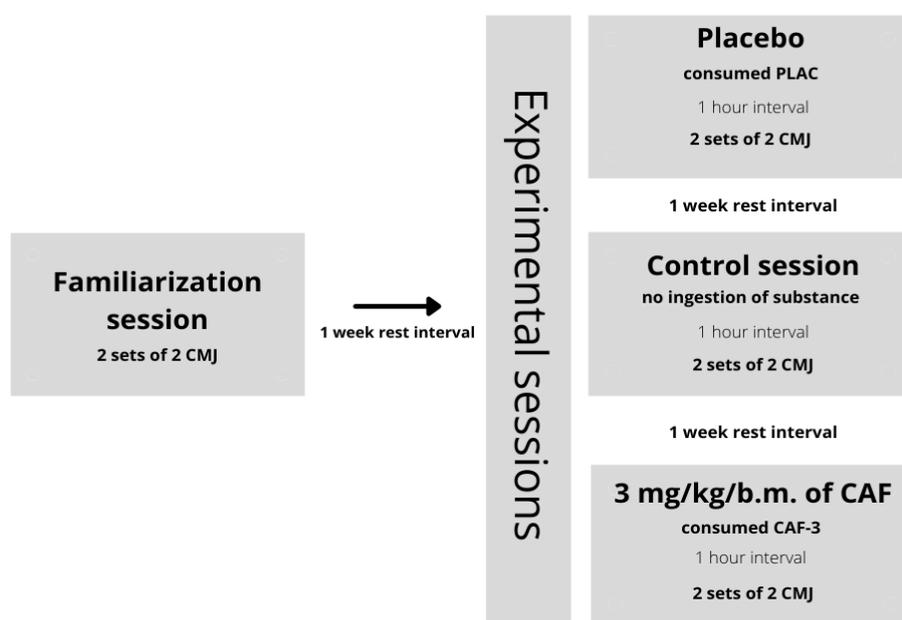


Fig. 1. Schematic representation of the study design.

CONT: control, PLAC: placebo, CAF-3: caffeine at a dose of 3 mg/kg, b.m.: body mass.

2.3. Statistical analysis

The Shapiro–Wilk test was used in order to verify the normality of the data. All data presented a normal distribution. Verification of differences between CONT, PLAC and CAF-3 was performed using ANOVA with repeated measures. Effect sizes (Cohen's d) were reported where appropriate. Parametric effect sizes (ES), were defined as large for $d > 0.8$, as moderate for d between 0.8 and 0.5, and as small for $d < 0.5$ [30]. The statistical significance was set at $p < 0.05$. All statistical analysis were performed using SPSS (version 25.0; SPSS, Inc., Chicago, IL, USA) and were expressed as means with standard deviations (\pm SD).

3. Results

The two-way repeated measure ANOVA (substance \times set) revealed no statistically significant interaction and no main effects for all measured variables. In comparison to the CONT and PLAC, the intake of CAF-3 did not improved PV (2.43 ± 0.36 vs. 2.48 ± 0.45 vs. 2.43 ± 0.3 m/s, respectively; $p = 0.553$; Figure 2) nor JH (27.1 ± 9.0 vs. 28.7 ± 11.5 vs. 27.2 ± 7.9 cm, respectively; $p = 0.417$; Figure 3) and PP (2602 ± 511 vs. 2618 ± 520 vs. 2587 ± 401 W, respectively; $p = 0.871$; Figure 4) during 2 sets of CMJ. Additionally, small ES was found

for all measured variables between the CONT, PLAC and CAF-3 groups, except for PV between CONT and CAF-3, where no effects were found (Table 1).

Table 1. Values of the effect size of peak velocity, jump height and peak power during 2 sets of CMJ with the ingestion of placebo and 3 mg/kg of caffeine or during control conditions.

Conditions		Peak Velocity [m/s]	Jump Height [cm]	Peak Power [W]
ES	CONT vs PLAC	0.12	0.15	0.03
	CONT vs CAF-3	0	0.12	0.03
	PLAC vs CAF-3	0.13	0.15	0.07

CONT: control, PLAC: placebo, CAF-3: caffeine at a dose of 3 mg/kg, ES: effect size

