Effect of low caffeine doses on jumping performance: a meta-analysis

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Abstract

Purpose – The aim of this review was to explore the effects of low doses of caffeine (<3 mg/kg) on jumping performance using a meta-analysis.

Design/methodology/approach – The search for eligible studies was performed through six databases, with additional backward and forward citation tracking. A random-effects meta-analysis was performed to compare the effects of caffeine vs. placebo on jump height. The methodological quality of the included studies was appraised using the PEDro checklist.

Findings – Eight studies were included in the review. They were classified as good or excellent methodological quality. The pooled number of participants across all studies was 203. Four studies provided caffeine in relative doses, ranging from 1 to 2 mg/kg. Four studies provided caffeine supplementation in absolute doses of 80, 150, or 200 mg. The meta-analysis found that caffeine ingestion increased vertical jump height (Cohen's *d*: 0.21; 95% confidence interval: 0.10, 0.31; $p < 0.001$; +3.5%).

Originality/value – The present meta-analysis found that caffeine doses of ∼1 to 2 mg/kg enhance jumping height. The effects observed herein are similar to those with higher caffeine doses, which is relevant as low caffeine doses produce minimal side effects. For most individuals, a caffeine dose of ∼1 to 2 mg/kg is equivalent to an amount of caffeine in an energy drink, one to two cups of coffee, one to two pieces of caffeinated chewing gum, or several cups of green tea.

Keywords: supplements; ergogenic aids; jumping performance; squat jump; countermovement jump

1. Introduction

Caffeine is one of the most established ergogenic aids (Grgic *et al*., 2020). Research has demonstrated that caffeine ingestion enhances various components of exercise performance, such as aerobic and muscular endurance, strength, and power (Grgic *et al*., 2020). Even though an ergogenic effect of caffeine is commonly observed, the protocols of caffeine supplementation used in studies varies substantially (Del Coso *et al*., 2012; McNaughton, 1986). For example, studies have explored the effects of caffeine on exercise performance while using doses from 1 to 15 mg/kg (Del Coso *et al*., 2012; McNaughton, 1986). Traditionally, a caffeine dose of 6 mg/kg was most often used in studies (Grgic *et al*., 2020). Still, research in recent years has moved toward exploring the effects of low doses of caffeine (<3 mg/kg) on exercise performance (Spriet, 2014). This change in the landscape of caffeine research is because high doses of caffeine are associated with side effects such as nausea and insomnia (Filip-Stachnik *et al*., 2021; Goldstein *et al*., 2010; Spriet, 2014). Indeed, a recent study that provided 9 mg/kg of caffeine reported that nearly all participants experienced some of these side effects (Filip-Stachnik *et al*., 2021). In contrast to high doses, low doses of caffeine produce minimal side effects (Spriet, 2014). Another aspect to consider is that low caffeine doses can be consumed even without targeted supplementation, as a caffeine dose of 2 mg/kg for a 70 kg individual is equivalent to a caffeine dose in an energy drink, one to two cups of coffee, or several cups of green tea (Burke, 2008).

In addition to side effects, the influence of low caffeine doses is important because of habitual caffeine intake (McLellan *et al*., 2016). Data are suggesting that habitual caffeine intake may moderate the effect of caffeine supplementation on exercise performance (Bell and McLellan, 2002). When examining the effect of caffeine supplementation among participants with varying habitual caffeine intakes, an ergogenic effect was not observed among those classified as high habitual caffeine users (Bell and McLellan, 2002). This lack of performance improvement is suggested to be associated with the mechanism of caffeine, given that caffeine's ergogenic effects are explained by its affinity to bind to adenosine receptors (Bell and McLellan, 2002; McLellan *et al*., 2016). After binding to adenosine receptors, caffeine alleviates fatigue, reduces perceived exertion, and enhances performance (McLellan *et al*., 2016). Animal model studies observed that regular caffeine consumption is associated with an upregulation of these receptors (Shi *et al*., 1993). Therefore, over time, larger doses of caffeine might be needed to produce the same effects previously observed with smaller caffeine doses. This notion is supported by a recent study that used a design where caffeine supplementation was provided daily for 20 straight days (Lara *et al*., 2019). While an ergogenic effect was consistently observed, it was the largest on the first day and then progressively attenuated (Lara *et al*., 2019). Thus, a prudent recommendation for those interested in caffeine supplementation would be to start with the lowest ergogenic doses. However, the effects of low caffeine doses (<3 mg/kg) on many components of exercise performance are still unclear.

