



## Article

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## Is coffee a useful source of caffeine pre-exercise?

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**26 Abstract**

27

28 Caffeine is a well-established ergogenic aid, with its performance-enhancing effects  
29 demonstrated across a wide variety of exercise modalities. Athletes tend to frequently  
30 consume caffeine as a performance enhancement method in training and competition. There  
31 are a number of methods available as a means of consuming caffeine around exercise,  
32 including caffeine anhydrous, sports drinks, caffeine-carbohydrate gels, and gum. One  
33 popular method of caffeine ingestion in non-athletes is coffee, with some evidence suggesting  
34 it is also utilized by athletes. In this article, we discuss the research pertaining to the use of  
35 coffee as an ergogenic aid, exploring (a) whether caffeinated coffee is ergogenic, (b) whether  
36 dose-matched caffeinated coffee provides a performance benefit similar in magnitude to  
37 caffeine anhydrous, and (c) whether decaffeinated coffee consumption affects the ergogenic  
38 effects of a subsequent isolated caffeine dose. There is limited evidence that caffeinated  
39 coffee has the potential to offer ergogenic effects similar in magnitude to caffeine anhydrous;  
40 however, this requires further investigation. Co-ingestion of caffeine with decaffeinated  
41 coffee does not seem to limit the ergogenic effects of caffeine. Whilst caffeinated coffee is  
42 potentially ergogenic, its use as a pre-exercise caffeine ingestion method represents some  
43 practical hurdles to athletes, including the consumption of large volumes of liquid, and  
44 difficulties in quantifying the exact caffeine dose, as differences in coffee type and brewing  
45 method may alter caffeine content. The use of caffeinated coffee around exercise has the  
46 potential to enhance performance, but athletes and coaches should be mindful of the practical  
47 limitations.

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## 51        **1. Introduction**

52

53            Caffeine is a well-established ergogenic aid, with performance-enhancing effects  
54 confirmed at meta-analysis level (Grgic et al., 2019) across a variety of exercise types,  
55 including aerobic and muscular endurance, muscle strength, anaerobic power, speed, and  
56 jumping performance (Polito et al., 2016; Grgic et al., 2018; Southward et al., 2018; Grgic et  
57 al., 2019; Grgic & Pickering, 2019). Caffeine enhances performance via a variety of  
58 mechanisms, including a reduction in perceived exertion and pain perception, as well as  
59 increases in motor unit recruitment (Doherty & Smith, 2004; Graham 2001). Athletes, never  
60 slow to adopt practices that might enhance performance, are well aware of caffeine's  
61 ergogenic benefits, with approximately 75% of athletes consuming caffeine around  
62 competitions (Aguilar-Navarro et al., 2019).

63

64            Caffeine is also widely utilized by the general public, seeking to harness caffeine's  
65 positive effects on alertness (Zwyghuizen-Doorenbos et al., 1990) and concentration (Haskell  
66 et al., 2008), particularly when sleep deprived (Wesensten et al., 2005), as well as a method  
67 to harness caffeine's purported health benefits, such as a decreased risk of Parkinson's  
68 disease and type-2 diabetes (Grosso et al., 2017). The most common method of consuming  
69 caffeine is via coffee (Frary et al., 2005), with an estimated 2.25 billion cups consumed  
70 globally per day (Denoeud et al., 2014).

71

72            Like the general public, athletes regularly consume caffeine in their daily lives  
73 (Tunncliffe et al., 2008). Alongside its direct, well-established ergogenic effects,  
74 consumption of caffeine can also offset the fatigue associated with regular, frequent training  
75 sessions (Doherty & Smith, 2005), mask training-induced soreness (Hurley et al., 2013;

76 Maridakis et al., 2007), or overcome sleep disruption caused by early morning training  
77 sessions and jet lag (Cook et al., 2011; Arendt, 2009). Athletes have a variety of options  
78 available when it comes to selecting how to obtain their caffeine dose. Whilst the majority of  
79 caffeine research studies utilize caffeine anhydrous, typically in tablet or capsule form  
80 (Wickham & Spriet, 2018), caffeine can also be ingested through caffeinated sports drinks  
81 (Souza et al., 2017)—with or without additional carbohydrate—alongside caffeinated bars  
82 (Hogervorst, 2008), gels (Cooper et al., 2014; Venier et al., 2019), and gum (Ryan et al.,  
83 2012), in addition to more experimental methods such as caffeinated sprays (De Pauw et al.,  
84 2017) and mouth rinses (Beaven et al., 2013). Caffeinated coffee represents an additional  
85 caffeine consumption method for athletes, with research suggesting coffee is widely used by  
86 athletes (Desbrow & Leveritt, 2006; Tunnicliffe et al., 2008), although it is not necessarily  
87 clear whether they consume coffee as a deliberate pre-exercise ergogenic aid, or via social  
88 habits.

