

# Placebo effect of caffeine on maximal strength and strength-endurance in healthy recreationally trained women habituated to caffeine

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## Research article

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# Abstract

## Background

By using deceptive experimental designs, several investigations have observed that athletes may increase their performance when told they were given caffeine, when in fact they received a placebo (i.e., the placebo effect of caffeine). However, most of these investigations used participants not familiarized to caffeine intake, while habituation to caffeine may affect the placebo effect of caffeine. Thus, the aim of the present study was to analyze the placebo effect of caffeine on maximal strength and strength-endurance performance during the bench press exercise (BP) in healthy recreationally trained women who consume caffeine on a daily basis.

## Methods

Thirteen resistance-trained women (BP 1RM =  $40.0 \pm 9.7$  kg) habituated to caffeine ( $4.1 \pm 1.7$  mg/kg/day) completed a deceptive randomized experimental design with two experimental trials. On one occasion, participants were told that they would receive 6 mg/kg of caffeine but received a placebo (PLAC) and in other occasion they did not receive any substance and participants were told that this was a control situation (CONT). In each experimental trial, participants underwent a 1RM BP test and a strength-endurance test consisting of performing the maximal number of repetitions at 50% of their 1RM.

## Results

In comparison to CONT, PLAC did not enhance 1RM ( $40.0 \pm 10.5$  vs  $41.0 \pm 9.5$ , respectively;  $p = 0.10$ ), nor the number of repetitions ( $32.2 \pm 5.1$  vs  $31.8 \pm 4.5$ ;  $p = 0.66$ ) or mean power ( $130 \pm 34$  vs  $121 \pm 26$ ;  $p = 0.08$ ) in the strength-endurance test.

## Conclusion

The expectancy induced by telling participants they were given caffeine did not modify any performance variable measured in this investigation. Thus, the use of the placebo effect of caffeine seemed an ineffective strategy to enhance muscle strength and strength-endurance during the BP exercise in women habituated to caffeine.

## Introduction

Caffeine (1,3,7 trimethylxanthine) is one of the most frequently used supplements before training and competition, with the aim of enhancing performance and readiness to exercise. In fact, three out of four elite athletes were reported to have caffeine present in their urine collections for doping control, indicating the wide utilization of caffeine before or during competition [1]. Furthermore, urinary caffeine

concentration has increased since the removal of caffeine from the list of banned substances of the World Antidoping Agency in 2004 suggesting an increasing use of this stimulant in elite sport [2]. In the last years, there has been a burst of research that supports the performance-enhancing effects of caffeine across a wide range of sporting activities including aerobic exercise [3] anaerobic-like exercise [4], and resistance exercise [5–7]. Overall, there is ample consensus to consider the antagonistic role of caffeine and its two metabolites, paraxanthine and theophylline, in adenosine receptors as the main mechanism behind its ergogenic effects during exercise, as caffeine can bind adenosine A<sub>1</sub>, A<sub>2A</sub> and A<sub>2B</sub> receptors in the central nervous system, reducing the fatiguing effect of adenosine [8]. However, several investigations have suggested that the belief of having ingested caffeine may also increase performance [9, 10], suggesting that psychological mechanisms may also be behind the potent ergogenic effect of caffeine. To this regard, the increase in performance produced just by the perception of consuming caffeine, without actually consuming it, is often referred as placebo effect of caffeine.

The placebo effect is not a phenomenon unique for caffeine, as the change in motivation and self-efficacy just by the expectation of ingesting an active substance has been widely reported in the literature [11]. By using deceptive experimental designs, it has been found that a placebo can increase performance when participants are informed that the substance ingested is caffeine [12–14]. To date, most of the research has confirmed the placebo effect of caffeine on several forms of exercise, and by using several deceptive protocols [9, 10, 12–18]. In some of these investigations, participants further increased performance when they knowingly ingested caffeine and it seems necessary that believing that they are ingesting caffeine is required to obtain an ergogenic effect [9, 19]. Interestingly, in most of these investigations, participants were naïve, or low caffeine consumers, while the only investigation that failed to report a placebo effect of caffeine used individuals habituated to this substance [14, 20].