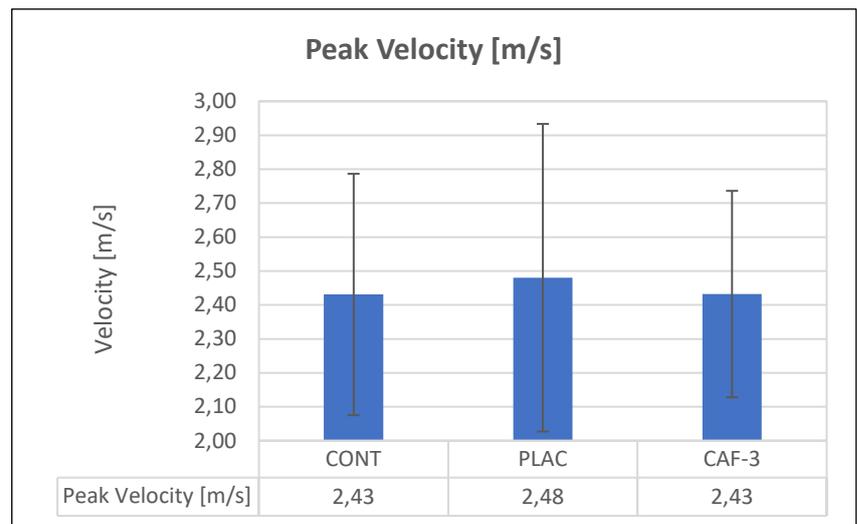


Fig. 2. Results of peak velocity during CMJ in the control, placebo and caffeine conditions. CONT: control, PLAC: placebo, CAF-3: caffeine at a dose of 3 mg/kg. Data are presented as means \pm SD.

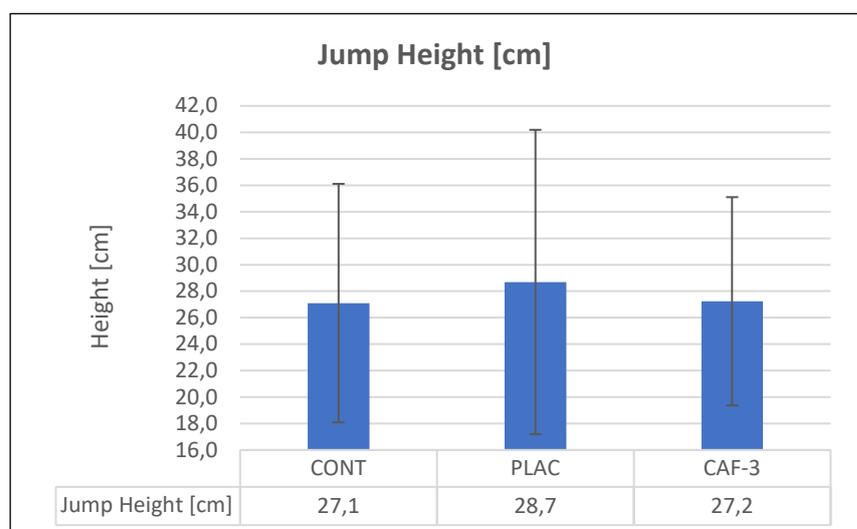


Fig. 3. Results of jump high during CMJ in the control, placebo and caffeine conditions. CONT: control, PLAC: placebo, CAF-3: caffeine at a dose of 3 mg/kg. Data are presented as means \pm SD.

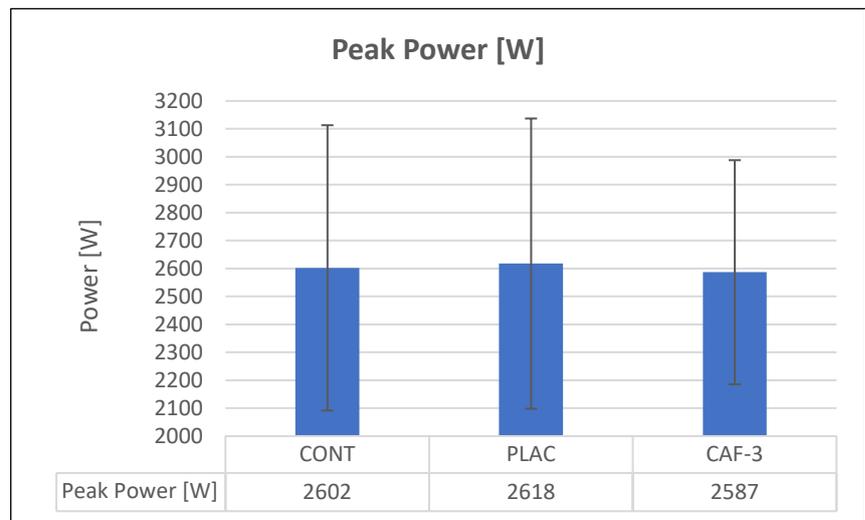


Fig. 4. Results of peak power during CMJ in the control, placebo and caffeine conditions. CONT: control, PLAC: placebo, CAF-3: caffeine at a dose of 3 mg/kg. Data are presented as means \pm SD.

