Caffeine ingestion enhances Wingate performance: a meta-analysis

Caffeine ingestion enhances Wingate performance: A meta-analysis

Abstract

The positive effects of caffeine ingestion on aerobic performance are well-established; however, recent findings are suggesting that caffeine ingestion might also enhance anaerobic performance. A commonly used test of anaerobic performance and power output is the 30-second Wingate test. Several studies explored the effects of caffeine ingestion on Wingate performance, with equivocal findings. To elucidate this topic, this paper aims to determine the effects of caffeine ingestion on Wingate performance using meta-analytic statistical techniques. Following a search through PubMed/MEDLINE, Scopus, and SportDiscus®, 16 studies were found meeting the inclusion criteria (pooled number of participants = 246). Random-effects meta-analysis of standardized mean differences (SMD) for peak power output and mean power output was performed. Study quality was assessed using the modified version of the PEDro checklist. Results of the meta-analysis indicated a significant difference (p = 0.005) between the placebo and caffeine trials on mean power output with SMD values of small magnitude (0.18; 95% confidence interval: 0.05, 0.31; +3%). The meta-analysis performed for peak power output indicated a significant difference (p = 0.006) between the placebo and caffeine trials (SMD = 0.27; 95% confidence interval: 0.08, 0.47 [moderate magnitude]; +4%). The results from the PEDro checklist indicated that, in general, studies are of good and excellent methodological quality. This meta-analysis adds on to the current body of evidence showing that caffeine ingestion can also enhance components of anaerobic performance. The results presented herein may be helpful for developing more efficient evidence-based recommendations regarding caffeine supplementation.

Keywords: exercise, nutrition, performance

Key points:

- Caffeine ingestion can enhance mean power output on the Wingate test.
- Caffeine ingestion can enhance peak power output on the Wingate test.
- More evidence is needed among athletes competing in anaerobic sports.

Introduction

Caffeine is a 1,3,7 trimethylxanthine and is commonly found in foods and beverages. In a detailed review of literature, Glade (2010) concluded that consumption of caffeine (1) increases energy availability, (2) enhances cognitive performance, (3) decreases mental fatigue, (4) increases concentration and focus attention, (5) improves memory, and (6) increases problem-solving that requires reasoning, among others. Besides its impact on the aspects mentioned above, caffeine has received attention from researchers due to its ergogenic effects on sport and exercise performance.

The effects of caffeine ingestion on improving aerobic performance are well-established (Berglund & Hemmingsson, 1982; Bruce et al., 2000); however, there is considerable evidence suggesting that caffeine intake might also enhance anaerobic components of performance (Davis & Green, 2009; Astorino & Roberson, 2010; Grgic & Mikulic, 2017). One common test of anaerobic capacity and power output is the Wingate test. Briefly, the Wingate test consists of a short warm-up and of pedaling or arm cranking at a maximal speed for 30 seconds. This test is widely accepted and commonly used as it is inexpensive, non-invasive, and feasible for administration across populations (Bar-Or, 1987). Several studies explored the effects of caffeine intake on Wingate performance, with equivocal findings. For instance, Greer, McLean, and Graham (1998) reported an ergolytic effect of caffeine ingestion compared to placebo on power output, specifically, on the fourth Wingate bout. No significant effect was noted with caffeine ingestion in the follow-up work by the same author (Greer, Morales, & Coles, 2006). Interestingly, while not reaching significance, it is important to highlight that 12 out of the 18 participants in that study did experience an increase in peak power output when caffeine was ingested compared with placebo. In contrast to Greer et al. (1998), Salinero et al. (2017) reported that caffeine ingestion increased both peak power and mean power output during the Wingate test in a group of young men and women.

Most of the studies that explored this topic have small sample sizes, which can be underpowered to detect statistical significance (at an a priori alpha level of 0.05), when in fact, an actual effect might exist (type II error). A way to surmount these issues is to perform a meta-analysis. Such statistical techniques allow integration of findings from studies that are addressing the same issue while providing greater statistical power than individual studies. However, such an analysis has yet to be done. Therefore, this paper aims to conduct a meta-analysis of studies that are investigating the effects of caffeine ingestion on Wingate performance.