The main factor determining the placebo effect of caffeine in the above-mentioned studies is related to the expectation of receiving caffeine, as it is recognized as a potentially beneficial ergogenic aid [21]. However, it has to be emphasized that chronic caffeine intake may modify the acute effect of caffeine on sport performance [22], so that individuals habituated to caffeine obtain no, or lesser, benefits from acute caffeine intake [7, 23–25]. Thus, the potential placebo effect of caffeine may also depend on the daily habitual consumption of caffeine of the athlete [26] as the deceptive protocol may be unsuccessful in those athletes who are well familiarized with the feelings of acute caffeine intake. Therefore, the main goal of this study was to assess the placebo effect of caffeine on maximal strength and strength-endurance in women habituated to caffeine. We hypothesized that placebo effect of caffeine would not be present in women athletes habituated to caffeine due to experience related with habitual caffeine intake.

## Methods

### Experimental design

A deceptive, randomized and cross-over design was used for this investigation. All testing was performed at the Strength and Power Laboratory of the Academy of Physical Education in Katowice under controlled ambient conditions. All experiments took place at the same time of day to avoid circadian variation. Each participant performed 2 familiarization sessions, one session to assess their 1 repetition maximum (1RM), and 2 experimental trials, for a total of 5 different visits to the laboratory. For the two experimental trials, participants were randomly assigned to two conditions: (1) ingestion of a capsule containing (PLAC) but participants were told that they were given 6 mg of caffeine per kg of body mass; (2) not ingesting any capsule (CONT) while participants were told that this was a control situation to assess the effect of caffeine on muscle performance. In PLAC condition, participants received a capsule containing all-purpose flour, one-hour before the onset of the exercise protocol. In CONT condition, participants did not receive any treatment to increase the belief that they were ingesting caffeine in the PLAC condition. The exercise protocol included a measurement of their 1RM in the bench press (BP) exercise and a strength-endurance test consisting of performing the highest number of repetitions against a load of 50% of their 1RM. 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 provided their written informed consent prior to participation in this study.

## **Study participants**

Thirteen healthy recreationally trained women (age =  $23.0 \pm 0.8$  year, body mass =  $62.5 \pm 6.9$  kg, 1RM in BP =  $40.0 \pm 9.7$  kg) volunteered to participate in the study. The participants had a minimum of 2 years of resistance training experience ( $3.0 \pm 0.8$  years). All of them were classified as mild to moderate habitual caffeine consumers with a daily ingestion of  $4.1 \pm 1.6$  mg of caffeine per kg of body mass, (range 1.5–5.9 mg/kg). Habitual caffeine intake was measured by using a modified version of the validated questionnaire by Bühler et al. [27] that recorded the type and amount of caffeine-containing foods and dietary supplements and this information was obtained for the four weeks before the start of the experiment, following previous recommendations [28]. The participants were instructed to maintain their usual hydration and dietary habits during the study period, including habitual caffeine intake. In addition, participants registered their food intake using “MyFitnessPal” software [29] 24 hours before the testing procedure. The average calorie intake was  $\sim 2300$  kcal/day and the proportion of macronutrients was similar before the two experimental trials. Participants were also asked to refrain from any source of caffeine 12 hours before each experimental trial.

## **Familiarization session and one repetition maximum test**

Three weeks before onset of the experimental trials, participants performed two familiarization sessions separated by one week to restrict possible learning effects during the experiment. In each familiarization session, participants arrived at the laboratory at the same time of day and performed a standardized warm-up. Then, participants performed one set of the BP exercise consisting of the maximal number of repetitions at a load of approximately 50% of their 1RM. One week before onset of the experimental trials, participants underwent a 1RM BP testing according with previous guidelines [30]. In the last

familiarization session, participants were informed about the findings of research related to acute effects of caffeine intake on resistance exercise performance through informal conversations that included information about the ergogenic effect of caffeine, dosage, and most common side effects.

## Experimental protocol

Participants arrived to the laboratory between 9:00 and 11:00 am. Upon arrival, participants received the treatment assigned for the session (i.e., PLAC or CONT) and rested for 45 min. Then, participants performed a warm-up that included 10 min of cycling and three sets of 8, 6, 3 and 1 repetitions of the bench press exercise using 50%, 70%, 80% and 90% of their 1RM established during the familiarization. Then, participants performed the 1RM test to assess upper-body maximal muscle strength. After five minutes of resting, the strength-endurance test was performed with the 50% of 1RM load measured in the previous test. The concentric and eccentric phase of each repetition during the strength-endurance test was performed at their maximal possible velocity. A linear position transducer system (Tendo Power Analyzer, Tendo Sport Machines, Trencin, Slovakia) was used to assess bar velocity during each repetition of the strength-endurance test [31] and mean and peak velocity were obtained for the test. The number of repetitions and the time under tension were also recorded.

