

**1 Caffeine ingestion enhances Wingate performance: A meta-analysis**

## 2 **Abstract**

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

23 **Keywords:** exercise, nutrition, performance

24

25 **Key points:**

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

## 29 **Introduction**

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

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

53 ingestion increased both peak power and mean power output during the Wingate test in a  
54 group of young men and women.

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

63

## 64 **Methodology**

### 65 *Inclusion criteria*

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

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

### 75 *Search strategy*

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

### 82 *Study coding and data extraction*

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

### 88 *Methodological quality*

89 To assess the methodological quality of the studies the previously validated 11-item  
90 PEDro scale was used (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003). Details from  
91 the checklist can be found elsewhere (Maher et al., 2003). Due to the specificity of the topic,  
92 the scale was modified, and the following question (item 12) was added: “Did the study assess  
93 the effectiveness of the blinding to the caffeine condition(s)?” With the addition of this  
94 question, the maximal score on the scale is 11, as the first item is not included in the total  
95 score. Each question is answered with a “yes” if the criteria are satisfied or with a “no” if the  
96 criteria are not satisfied. Based on the score, the studies were classified as being of excellent  
97 (10-11 points), good (7–9 points), fair (5–6 points) or poor (<5 points) methodological quality  
98 (McCrary, Ackermann, & Halaki, 2015).

### 99 *Statistical analyses*

100 A random-effects meta-analysis of standardized mean differences (SMD) expressed as  
101 Hedge's  $g$  was performed using the Comprehensive Meta-analysis software (Biostat Inc.,  
102 Englewood, NJ, USA). SMDs and 95% confidence intervals (CI) were calculated using the  
103 sample size ( $n$ ), the correlation between the conditions, and mean  $\pm$  standard deviation values  
104 of the placebo and caffeine trials. None of the included studies reported correlation values;  
105 therefore, a conservative 0.5 correlation was assumed for all studies (Follmann, Elliott, Suh,  
106 & Cutler, 1992). If a study measured Wingate performance under multiple conditions, such as  
107 multiple caffeine doses, the average values were used for the analysis. As presented by Cohen  
108 (1988), the SMDs were classified as: [i] small ( $\leq 0.2$ ); [ii] moderate (0.2-0.5); [iii] large (0.5-  
109 0.8); and [iv] very large ( $> 0.8$ ). Sensitivity analysis was performed by excluding two studies  
110 performed in children and examining the outcomes (Turley et al., 2012; Turley, Eusse,  
111 Thomas, Townsend, & Morton, 2015). Statistical significance was set at  $p < 0.05$ . In addition  
112 to SMDs, percent changes were calculated. Heterogeneity was assessed using the  $I^2$  statistic.  
113  $I^2$  values that were  $\leq 50\%$  indicated low heterogeneity,  $I^2$  values from 50-75% indicated  
114 moderate heterogeneity and  $I^2$  values  $> 75\%$  indicated a high level of heterogeneity. Standard  
115 error was plotted against Hedge's  $g$  for the funnel plots. The Trim-and-Fill method was used  
116 for assessing the asymmetry of the funnel plots.

117

## 118 **Results**

### 119 *Search results*

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

124 Glickman, 2012; Cakir-Atabek, 2017; Collomp, Ahmaidi, Audran, Chanal, & Préfaut, 1991;  
125 Duncan, 2009; Greer et al., 1998; Greer et al., 2006; Lorino, Lloyd, Crixell, & Walker, 2006;  
126 Mahdavi, Daneghian, Jafari, & Homayouni, 2015; Pereira et al., 2010; Salinero et al., 2017;  
127 Turley et al., 2012; Turley et al., 2015; Warnock, Jeffries, Patterson, & Waldron, 2017;  
128 Williams, Cribb, Cooke, & Hayes, 2008; Woolf, Bidwell, & Carlson, 2008). Publication dates  
129 of the included studies ranged from 1991 to 2017. The pooled number of participants across  
130 the studies was 246 (median = 15; range = 6-26). All of the participants were classified as  
131 being young or children. Thirteen of the studies employed a double-blind design (Bell et al.,  
132 2001; Bellar et al., 2012; Cakir-Atabek, 2017; Greer et al., 1998; Greer et al., 2006; Lorino et  
133 al., 2006; Mahdavi et al., 2015; Pereira et al., 2010; Salinero et al., 2017; Turley et al., 2012;  
134 Turley et al., 2015; Williams et al., 2008; Woolf et al., 2008), two a single-blind design  
135 (Collomp et al., 1991; Warnock et al., 2017), while in one study there was no blinding  
136 (Duncan, 2009). Caffeine doses ranged from 1 mg.kg<sup>-1</sup> to 5 mg.kg<sup>-1</sup>, with two studies using a  
137 fixed dose of caffeine. Only one study used caffeine in the form of gum (Bellar et al. 2012),  
138 while in the rest, either a liquid or a capsule form was used. Time of caffeine ingestion before  
139 testing sessions was most commonly 60 minutes. All of the studies used the lower body  
140 Wingate test. Summary of individual studies can be found in Table 1.

