Effects of caffeine on isometric handgrip strength: a meta-analysis

Effects of caffeine on isometric handgrip strength: a systematic review and meta-analysis

Jozo Grgic[1]

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

jozo.grgic@live.vu.edu.au

Abstract

Objective: Several studies explored the effects of caffeine on isometric handgrip strength, but their findings varied. Therefore, the aim of this systematic review was to perform a meta-analysis of studies exploring the effects of caffeine on isometric handgrip strength.

Methods: Search for studies was performed through five databases (Academic Search Elite, Cochrane Library, PubMed/MEDLINE, SPORTDiscus, and Scopus) with additional secondary searches. RoB 2 scale was used to evaluate the risk of bias of the included studies. The effects of caffeine vs. placebo were analyzed in a random-effects meta-analysis.

Results: Sixteen studies were included ($n = 353$; $n = 34$ females). The studies were classified as having "some concerns" (possible bias from the randomization process and in the measurement of the outcome) on the RoB 2 scale. In the main meta-analysis, caffeine ingestion enhanced isometric handgrip strength (*d*: 0.17; 95% confidence interval [CI]: 0.10, 0.23; $p < 0.001$). In subgroup analyses, an ergogenic effect of caffeine on isometric handgrip strength was found when consumed in small doses (1–3 mg/kg; *d*: 0.20; 95% CI: 0.10, 0.30; $p < 0.001$), moderate-to-high doses (5–7 mg/kg; *d*: 0.15; 95% CI: 0.07, 0.23; $p < 0.001$), liquid form (*d*: 0.19; 95% CI: 0.09, 0.30; $p < 0.001$), and capsule form (*d*: 0.15; 95% CI: 0.06, 0.23; $p < 0.001$).

Conclusions: Overall, individuals interested in the acute enhancement of isometric handgrip strength may consider caffeine supplementation in small or moderate-to-high doses. However, these ergogenic effects were very small and were observed mostly among male participants.

Keywords: ergogenic aids; supplements; performance-enhancing effects; data synthesis

Introduction

The handgrip test is widely used to evaluate strength (1). As the name implies, the task in this test is to squeeze the dynamometer handle as hard as possible to obtain peak force values (1). This test is non-invasive and can be easily performed with minimal equipment (1). Data also indicate that the isometric handgrip strength test is highly reliable (intraclass correlation coefficient ≥0.90) in various populations (1-3). Due to these advantages (i.e., high reliability, non-invasiveness, ease of use), this test is commonly utilized in research. For example, wide-scale epidemiological studies that focus on outcomes such as mortality and quality of life used the isometric handgrip strength test (4, 5). Studies interested in exploring temporal trends in strength also evaluated isometric handgrip strength (6). Besides its use in the general population, the isometric handgrip strength test is utilized to explore the efficacy of training programs and is relevant in some sports (e.g., weightlifting, powerlifting, judo) (7).

Caffeine is a widely used supplement that has established performance-enhancing effects (8). Currently available studies indicate that caffeine is ergogenic for aerobic and muscular endurance, jump height, and power output (8). Several studies have also explored the effects of caffeine on isometric handgrip strength, but the findings are equivocal (9-24). For example, Kammerer et al. (16) explored the effects of caffeine (fixed dose of 80 mg; 1.2 mg/kg) ingestion on isometric handgrip strength in 14 participants. In this study, there were no significant differences between caffeine and placebo. Other studies, however, reported that caffeine ingestion (3 mg/kg) enhanced isometric handgrip strength (13, 14). Due to the conflicting reports, there is still no consensus on this topic. Reasons for the varying finding might be associated with the use of different dynamometer models or test protocols (i.e., left vs. right or dominant vs. non-dominant hand used for testing). Additionally, the discrepancies between the studies might be due to the differences in caffeine dose. Indeed, previous studies have reported that caffeine dose influences its effects on strength (25).

Besides caffeine dose, the contrasting findings between the studies may be explained by the small sample sizes commonly observed in research on sports supplements. Specifically, it might be that some of the studies published on this topic were underpowered to find significant differences. Most of the studies that explored the effects of caffeine on isometric handgrip strength involved sample sizes ranging from 6 to 16 participants (9-11, 13-19, 24).