Spriet (2014) published a narrative review that examined the effects of low doses of caffeine on exercise performance. However, the major focus of that review was on endurance, with less attention provided to performance in high-intensity activities, such as jumping performance (Spriet, 2014). Jumping performance is important in many sports, such as volleyball, basketball, and soccer (Vescovi and McGuigan, 2008). Studies have demonstrated that caffeine ingestion enhances vertical jump performance (Bloms *et al*., 2016; Foskett *et al*., 2009). However, such effects are observed with higher doses of caffeine. For example, Foskett et al. (2009) reported that 6 mg/kg of caffeine increases jump height in the countermovement jump test. A recent meta-analysis also found that caffeine ingestion enhances jumping performance (Salinero *et al*., 2019). However, closer scrutiny of the data highlights that these effects are observed only with moderate-to-high doses as the analysis restricted the inclusion criteria to studies providing caffeine in doses of 3 mg/kg or higher (Salinero *et al*., 2019). Therefore, the influence of low doses of caffeine on jumping performance is not yet well-established.

While several recent studies explored the effects of low doses of caffeine on jumping performance, their findings varied (Arazi *et al*., 2016; Ellis *et al*., 2019; Kammerer *et al*., 2014; Lane *et al*., 2019; Ranchordas *et al*., 2018; Ranchordas *et al*., 2019; Sabol *et al*., 2020; Wong *et al*., 2021). For example, some have found an ergogenic effect of such caffeine doses, whereas others observed that performance was similar following the ingestion of low doses of caffeine and placebo (Arazi *et al*., 2016; Sabol *et al*., 2020). Given the inconsistent evidence on the topic, this review aimed to explore the effects of low doses of caffeine on jumping performance by using a meta-analysis.

2. Methods

2.1 Search strategy

The search for eligible studies was performed in two phases (primary and secondary searches). The primary search involved examining literature in the following bibliographic databases: Academic Search Elite, Networked Digital Library of Theses and Dissertations, PubMed/MEDLINE, Scopus, SPORTDiscus, and Web of Science. The following search syntax was applied: caffeine AND (jump OR jumping OR "countermovement jump" OR "squat jump" OR plyometrics OR "sargent test"). Quotation marks in the syntax were used for phrase searching. Secondary searches were comprised of forward and backward citation tracking. Forward citation tracking included examining studies that cited the included studies using the Google Scholar database. Backward citation tracking included examining the reference lists of the included studies. The search for studies was performed on January 28th, 2022.

2.2 Inclusion criteria

Using the PICO criteria, the following studies were included:

- Population (P): healthy participants
- Interventions (I): caffeine supplementation provided in doses <3 mg/kg
- Comparison (C): placebo
- Outcome (O): jump height

2.3 Data extraction

We extracted the following data from each included study:

- Lead author name and year of study publication
- Participants characteristics (e.g., sex, training status, habitual caffeine intake)
- Caffeine supplementation protocol
- Jump performance test
- Main study findings

2.4 Methodological quality

The quality of the included studies was appraised using the PEDro checklist (Maher *et al.*, 2003). The PEDro checklist has 11-items that evaluate various methodological aspects (Maher *et al.*, 2003). These include randomization, blinding, allocation concealment, data reporting, attrition, and inclusion criteria. The answers to all items on the checklist are binary ("yes" or "no"), where only the "yes" answer is associated with a point. The first item does not contribute to the summary score and therefore the maximum number of points on the checklist is 10. Based on the summary scores, studies were classified as poor, fair, good, or excellent quality if they scored ≤3 points, 4–5 points, 6–8 points, and 9–10 points, respectively (Grgic, 2018; Grgic and Pickering, 2019).