## Statistical analysis

The differences between the PLAC vs. CONT was identified using paired T-tests. The relative PLAC-CONT effect was also calculated as the difference between trials in percentage and through effect sizes (Cohen's  $d$ ). The magnitude of the effect size was interpreted as: large ( $d > 0.8$ ); moderate ( $d$  between 0.8 and 0.5); small ( $d$  between 0.49 and 0.20) and trivial ( $d < 0.2$ ). Statistical significance was set at  $p < 0.05$ . All statistical analyses were performed using Statistica 9.1. Data are presented as means  $\pm$  standard deviations.

## Results

In comparison to CONT, PLAC did not change the load achieved in the 1RM test (Table 1). Furthermore, PLAC did not produce any statistically significant effect in the number of repetitions, the time under tension, or in the power-related variables during the strength-endurance test (SET). Further, a moderate effect size was observed in PV between the PLAC and CONT condition (Table 1).

Table 1  
Muscle performance variables for PLAC and CONT conditions.

| Variable  | CONT<br>(95% CI)              | PLAC<br>(95% CI)              | <i>p</i> | <i>d</i> | Relative effect [%] |
|---|-------------------------------|-------------------------------|----------|----------|---------------------|
| 1RM [kg]  | 40.0 ± 10.5<br>(33.7 to 46.3) | 41.0 ± 9.5<br>(35.2 to 46.7)  | 0.10     | 0.10     | 3.1 ± 4.9           |
| SET Repetitions [n]   | 32.2 ± 5.1<br>(29.2 to 35.3)  | 31.8 ± 4.5<br>(29.1 to 34.5)  | 0.66     | 0.08     | -0.6 ± 11.5         |
| SET Time under tension [s]  | 48.2 ± 6.3<br>(44.4 to 52.1)  | 49.2 ± 7.4<br>(44.7 to 53.6)  | 0.67     | 0.15     | 2.8 ± 17.1          |
| SET Mean power output [W]   | 130 ± 34<br>(110 to 151)      | 121 ± 26<br>(106 to 137)      | 0.08     | 0.30     | -5.4 ± 11.2         |
| SET Peak power output [W]   | 293 ± 82<br>(244 to 343)      | 268 ± 48<br>(239 to 297)      | 0.12     | 0.37     | -5.5 ± 15.4         |
| SET Mean velocity [m/s]   | 0.62 ± 0.09<br>(0.56 to 0.67) | 0.60 ± 0.10<br>(0.54 to 0.65) | 0.43     | 0.21     | -2.3 ± 14.8         |
| SET Peak velocity [m/s]   | 1.17 ± 0.10<br>(1.11 to 1.23) | 1.11 ± 0.10<br>(1.06 to 1.17) | 0.07     | 0.60     | -4.5 ± 8.3          |
| All data are presented as mean ± standard deviation and 95% confidence intervals. 1RM = repetition maximum. |                               |                               |          |          |                     |

## Discussion

The main finding of the study was that there was no placebo effect of caffeine in women habituated to caffeine when misled to believe that they had ingested 6 mg/kg of caffeine. The lack of placebo effect of caffeine was evident in both the 1RM test as well as on all measured variables during the strength-endurance test performed at 50% 1RM. Therefore, the use of a deceptive protocol to induce the placebo effect of caffeine is likely an ineffective measure to enhance muscle performance in women athletes who are habituated to caffeine. To this respect, the actual ingestion of caffeine may be recommended [7] although doses higher than the daily level of its consumption may be necessary to obtain the potential ergogenic effect of caffeine in athletes habituated to this substance [23, 24].

To the best of our knowledge, this is the first study analyzing the placebo effect of caffeine on exercise performance in women habituated to this stimulant. In contrast to the outcomes of this study, previous research on male athletes showed a placebo effect of caffeine on resistance exercise performance [10,