However, to detect a small effect (Cohen's *d*: 0.20), with an alpha value of 0.05, power of 80%, and correlation between repeated measures of 0.90, a sample size of 42 participants is needed. One way to overcome the limitation of small sample sizes is to conduct a meta-analysis. While several meta-analyses explored the effects of caffeine on various outcomes, none of them focused on isometric handgrip strength (8). Therefore, this systematic review aimed to perform a meta-analysis of studies exploring the effects of caffeine on isometric handgrip strength.

Methods

Search strategy

The search for studies was carried out in three databases: Academic Search Elite, Cochrane Library, PubMed/MEDLINE, SPORTDiscus, and Scopus. In all of these databases, the following search syntax was used: (caffeine OR coffee OR "energy drink") AND (handgrip OR "hand grip" OR "grip strength" OR "isometric handgrip strength"). The search through the databases was performed on July 10th, 2021. After completing this part of the search process, two secondary searches were conducted, that examined the reference list of the included studies and explored the papers that cited the included studies in the Google Scholar database.

Inclusion criteria

To be included in the present review, studies were required to satisfy the following criteria:

- Published in English
- Utilized a double-blind placebo-controlled study design
- Examined the effects of caffeine ingestion on isometric handgrip strength
- Presented mean ± standard deviation (or standard error) for isometric handgrip strength following the ingestion of caffeine and placebo

Data extraction

The following data were extracted from the included studies:

- Author names and year of study publication

- Characteristics of the included participants
- Caffeine supplementation protocol (dose, timing, and form of ingestion)
- Model of the dynamometer used for the isometric handgrip strength test
- Mean ± standard deviation (or standard error) isometric handgrip strength test values following placebo and caffeine ingestion

Risk of bias

The risk of bias of the included studies was evaluated using the "RoB 2" tool with additional considerations for crossover trials (26). The RoB 2 tool was used for this review as it is designed to evaluate features of the trial relevant to the risk of bias—defined as the risk of overestimation or underestimation of the true intervention effect (26). This tool evaluates the risk of bias in different domains, including:

- Domain 1 – bias arising from the randomization process
- Domain S – bias arising from period and carryover effects
- Domain 2 – bias due to deviations from intended intervention
- Domain 3 – bias due to missing outcome data
- Domain 4 – bias in measurement of the outcome
- Domain 5 – bias in selection of the reported result.

Each of these domains and the overall evaluation of the risk of bias is classified as "low risk", "some concerns" or "high risk".

Statistical analysis

Meta-analyses were performed using Cohen's *d* effect sizes in a random-effects model. Cohen's *d* for the comparison of the effects between caffeine and placebo was calculated using the mean ± standard deviation data from the two trials, total sample size, and correlation between the trials. Correlation values were estimated using the recommended approach in the Cochrane Handbook (27). Specifically, the following equation was used:

$$r = \frac{S_{placebo}^2 + S_{caffeine}^2 - S_D^2}{2 \cdot S_{placebo} \cdot S_{caffeine}}$$

S represents the standard deviation while S_D is the standard deviation of the difference score, calculated as:

$$S_D = \left(\frac{S^2_{placebo}}{n} + \frac{S^2_{caffeine}}{n}\right)^{1/2}$$

In the main meta-analysis, all studies were considered. Subgroup meta-analyses were performed to examine the effects of caffeine dose and caffeine form. In the analysis for caffeine dose, the effects of small caffeine doses (1–3 mg/kg) and moderate-to-high doses (5–7 mg/kg) were examined. In the subgroup analysis for caffeine form, the effects of caffeine consumed in liquid vs. capsules were examined. The interpretation of effect sizes was based on the following thresholds: very small (<0.20), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80) (28). I^2 statistic was used to evaluate heterogeneity. I^2 values were 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).

Results

Search results

In the primary search, there was a total of 306 results. Out of this number of references, 35 full-text papers were read, and 16 studies were found to satisfy all inclusion criteria (9-24). Reference screening and forward citation tracking resulted in an additional 534 and 601 references, respectively. However, there were no additional studies found meeting the inclusion criteria (Figure 1). While there were 16 included studies, there were 19 comparisons in the meta-analysis because two studies (20, 21) presented the data separately for participants with different variations of the *CYP1A2* genotype.