Methodology

Inclusion criteria

To be included in the review, studies were required to meet the following criteria: (i) the original research was published in an English-language refereed journal; (ii) the study assessed the effects of caffeine ingestion in the form of capsule, liquid, gum or gel on performance in the 30-second Wingate test; (iii) the study employed a crossover design, and (iv) included apparently healthy human participants.

Coffee ingestion was not considered because coffee has other compounds that might moderate the impact of caffeine (Trexler, Smith-Ryan, Roelofs, Hirsch, & Mock, 2016). Further, studies were not included if caffeine was co-ingested with other potentially ergogenic substances or compounds, such as taurine.

Search strategy

Searches were performed through PubMed/MEDLINE, Scopus, and SportDiscus®. The following word syntax was used for the search through titles, abstracts, and keywords: caffeine AND (Wingate OR anaerobic OR “peak power” OR “mean power”). No year restriction was applied to the search strategy. Secondary searches were performed by screening the reference lists of all selected studies and relevant review papers. The search concluded on August 8th, 2017.

Study coding and data extraction

The following information from the studies found meeting the inclusion criteria was extracted on an Excel spreadsheet: (i) sample characteristics including sample size, participant’s sex and age; (ii) caffeine form, dosage, and time of ingestion before the testing sessions; (iii) main findings related to the placebo and caffeine trials; (iv) and reported side effects.

Methodological quality

To assess the methodological quality of the studies the previously validated 11-item PEDro scale was used (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003). Details from the checklist can be found elsewhere (Maher et al., 2003). Due to the specificity of the topic, the scale was modified, and the following question (item 12) was added: “Did the study assess the effectiveness of the blinding to the caffeine condition(s)?” With the addition of this question, the maximal score on the scale is 11, as the first item is not included in the total score. Each question is answered with a “yes” if the criteria are satisfied or with a “no” if the criteria are not satisfied. Based on the score, the studies were classified as being of excellent (10-11 points), good (7–9 points), fair (5–6 points) or poor (<5 points) methodological quality (McCrary, Ackermann, & Halaki, 2015).

Statistical analyses

A random-effects meta-analysis of standardized mean differences (SMD) expressed as Hedge's g was performed using the Comprehensive Meta-analysis software (Biostat Inc., Englewood, NJ, USA). SMDs and 95% confidence intervals (CI) were calculated using the sample size (*n*), the correlation between the conditions, and mean ± standard deviation values of the placebo and caffeine trials. None of the included studies reported correlation values; therefore, a conservative 0.5 correlation was assumed for all studies (Follmann, Elliott, Suh, & Cutler, 1992). If a study measured Wingate performance under multiple conditions, such as multiple caffeine doses, the average values were used for the analysis. As presented by Cohen (1988), the SMDs were classified as: [i] small (≤0.2); [ii] moderate (0.2-0.5); [iii] large (0.5-0.8); and [iv] very large (>0.8). Sensitivity analysis was performed by excluding two studies performed in children and examining the outcomes (Turley et al., 2012; Turley, Eusse, Thomas, Townsend, & Morton, 2015). Statistical significance was set at $p < 0.05$. In addition to SMDs, percent changes were calculated. Heterogeneity was assessed using the I^2 statistic. I^2 values that were ≤50% indicated low heterogeneity, I^2 values from 50-75% indicated moderate heterogeneity and I^2 values >75% indicated a high level of heterogeneity. Standard error was plotted against Hedge's g for the funnel plots. The Trim-and-Fill method was used for assessing the asymmetry of the funnel plots.