13, 16]. Pollo et al. [13] showed that placebo intake increased exercise performance during a strength-endurance test in a group of men who believed they had ingested high doses of caffeine. Similarly, a placebo effect of caffeine was obtained by Duncan et al. [10], who additionally strengthened their deceptive experimental design by providing the participants with scientific data confirming the effectiveness of acute caffeine intake on resistance exercise. Lastly, Costa et al. [16] observed that placebo intake, when the athletes were informed they were taking caffeine, was effective to enhance bench press throw performance in Paralympic weightlifters. The main difference between these three investigations and the current protocol, beyond the sex of the participants, is the habituation to caffeine. In the current investigation, participants were habituated to caffeine because they ingested on average  $4.1 \pm 1.6$  mg of caffeine per kg of body mass per day. Due to high daily caffeine intake, beliefs of acute caffeine intake in habitual users of caffeine may differ in comparison to naive or low users. It has been found that chronic caffeine ingestion results in more newly created adenosine receptors that partially reduce the blocking-action of caffeine on the central nervous system [32] and may modify the physiological and cognitive responses to acute caffeine intake, which could negatively impact its ergogenic effect [33, 34]. If such suppressed reactions represent beliefs of habitual caffeine users, it could explain no improvement in performance in this group. These results suggest that resistance-trained athletes familiarized with the use of caffeine-containing products do not obtain the placebo effect of caffeine. Those athletes not familiarized with caffeine may be effectively misled about caffeine intake to obtain a potential performance improvement, but this remains to be studied in women.

The lack of placebo effect of caffeine in individuals habituated to caffeine may be reinforced by outcomes of previous investigations. While the placebo effect of caffeine has been confirmed by using several deceptive protocols [9, 10, 12–18], the two investigations carried out with participants habituated to caffeine showed that the deception was not successful. Foad et al. [14] found that, in participants ingesting at least 300 mg/day of caffeine, informing that they had received caffeine, when they had ingested placebo, was not effective at increasing performance during a 40-km cycling time trial. In fact, the actual intake of 5 mg/kg of caffeine was effective to increase cycling performance, irrespective of whether they were informed that they received caffeine or placebo. Similarly, Tallis et al. [20] observed that the placebo effect of caffeine was not present in individuals habituated to caffeine (92 mg/day) during a test of maximal voluntary concentric force of the knee flexors and extensors. Again, the actual ingestion of 5 mg/kg of caffeine was necessary to obtain muscle performance benefits in comparison to a control situation. All this information, together, point towards the lack of placebo effect of caffeine in endurance and resistance-based exercise in individuals who are habituated to caffeine. Thus, the acute ingestion of caffeine seems necessary to obtain the potential effect of this substance in the population samples.

Despite the uniqueness of the presented results, there were several limitations in the experimental design employed which should be addressed to understand the significance of the outcomes. First, this study did not contain a double-dissociation design. This is because we did not aim to study the additive effect of being informed of receiving caffeine plus actually receiving caffeine, as previous investigations have done [17]. Instead, the purpose of the current investigation was to determine in isolation the placebo

effect of caffeine in women athletes habituated to this substance. For this reason, we used a deceptive experimental design that included two identical trials that differed only in the participant's belief of having received caffeine. Second, the study did not include any measurement to assess how effective was our deceptive protocol in terms of participants' actual belief on receiving caffeine. Thus, the current investigation is unable to determine the effect of participants' expectations on the placebo effect of caffeine in our study sample. Lastly, as our participants were moderate caffeine users, it would also be interesting to assess withdrawal symptoms in the two trials to determine whether our participants perceived the lack of feelings habitually associated to caffeine. Despite these limitations, we believe the current manuscript is sound to determine the lack of the placebo effect of caffeine on women athletes habituated to caffeine. The manuscript adds valuable information for resistance-trained women seeking to obtain benefits related to caffeine supplementation.

## Conclusions

The results of the present study indicate that intake of a placebo in women habituated to caffeine is not an effective strategy to improve maximal strength as well strength-endurance performance during the bench press exercise. This suggests the lack of the placebo effect of caffeine in individuals habituated to caffeine, likely because habituation to caffeine modifies the potential psychological benefits of being told that caffeine was ingested. As a practical application, the use of a deceptive protocol to induce the placebo effect of caffeine is not recommended to enhance muscle performance in women athletes habituated to caffeine. Instead, the actual ingestion of caffeine should be recommended [14, 20] although high doses may be necessary to obtain the potential ergogenic effect of caffeine in athletes habituated to this substance [23, 24].

## Declarations

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**Conflicts of interest:** The authors declare that they have no conflict of interest.

**Ethics approval:** The study protocol was approved by the Bioethics Committee for Scientific Research, at the Academy of Physical Education in Katowice, Poland according to the ethical standards of the Declaration of Helsinki, 1983. Protocol number: 3/2019

**Consent for publication:** Not applicable

**Availability of data and material:** The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request

**Authors' contributions:** AF, MW participated in the concept and design of the study. AF, MK and MH were involved in data collection, while MW performed the statistical analysis. All authors participated in data interpretation. MW, MK performed the literature review, while AF, MW, AZ and JDC wrote the discussion and conclusions. All authors approved the final version of the manuscript.

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