Summary of studies

There were 353 participants across the 16 included studies (34 females). The median number of participants per study was 15. Most of the studies included athletes competing in sports such as badminton, jiu-jitsu, tennis, swimming, and handball as participants. Studies generally provided caffeine in relative doses, ranging from 1 mg/kg to 7 mg/kg (Table 1). One study (16) used an absolute dose of 80 mg. When expressed in relative terms, the amount of caffeine in that study was 1.2 mg/kg (16). Nine studies provided caffeine in capsule form. Seven studies provided caffeine in liquid form, most commonly as a part of an energy drink (Table 1). However, the only difference between the energy drink and placebo solutions in these studies was the amount of caffeine ingested, which allowed the isolation of caffeine's effects. Only one study provided caffeine 45 min before exercise, while all other studies used timing of 60 min before exercise. The effectiveness of the blinding was explored in six studies (Table 1).

Risk of bias

In domains S, 2, 3, and 4 the evaluation for all studies was "low risk". In domains 1 and 5 the classification for all included studies was "some concerns". The overall evaluation on the RoB 2 scale for the included studies was "some concerns" (Table 2).

Meta-analysis results

In the main meta-analysis, caffeine ingestion enhanced isometric handgrip strength (Cohen's *d*: 0.17; 95% confidence interval [CI]: 0.10, 0.23; $p < 0.001$; $I^2 = 62\%$; Figure 2). In subgroup analyses, an ergogenic effect of caffeine was found when consumed in small doses (1–3 mg/kg; Cohen's *d*: 0.20; 95% CI: 0.10, 0.30; $p < 0.001$; $I^2 = 58\%$), moderate-to-high doses (5–7 mg/kg; Cohen's *d*: 0.15; 95% CI: 0.07, 0.23; $p < 0.001$; $I^2 = 64\%$), liquid form (Cohen's *d*: 0.19; 95% CI: 0.09, 0.30; $p < 0.001$; $I^2 = 54\%$), and capsule form (Cohen's *d*: 0.15; 95% CI: 0.06, 0.23; $p < 0.001$; $I^2 = 65\%$).

Discussion

The main finding of this review is that caffeine ingestion acutely enhances isometric handgrip strength. An ergogenic effect of caffeine was observed when consuming doses of 1–3 mg/kg or 5–7 mg/kg. The effect size of caffeine was similar when it was consumed either in small or moderate-to-high doses. Additionally, increases in isometric handgrip strength were found when caffeine was consumed either in liquid or capsule form. These findings are based on 16 studies with a double-blind design.

From a practical perspective, the results presented herein suggest that individuals interested in increasing isometric handgrip strength may consider supplementing with caffeine. Isometric handgrip strength may be of importance in several sports (7). For example, isometric handgrip strength is relevant in climbing and gymnastics, where the tasks require the athlete to move his/her body around an immovable apparatus (7). Additionally, isometric handgrip strength is also an important component of performance in combat sports. In judo, the athletes need to pull or push the opponent in the desired direction while gripping the kimono (29). In some events in powerlifting (e.g., deadlift), high levels of grip strength are needed to complete the lift (30). Besides these sports, isometric handgrip strength is also relevant in baseball, golf, hockey, tennis, and weightlifting (7, 31-35). Thus, as caffeine increases isometric handgrip strength, it may also improve performance in some sports-specific outcomes.

It is important to standardize testing conditions to obtain a reliable measurement of isometric handgrip strength. In 1999, Innes (1) provided an overview of testing variables that may influence outcomes in the isometric handgrip strength test. These variables include testing position, number of trials, contraction time, warm-up, instructions provided to the participant, and time of day. Caffeine's effects on isometric handgrip strength were not mentioned, likely owing to the lack of studies on the topic at that point in time. However, in light of the findings presented herein, there is clear importance of standardizing caffeine intake before isometric handgrip strength testing. Specifically, given that an ergogenic effect was observed, the results presented herein suggest that caffeine intake should be limited or kept consistent before isometric handgrip strength testing. Furthermore, as reported in subgroup analyses, even 3 mg/kg of caffeine may enhance isometric handgrip strength, and such doses can be consumed even without targeted supplementation. For example, for a person of 70 kg, 210 mg of caffeine can be consumed through two cups of coffee (36). Therefore, researchers and practitioners should standardize for caffeine intake, especially if using this test to evaluate the efficacy of a given training intervention or conducting a between-group comparison.