2.5 Statistical analysis

The comparison of the effects of placebo vs. caffeine on jumping height was performed using effect sizes (Cohen's *d*) in a random-effects model. To calculate effect sizes, the following data are needed:

- Jump height mean ± standard deviation data from the placebo and caffeine trials
- Sample size
- Correlation between the caffeine and placebo trials within each study

None of the included studies presented correlation between trials. Based on the available access to the data from one study (Sabol *et al.*, 2020), correlation between the caffeine and placebo trials was calculated and it amounted to $r = 0.77$. This correlation value was therefore used for all other studies. Sensitivity analyses were performed by examining the pooled results after excluding the data from one study at a time. Additionally, a sensitivity analysis was performed by excluding the data from one study (Wong *et al.*, 2021) that used the squat jump test, as all other studies used the countermovement jump test. Effect sizes were interpreted by using the established thresholds (Cohen, 1992):

- Trivial (<0.20)
- Small (0.20–0.49)
- Medium (0.50–0.79)
- Large (≥0.80)

The I^2 statistic (which examines the percentage of variation across studies associated with heterogeneity), was used to examine heterogeneity and interpreted as low (<50%), moderate (50–75%), and high heterogeneity (>75%). The statistical significance threshold was set at $p < 0.05$. All analyses were performed using the Comprehensive Meta-analysis software, version 2 (Biostat Inc., Englewood, NJ, USA).

3. Results

3.1 Search results

In the search performed through the bibliographic databases, there were 569 search results. In this part of the search process, 521 results were excluded after reading the title or abstract. Therefore, 48 full-text studies were read and eight studies were included (Arazi *et al*., 2016; Ellis *et al*., 2019; Kammerer *et al*., 2014; Lane *et al*., 2019; Ranchordas *et al*., 2018; Ranchordas *et al*., 2019; Sabol *et al*., 2020; Wong *et al*., 2021). In the backward citation tracking and forward citation tracking, there were 289 and 169 search results, respectively. However, there were no studies additionally included. The flow diagram of the search process is depicted in Figure 1.

3.2 Summary of studies

The sample sizes in the included studies varied from 10 to 97 participants. The pooled number of participants across all studies was 203. Six studies included males, while two studies included females (Table 1). Four studies provided caffeine in relative doses, ranging from 1 to 2 mg/kg. Four studies provided caffeine supplementation in absolute doses of 80, 150, or 200 mg. When expressed in relative values, the caffeine dose amounted to ~1.2, ~1.7, ~2.3, or ~2.7 mg/kg. Most studies provided caffeine 60 min before exercise. All studies evaluated jumping performance using the countermovement jump test. One study also used the squat jump test (Wong *et al*., 2021).

3.3 Methodological quality

Seven studies (Arazi *et al*., 2016; Ellis *et al*., 2019; Kammerer *et al*., 2014; Lane *et al*., 2019; Ranchordas *et al*., 2018; Ranchordas *et al*., 2019; Sabol *et al*., 2020; Wong *et al*., 2021) scored 9 points on the PEDro checklist and were classified as "excellent" methodological quality. One study (Ellis *et al*., 2019) scored 7 points and was classified as "good" methodological quality (Table 2).

3.4. Meta-analysis results

Seven studies were included in the meta-analysis as one study (Lane *et al*., 2019) did not present the data needed for the calculation of effect sizes and the required data were not received upon written request.

The meta-analysis found that caffeine ingestion increased vertical jump height (Cohen's *d*: 0.21; 95% confidence interval: 0.10, 0.31; $p < 0.001$; $I^2 = 0\%$; Figure 2).

There were minimal changes in the pooled results in the sensitivity analysis that involved excluding one study at a time. The largest change was observed when excluding the study by Wong *et al*. (2021), with a small increase in the pooled effect size (Cohen's *d*: 0.24; 95% confidence interval: 0.08, 0.39).