141

142

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

143

144 *Meta-analysis results*

145

Meta-analysis for mean power output indicated a significant difference ( $p = 0.005$ )

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between the placebo and caffeine trials, with SMD values of 0.18 (95% CI: 0.05, 0.31; +3;  $I^2$

147

= 0.0% [Figure 1]). The meta-analysis performed for peak power output indicated a

148 significant difference (SMD = 0.27; 95% CI: 0.08, 0.47; +4%;  $p = 0.006$ ;  $I^2 = 52.1\%$  [Figure  
149 2]) between the placebo and caffeine trials. The sensitivity analysis did not change the  
150 outcomes by a meaningful degree. Funnel plots did not indicate any substantial asymmetry in  
151 both analyses. The Trim-and-Fill method did not have an impact in either analysis.

152

153 **\*\*\*Insert Figure 1. about here\*\*\***

154 **\*\*\*Insert Figure 2. about here\*\*\***

155

#### 156 *Methodological quality*

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

163

164 **\*\*\*Insert Table 2. about here\*\*\***

165

#### 166 **Discussion**

167 The present study is the first to assess the effectiveness of caffeine ingestion on  
168 Wingate performance using meta-analytic statistical techniques. The results presented herein  
169 indicate that caffeine ingestion can augment mean and peak power output on the Wingate test

170 by +3% and +4%, respectively. This meta-analysis adds on to the current body of evidence  
171 supporting the notion that caffeine ingestion can also be ergogenic for anaerobic performance.

172 It is important to highlight that while caffeine ingestion can enhance performance on  
173 the Wingate test, the SMDs for mean and peak power output are classified as being of small  
174 and moderate magnitude, respectively. While athletes would likely benefit the most for such  
175 small improvements in performance, only four studies included that population (Duncan,  
176 2009; Mahdavi et al., 2015; Warnock et al., 2017; Woolf et al., 2008). Therefore, the practical  
177 usability of these findings remains somewhat questionable.

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

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

191 Besides the study by Williams et al. (2008) which reported a coefficient of variation of  
192 1% to 5% on the Wingate test, none of the other included studies reported their coefficient of  
193 variation for repeated measures. It might be that some of the differences between the placebo

194 and caffeine conditions are the effect of an error of the measurement and not truly related to  
195 the effects of the condition. Therefore, possible issues with measurement error between  
196 placebo and caffeine trials in the analyzed studies should not be excluded. Most of the studies  
197 did include at least one practice trial to prevent any learning effects; however, two studies did  
198 not report any familiarization sessions (Collomp et al., 1991; Greer et al., 2006), which  
199 presents a confounding factor to their results, and should be avoided in future research.  
200 Besides the differences in the protocols used, it is also important to note that some studies  
201 used a mechanically-braked ergometer (Bell et al., 2001), while others used an electrically-  
202 braked ergometer (Warnock et al., 2017), which might also be a reason for differences in  
203 estimates across studies (Astorino & Cottrell, 2012).

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

211         The current body of evidence suggests that caffeine ingestion might result in several  
212 side effects such as insomnia, headaches, nervousness, gastrointestinal problems, and muscle  
213 soreness, among others (Astorino, Rohmann, & Firth, 2008; Goldstein, Jacobs, Whitehurst,  
214 Penhollow, & Antonio, 2010). Only three of the included studies assessed the side effects of  
215 caffeine ingestion in their experimental trials. Williams et al. (2008) reported that no side  
216 effects occurred. Lorino et al. (2006) reported that one of the participants vomited following  
217 caffeine ingestion, while Salinero et al. (2017) noted a slight increase in self-reported  
218 insomnia and nervousness following the caffeine trials. It seems that some of the side effects

219 mentioned above may be augmented in individuals with low habitual caffeine intake so extra  
220 precaution might be necessary for these individuals (Astorino et al., 2008; Goldstein et al.,  
221 2010). Future studies should consider tracking and reporting side effects to highlight the  
222 possible disadvantages of supplementing with caffeine.

### 223 *Future directions*

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

236

### 237 **Conclusions**

238         In contrast to previous reviews which suggested that caffeine does not have an impact  
239 on Wingate performance, this meta-analysis provides findings that caffeine ingestion may  
240 increase both peak power output and mean power output during the Wingate test. Therefore,  
241 the results presented in this paper may be helpful for developing more efficient evidence-  
242 based recommendations regarding caffeine supplementation. While this would suggest that

243 athletes who compete in anaerobic dominant sports might consider supplementing with  
244 caffeine, this remains tentative as it is unclear to which extent these effects could transfer in  
245 the sports context. Furthermore, the effects are not of a large magnitude which limits the  
246 practical usability of the findings. Because of the inter-individual response to caffeine  
247 ingestion, potential supplementation with caffeine needs to be adjusted on a case-by-case  
248 basis.

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