Subgroup analyses were conducted to explore the effects of caffeine form (liquid vs. capsule) and caffeine dose (1–3 mg/kg vs. 5–7 mg/kg) on isometric handgrip strength. It is interesting to point out that a similar ergogenic effect of caffeine was found when consuming small doses and moderate-to-high doses. These findings are generally in accord with those from recent studies that compared the effects of 3 vs. 6 mg/kg of caffeine on exercise performance. In most of these studies, both caffeine doses were ergogenic, with no significant differences between them (37-39). Therefore, it seems that higher doses of caffeine may not be required for an ergogenic effect on isometric handgrip strength. High doses should likely be avoided as they are associated with a higher incidence and severity of side effects (40). While we currently know that high doses may not be needed for an ergogenic effect, future research is needed to establish the minimal ergogenic dose of caffeine on isometric handgrip strength. In the subgroup analysis for small doses of caffeine (1–3 mg/kg), most studies used a dose of 3 mg/kg. Two studies (16, 22) used even smaller doses (1 and 1.2 mg/kg), and they did not observe an ergogenic effect of caffeine. Therefore, it seems that the minimal ergogenic dose of caffeine on isometric handgrip strength is 3 mg/kg. However, studies that focused on other strength tests such as the one-repetition maximum (1RM) and isometric knee extension reported ergogenic effects of caffeine consumed in doses from 1.5 to 2 mg/kg (25, 41). These results suggest that doses lower than 3 mg/kg may enhance strength, but future dose-response studies are needed to establish the minimal effective dose of caffeine in the handgrip test.

Some studies evaluated isometric handgrip strength in both left and right hands (Table 1). Such an approach has limitations, given that it disregards hand dominance. Two studies, however, explored the effects of caffeine in both dominant and non-dominant hands (12, 14). These studies reported comparable caffeine effects on isometric handgrip strength in both dominant (Cohen's *d*: 0.18–0.58) and non-dominant hands (Cohen's *d*: 0.11–0.46). While more studies with a similar design are needed, preliminary evidence suggests an ergogenic effect of caffeine in the dominant and non-dominant hands.

The data presented in this meta-analysis add to the body of evidence supporting an ergogenic effect of caffeine on strength (39, 42-45). For example, Warren et al. (42) published a meta-analysis examining the effects of caffeine on muscular strength. Most of the included studies focused on isometric tests to evaluate muscular strength (e.g., maximal voluntary knee extension). In this meta-analysis, caffeine ingestion enhanced muscular strength by an effect size of 0.19 (42). Two meta-analyses (43, 44) examined the effects of caffeine on 1RM and reported ergogenic effects (Cohen's *d*: 0.18–0.20). An ergogenic effect of caffeine was also found on torque in isokinetic strength tests (Cohen's *d*: 0.16) (45). Thus, when considering the whole body of evidence, it seems clear that caffeine ingestion may enhance force production by a small magnitude in 1RM, isokinetic, and isometric (including handgrip) tests (42-45).

Risk of bias

All included studies had a double-blind design, which is recommended for studies in sports nutrition. However, in the risk of bias assessment, an overall evaluation of "some concerns" was provided to the included studies. While the studies did use a double-blind design, none provided any details on allocation concealment. Additionally, these studies did not pre-register their protocols and planned analyses. Only six included studies evaluated the effectiveness of the blinding (9, 12, 13, 17-19). These studies reported that anywhere from 6% to 83% of the participants correctly identified the trials. Future studies should also evaluate the effectiveness of blinding, as correct supplement identification may influence the outcome of an exercise task and lead to bias in the results (46, 47).

Limitations

One of the main limitations of this review is that most participants in the included studies were males. Specifically, out of the 353 participants, only 34 were females. Therefore, an argument can be made that the results presented herein are limited to the male population. However, it should be considered that one study included only female participants and reported an ergogenic effect of caffeine on isometric handgrip strength (19). While they did not use the isometric handgrip strength test, recent studies compared the effects of caffeine between sexes and reported that the overall effects are similar in males and females (48, 49). Thus, collectively, an ergogenic effect of caffeine on isometric handgrip strength test may be expected in both sexes, even though the evidence base for caffeine's effect among females is not as large.

Conclusions

This meta-analysis found that caffeine ingestion has an ergogenic effect on isometric handgrip strength. Subgroup analyses also found an ergogenic effect of caffeine when consumed in small doses (1–3 mg/kg) vs. moderate-to-high doses (5–7 mg/kg) and when caffeine is consumed either in liquid or capsule form. Overall, individuals interested in the acute enhancement of isometric handgrip strength may consider caffeine supplementation.

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Contributions: JG conceived the idea and conceptualized the review, conducted the study selection, data extraction, and methodological quality assessment, performed the analyses and wrote the manuscript.

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