Results

Search results

The search syntax resulted with a total of 540 results (PubMed/MEDLINE = 159; Scopus = 259; SportDiscus® = 122). Of the total results, 34 full-text articles were read. Eighteen studies were excluded as they did not meet the inclusion criteria, which resulted in the inclusion of 16 studies (Bell, Jacobs, & Ellerington, 2001; Bellar, Lawrence, Kamimori, &

Glickman, 2012; Cakir-Atabek, 2017; Collomp, Ahmaidi, Audran, Chanal, & Préfaut, 1991; Duncan, 2009; Greer et al., 1998; Greer et al., 2006; Lorino, Lloyd, Crixell, & Walker, 2006; Mahdavi, Daneghian, Jafari, & Homayouni, 2015; Pereira et al., 2010; Salinero et al., 2017; Turley et al., 2012; Turley et al., 2015; Warnock, Jeffries, Patterson, & Waldron, 2017; Williams, Cribb, Cooke, & Hayes, 2008; Woolf, Bidwell, & Carlson, 2008). Publication dates of the included studies ranged from 1991 to 2017. The pooled number of participants across the studies was 246 (median = 15; range = 6-26). All of the participants were classified as being young or children. Thirteen of the studies employed a double-blind design (Bell et al., 2001; Bellar et al., 2012; Cakir-Atabek, 2017; Greer et al., 1998; Greer et al., 2006; Lorino et al., 2006; Mahdavi et al., 2015; Pereira et al., 2010; Salinero et al., 2017; Turley et al., 2012; Turley et al., 2015; Williams et al., 2008; Woolf et al., 2008), two a single-blind design (Collomp et al., 1991; Warnock et al., 2017), while in one study there was no blinding (Duncan, 2009). Caffeine doses ranged from 1 $mg.kg^{-1}$ to 5 $mg.kg^{-1}$, with two studies using a fixed dose of caffeine. Only one study used caffeine in the form of gum (Bellar et al. 2012), while in the rest, either a liquid or a capsule form was used. Time of caffeine ingestion before testing sessions was most commonly 60 minutes. All of the studies used the lower body Wingate test. Summary of individual studies can be found in Table 1.

*****Insert Table 1. about here*****

Meta-analysis results

Meta-analysis for mean power output indicated a significant difference (p = 0.005) between the placebo and caffeine trials, with SMD values of 0.18 (95% CI: 0.05, 0.31; +3; I^2 = 0.0% [Figure 1]). The meta-analysis performed for peak power output indicated a significant difference (SMD = 0.27; 95% CI: 0.08, 0.47; +4%; $p = 0.006$; $I^2 = 52.1\%$ [Figure 2]) between the placebo and caffeine trials. The sensitivity analysis did not change the outcomes by a meaningful degree. Funnel plots did not indicate any substantial asymmetry in both analyses. The Trim-and-Fill method did not have an impact in either analysis.

*****Insert Figure 1. about here*****

*****Insert Figure 2. about here*****

Methodological quality

The average score on the PEDro scale was 9 ± 1. Nine of the studies were classified as being of excellent quality, six as being of good quality, and one as being of fair methodological quality. None of the studies satisfied the added item regarding the assessment of the effectiveness of the blinding. Only three studies specified who was eligible to participate in the study (checklist item 1). The scores from individual studies can be found in Table 2.

*****Insert Table 2. about here*****

Discussion

The present study is the first to assess the effectiveness of caffeine ingestion on Wingate performance using meta-analytic statistical techniques. The results presented herein indicate that caffeine ingestion can augment mean and peak power output on the Wingate test by +3% and +4%, respectively. This meta-analysis adds on to the current body of evidence supporting the notion that caffeine ingestion can also be ergogenic for anaerobic performance.

It is important to highlight that while caffeine ingestion can enhance performance on the Wingate test, the SMDs for mean and peak power output are classified as being of small and moderate magnitude, respectively. While athletes would likely benefit the most for such small improvements in performance, only four studies included that population (Duncan, 2009; Mahdavi et al., 2015; Warnock et al., 2017; Woolf et al., 2008). Therefore, the practical usability of these findings remains somewhat questionable.

In a review by Bar-Or (1987), the author concluded that the correlation between performance on the Wingate test and other anaerobic tasks (e.g. short sprinting) is quite high ($r = 0.84$). However, it is relevant to emphasize that performance in the Wingate test does not necessarily reflect the performance in sports-specific activities. Therefore, the generalizability of these findings to other anaerobic tasks is limited. While a transfer of effects can be hypothesized, the current body of evidence prevents concrete conclusions regarding possible benefits of these findings to other sport and exercise activities.