There was a small reduction in the pooled effect size in the sensitivity analysis that involved excluding the squat jump test data (Cohen's *d*: 0.17; 95% confidence interval: 0.06, 0.27).

Percent changes between the placebo and caffeine trials varied from 0% to 7.1%. Average and median percent changes following caffeine ingestion were 3.5% and 3.4%, respectively.

4. Discussion

The main finding of this meta-analysis is that caffeine ingestion in low doses (~1 to 2 mg/kg) enhances jumping performance. These results extend previous data that caffeine ingestion in moderate-to-high caffeine doses is ergogenic for jumping performance. More importantly, the effect size observed following the ingestion of low caffeine doses is similar to that observed with higher caffeine doses (Grgic *et al*., 2018; Salinero *et al*., 2019). For an individual weighing 70 kg, a caffeine dose of 1 to 2 mg/kg would be an absolute dose of 70 to 140 mg, equivalent to an amount of caffeine in an energy drink, one to two cups of coffee, one to two pieces of caffeinated chewing gum, or several cups of green tea.

Current recommendations for caffeine supplementation are to use doses from 3 to 9 mg/kg for acute improvements in exercise performance (Grgic *et al*., 2019; Guest *et al*., 2021). The findings presented herein highlight that the minimal ergogenic doses of caffeine are lower than previously suggested. The results observed in this meta-analysis are similar to those found in previously published meta-analytical data (Grgic *et al*., 2018; Salinero *et al*., 2019). In the first meta-analysis that explored the effects of caffeine on jumping performance, Grgic *et al*. (2018) found a small ergogenic effect of caffeine (Cohen's *d*: 0.17; 95% confidence interval: 0.00, 0.34). However, 89% of caffeine doses used in the ten included studies were between 3 and 7 mg/kg. The average caffeine dose across all studies was 5 mg/kg. In the second meta-analysis (Salinero *et al*., 2019), an ergogenic effect of caffeine was found for single jump performance (Cohen's *d*: 0.19; 95% confidence interval: 0.14, 0.25) and repeated jump performance (Cohen's *d*: 0.29; 95% confidence interval: 0.16, 0.42). Still, this previous review limited their inclusion criteria only to studies using caffeine doses of 3 mg/kg or higher. Due to these restrictions, the range of caffeine doses was from 3 to 6 mg/kg, while the average caffeine dose was 5 mg/kg. Therefore, an argument can be made that the previous data on the ergogenic effects of caffeine are limited to ingesting caffeine in moderate doses, which highlights the novelty of this review.

Based on the effect sizes reported in previous meta-analytical data, it seems that low caffeine doses produce a similar ergogenic effect as moderate-to-high caffeine doses. Specifically, the pooled effect size in the present analysis is 0.21, which is similar to previously reported effect sizes (Cohen's *d*: 0.17–0.29) (Grgic *et al*., 2018; Salinero *et al*., 2019). However, this comparison is also based on the analysis of studies that differed in a range of methodological characteristics that may have affected the effect sizes independent of the caffeine dose (e.g., training status, habitual caffeine intake, and timing of caffeine). Therefore, the most robust conclusions on the dose-response effects of caffeine can be made when analyzing the effects of different doses of caffeine within the same study. Three out of the eight included studies utilized such a design. In one study (Arazi *et al*., 2016), caffeine doses of 2 and 5 mg/kg were not ergogenic. In another study (Ellis *et al*., 2019), caffeine doses of 1, 2, and 3 mg/kg enhanced jumping performance. However, the probability of improvement was the largest (96%) with 3 mg/kg and then progressively decreased with the dose reduction (i.e., 84% for 2 mg/kg and 77% for 1 mg/kg). Finally, Sabol *et al*. (2020) explored the effects of caffeine in doses of 2, 4, and 6 mg/kg. All three doses were ergogenic in this study, with similar overall effectiveness (Cohen's *d*: 0.35–0.42; 3.7%–4.1%). This would suggest that lower doses of caffeine are comparably ergogenic as higher caffeine doses, but more research is needed to confirm these findings.