4. Discussion

Given that the available literature concerning the topic of CAF ergogenicity among habituated women is scarce, particularly as regards power performance, the objective of this study was to assess the impact of acute intake of CAF-3 on CMJ performance in recreationally trained women habituated to CAF. The main finding of this study was that CAF-3 did not provide an ergogenic effect on CMJ performance compared to CONT and PLAC condition. Therefore, the low CAF dose (CAF-3) may be considered not to be ergogenic during lower body ballistic tasks among recreationally trained women habituated to CAF. Currently, there are several studies exploring CAF impact on muscle power, utilizing the CMJ test [8, 16, 31]. The CMJ test is considered to be a reliable and valid test for lower body power, and it is commonly used by scientist and sport practitioners [32, 33]. Furthermore, the meta-analysis by Grigic et al. [9] showed significant ergogenic effects of acute CAF consumption on power output, as assessed by vertical jump height. However, the results of the current study are inconsistent with most of the previous findings, which indicated an improvement of power output in lower body ballistic tasks after acute CAF intake [8, 9, 34]. Although, acute CAF intake has been shown to improve CMJ performance, previous studies mostly involved male subjects [31, 35–37] or both sexes [8, 38], thus indicating that the gender may have an impact on CAF ergogenicity during ballistic tasks, such as CMJ. To the best of the authors' knowledge, only few studies examined CAF impact on CMJ performance in women [16, 34, 39]. Stojanović et al. [39] reported that CAF dose of 3 mg/kg/body mass provided small non-significant increases in CMJ performance in professional female basketball players. By contrast, Norum et al. [34] demonstrated that CAF dose of 4 mg/kg/body mass significantly increased CMJ height in resistance-trained females during the early follicular phase. It should be pointed that the phase of the menstrual cycle is a factor that might influence strength and power performance; however, this issue has not been taken into account in other studies [34]. The aforementioned research is contrary to the present study, which included recreationally trained women, thus suggesting that the CAF impact on CMJ performance may also be related to the level of athletic performance [2, 4, 40]. It has been proposed in the literature that the ergogenic effect of CAF differs between trained and untrained individuals, and such disparity may be related to higher reliability of exercise performance (less day-to-day variation) or greater adenosine A2a receptor densities in trained compared to untrained individuals

[13, 27]. However, only limited data related to this topic is available; furthermore, the research provides conflicting findings. Thus, further investigation regarding this issue is required [13].

It should be taken into account that the habituation to CAF resulting in up-regulation of adenosine receptors may modify the physiological responses to acute CAF intake [41, 42]. Moreover, it has been suggested that application of doses higher than an individual's daily intake may be required to achieve an ergogenic effect of CAF [5]. However, as shown in other studies, application of higher doses of CAF in habituated subjects is not beneficial, not only in regard to resistance exercise [17, 43] but also to ballistic tasks performance [7, 41]. Nonetheless, it should be noted that all of the aforementioned studies included male subjects. Thus extrapolation of these findings to female subjects should be made with caution. In the present study female subjects were administered a CAF dose of 3 mg/kg/body mass, which almost equaled their daily intake (3.2 ± 1.2 mg/kg/body mass) and did not improve CMJ performance. However, in the study by Norum et al. [34], which produced contrary findings, subjects' daily CAF intake (5.4 ± 2.9 mg/kg/body mass) was greater than the dose ingested (4 mg/kg/body mass), and still administration of CAF significantly improved the CMJ height. Therefore, these findings suggest, similarly to male subjects, that application of CAF doses exceeding one's daily intake might not be the sole factor impacting on ergogenicity of CAF in ballistic tasks, such as CMJ in habituated subjects [7]. In support of this, one other study [16] found that even a higher CAF dose (6 mg/kg/body mass) did not improve CMJ performance in female team-sport players. However, these results may also be explained by diversified daily CAF intake among subjects (0–300 mg/day), as well as their sports level, ranging from recreational to international. Thus, further research of CAF ergogenicity among habituated women should consider such disjunctions.

Beyond the strengths of the present study, such as the participation of female subjects habituated to CAF, also its limitations should be considered. The current research did not account for the use of oral contraceptives among the subjects, as well as did not take account of the phase of the menstrual cycle. Furthermore, there were no physiological measurements which could provide an explanation of the obtained results. It is noteworthy that genetic variation between individuals may influence the magnitude of performance improvement after CAF ingestion [5, 15]; however, no genetic assessments regarding CAF metabolism were performed.

5. Conclusions

The results of the present study indicated that the acute intake of the CAF dose of 3 mg/kg/body mass did not improve CMJ performance in recreationally trained women habituated to CAF. These results suggest that the level of athletic performance might be considered a factor in regard to CAF ergogenicity. Furthermore, the administration of higher doses of CAF may not further enhance ballistic tasks performance in recreationally trained female habituated to CAF. However, the available literature regarding this topic is scarce and only few studies included populations of women habituated to CAF. Thus, further research on this issue is needed.

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