Mechanisms by which caffeine ingestion might enhance anaerobic performance include an increase in calcium release from the sarcoplasmic reticulum, which may lead to an increase in tetanic tension, and the alterations that caffeine might have on the neuromuscular transmission (Davis & Green, 2009). However, discussion on the potential mechanisms is beyond the scope of this article (for a review the reader is directed to the work by Davis & Green [2009]).

Besides the study by Williams et al. (2008) which reported a coefficient of variation of 1% to 5% on the Wingate test, none of the other included studies reported their coefficient of variation for repeated measures. It might be that some of the differences between the placebo and caffeine conditions are the effect of an error of the measurement and not truly related to the effects of the condition. Therefore, possible issues with measurement error between placebo and caffeine trials in the analyzed studies should not be excluded. Most of the studies did include at least one practice trial to prevent any learning effects; however, two studies did not report any familiarization sessions (Collomp et al., 1991; Greer et al., 2006), which presents a confounding factor to their results, and should be avoided in future research. Besides the differences in the protocols used, it is also important to note that some studies used a mechanically-braked ergometer (Bell et al., 2001), while others used an electrically-braked ergometer (Warnock et al., 2017), which might also be a reason for differences in estimates across studies (Astorino & Cottrell, 2012).

A confounding factor to the present findings is that none of the studies assessed the effectiveness of the blinding. Salinero et al. (2017) reported that they did ask the participants to indicate which trial they perceived to be the caffeine trial. However, the results of this assessment were not reported. Assessing the effectiveness of the blinding can be of significant impact due to the possible placebo effects of “caffeine” ingestion on performance (Beedie, Stuart, Coleman, & Foad, 2006). Therefore, future studies should assess the effectiveness of the blinding following the trials, to increase the robustness of their findings.

The current body of evidence suggests that caffeine ingestion might result in several side effects such as insomnia, headaches, nervousness, gastrointestinal problems, and muscle soreness, among others (Astorino, Rohmann, & Firth, 2008; Goldstein, Jacobs, Whitehurst, Penhollow, & Antonio, 2010). Only three of the included studies assessed the side effects of caffeine ingestion in their experimental trials. Williams et al. (2008) reported that no side effects occurred. Lorino et al. (2006) reported that one of the participants vomited following caffeine ingestion, while Salinero et al. (2017) noted a slight increase in self-reported insomnia and nervousness following the caffeine trials. It seems that some of the side effects mentioned above may be augmented in individuals with low habitual caffeine intake so extra precaution might be necessary for these individuals (Astorino et al., 2008; Goldstein et al., 2010). Future studies should consider tracking and reporting side effects to highlight the possible disadvantages of supplementing with caffeine.

Future directions

None of the included studies used the upper-body Wingate test in their trials. Therefore, the results presented in this meta-analysis cannot be generalizable to upper body power, as it has been shown that the effects of caffeine ingestion might differ between upper and lower body (Grgic & Mikulic, 2017). This gap in the literature opens an avenue for future research to test the effects of caffeine ingestion on upper body Wingate performance. Furthermore, studies might consider exploring the effects of caffeine ingestion and Wingate performance in older adults, as to date, there are no such studies. More evidence is needed on females, as most of the included studies were performed in men. Some studies included a mixed-gender sample, but the total number of female participants was small (n = 23). Besides females, more studies are needed on athletes, in particular on those competing in anaerobic sports. It would be desirable for future studies to plot the individual values from the placebo and caffeine trials, to examine the variation in responses to caffeine ingestion.

Conclusions

In contrast to previous reviews which suggested that caffeine does not have an impact on Wingate performance, this meta-analysis provides findings that caffeine ingestion may increase both peak power output and mean power output during the Wingate test. Therefore, the results presented in this paper may be helpful for developing more efficient evidence-based recommendations regarding caffeine supplementation. While this would suggest that athletes who compete in anaerobic dominant sports might consider supplementing with caffeine, this remains tentative as it is unclear to which extent these effects could transfer in the sports context. Furthermore, the effects are not of a large magnitude which limits the practical usability of the findings. Because of the inter-individual response to caffeine ingestion, potential supplementation with caffeine needs to be adjusted on a case-by-case basis.

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