Habitual caffeine intake has been suggested as a moderator of the ergogenic effects of caffeine supplementation (Bell and McLellan, 2002; Guest *et al*., 2021). Specifically, it was suggested that: (i) caffeine ingestion is ergogenic only in low habitual users; and (ii) the caffeine dose pre-exercise needs to be higher than the amount of caffeine habitually ingested to experience an ergogenic effect (Bell and McLellan, 2002; Pickering and Grgic, 2019). Out of the eight included studies, only one compared the effects of caffeine among participants with varying habitual caffeine intakes. Sabol *et al*. (2020) explored the effects of 2 mg/kg of caffeine in low users (27 ± 36 mg/day) and high users (358 ± 210 mg/day). While an overall ergogenic effect of caffeine on jumping performance was observed, there was no significant group × condition interaction. These findings are in accord with other studies that did not find a moderating effect of habitual caffeine intake (Gonçalves *et al*., 2017; Grgic and Mikulic, 2021). Still, it might be that low caffeine doses are not ergogenic in very high habitual caffeine users, but future studies are needed to explore this hypothesis.

While caffeine supplementation has well-established ergogenic effects, several side effects are associated with its consumption. For example, studies that provided 6 mg/kg of caffeine reported side effects such as nausea, insomnia, and others (Goldstein *et al*., 2010; Mora-Rodríguez *et al*., 2015). Given that side effects increase along with the increase in caffeine dose, the primary advantage of low caffeine doses is that they produce minimal side effects. This notion is best demonstrated by one study that provided a caffeine dose of 1 mg/kg and reported no caffeine-induced side effects (Del Coso *et al*., 2012). Unfortunately, the studies included in this review did not directly evaluate side effects following caffeine consumption, which is something that future research on the topic should consider to provide a more comprehensive depiction of the effects of low caffeine doses.

While the included studies received a "good" or "excellent" methodological quality rating on the PEDro checklist, a few methodological limitations need to be mentioned. First, one study

(Ellis *et al*., 2019) used a single-blind study design, which offers lower methodological quality than the recommended double-blind design. Still, the effect size observed in that study was similar to the effects observed in other studies, suggesting that this methodological difference did not affect the results. Additionally, four studies (Arazi *et al*., 2016; Ellis *et al*., 2019; Kammerer *et al*., 2014; Lane *et al*., 2019) did not evaluate the effectiveness of participants blinding to the caffeine and placebo trials. In the remaining four studies (Ranchordas *et al*., 2018; Ranchordas *et al*., 2019; Sabol *et al*., 2020; Wong *et al*., 2021), blinding was explored and was considered to be effective, given that 5% to 40% of participants were able to identify the caffeine condition. Future studies should evaluate the effectiveness of the blinding as correct supplement identification may influence the outcome of an exercise task and confound the results (Grgic *et al*., 2021; Saunders *et al*., 2017). It should also be mentioned that the majority of the studies included males as participants. Therefore, the results presented herein are mostly specific to males and future research is needed to explore the effects of low caffeine doses on jumping performance in females. Future studies are also needed to establish the minimal ergogenic dose of caffeine. While the findings presented herein suggest an ergogenic effect of ∼1 to 2 mg/kg caffeine doses, it is unclear if even lower doses may be ergogenic.

5. Conclusions

Previous studies and meta-analyses found that caffeine ingestion enhances jumping performance. However, these ergogenic effects were generally observed when consuming moderate-to-high doses of caffeine. Thus, the effect of low caffeine doses on jumping performance was unclear. The present meta-analysis found that caffeine doses of ∼1 to 2 mg/kg increase jumping height. The effects observed herein are similar to those observed with higher doses of caffeine, which is of relevance as low caffeine doses produce minimal side effects. For most individuals, a caffeine dose of ∼1 to 2 mg/kg is equivalent to an amount of caffeine in an energy drink, one to two cups of coffee, one to two pieces of caffeinated chewing gum, or several cups of green tea.

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