89  
90 Whilst coffee contains caffeine, it is also comprised of a variety of other components,  
91 such as chlorogenic acids (de Paulis et al., 2002), ferulic acid and caffeic acid (Hall et al.,  
92 2015). These additional components may modify the ergogenic effects of caffeine contained  
93 in coffee, either offering additional performance benefits, or reducing caffeine's  
94 performance-enhancing effects. Given the well-established ergogenic effects of caffeine  
95 (Grgic et al., 2019), and that coffee represents one of the most widely used methods of  
96 caffeine ingestion in athletes and non-athletes (Tunnicliffe et al., 2008; Denoeud et al., 2014),  
97 it is important to fully understand whether caffeinated coffee offers ergogenic benefits, and  
98 whether these benefits are similar to an equivalent dose of isolated caffeine. A previous  
99 review (Higgins et al., 2016) found that five of nine studies exploring the effects of  
100 caffeinated coffee on endurance performance reported that coffee was ergogenic, suggesting

101 it may be a safe alternative to anhydrous caffeine as a performance-enhancer. This previous  
102 review (Higgins et al., 2016) focused only on endurance performance; however, since its  
103 publication, several other studies have been published, exploring the use of caffeinated coffee  
104 on both endurance (Clarke et al., 2018; Marques et al., 2018) and high-intensity (Trexler et  
105 al., 2016; Richardson & Clarke, 2016) performance. Furthermore, the authors of this previous  
106 review included anhydrous caffeine powder dissolved into decaffeinated coffee within their  
107 definition of caffeinated coffee. While this practice is valid in research settings, it likely does  
108 not mirror how caffeine is utilized by active populations in the real world (i.e. these  
109 individuals would likely consume either caffeinated coffee or a caffeinated supplement, being  
110 unlikely to add supplemental caffeine to decaffeinated coffee). As such, the aim of this  
111 review is to re-examine and critically review the evidence for the use of caffeinated coffee—  
112 defined as coffee in its caffeinated form, and not as decaffeinated coffee with additional  
113 caffeine anhydrous—as an ergogenic aid, with specific reference to the practical implications  
114 and limitations of utilizing coffee as a pre-exercise caffeine source, allowing athletes and  
115 practitioners to better weigh the evidence regarding the use of coffee within sporting  
116 contexts.

117

## 118 **2. Does caffeinated coffee provide an ergogenic benefit?**

119

120 Before discussing the results of individual studies, some methodological aspects  
121 warrant a brief discussion. Decaffeinated coffee generally contains very low amounts of  
122 caffeine (up to 16 mg) that might not be ergogenic, therefore allowing a valid “placebo”  
123 comparison (McClusker et al., 2006). The process of decaffeinated coffee production  
124 involves treatment of the coffee beans, which results in the reduction of the caffeine content.  
125 This process alters the content of other nutritional properties in the coffee, such as

126 polyphenols (Silvarolla et al., 2004). This also needs to be considered from a study design  
127 perspective, ideally, the only difference between caffeinated and decaffeinated coffee should  
128 be the caffeine content. Studies exploring the ergogenic effects of coffee should employ three  
129 conditions; caffeinated coffee, decaffeinated coffee, and a beverage that mimics the taste of  
130 coffee but provides no caffeine or other nutritional properties. Of the discussed studies, only  
131 a few (Clarke and colleagues 2016 and 2018; Hodgson et al., 2013) employed such a design.  
132 Additionally, habitual caffeine use may blunt the expected ergogenic benefits of caffeine use  
133 (Lara et al., 2019), although this is currently a contentious subject (Pickering & Kiely, 2019),  
134 with a number of studies reporting no influence of habituation on caffeine's subsequent  
135 ergogenic effect (e.g. Goncalves et al., 2017; Sabol et al., 2019). Researchers often control  
136 for this by reporting the habitual caffeine use of their subjects (as detailed in the tables within  
137 this manuscript), and by requiring a period of caffeine abstinence prior to experimental trials.

138

139 A number of studies, summarized in table 1, have demonstrated that caffeinated  
140 coffee can provide an ergogenic effect above decaffeinated coffee. Wiles and colleagues  
141 (1992) demonstrated that 3g of instant caffeinated coffee, providing 150-200 mg of caffeine,  
142 significantly enhanced 1500m run performance compared to decaffeinated coffee. Clarke and  
143 colleagues (2018) compared the ergogenic effects of caffeinated coffee (providing  
144 approximately 3 mg/kg caffeine) with decaffeinated coffee and placebo on a competitive one-  
145 mile run, finding that race time was significantly faster in the caffeinated compared to  
146 decaffeinated (+1.3%; -0.06s, 95% confidence interval [CI]: -.011 to -0.01 min:s.ms) and  
147 placebo (+1.9%; -0.09, 95% CI: -0.15 to -0.03 min:s.ms) trials. No difference was observed  
148 between decaffeinated coffee and placebo, even though there was a small favouring of the  
149 decaffeinated coffee condition (+0.6%; -0.03: 95% CI: -0.09 to 0.03 min:s.ms). Hodgson and  
150 colleagues (2013) reported that caffeinated coffee (5 mg/kg of caffeine) enhanced

151 performance in a 45-minute time trial compared to decaffeinated coffee. Demura et al, (2007)  
152 reported that caffeinated coffee ingestion (6 mg/kg caffeine; 800 to 1000 ml of fluid)  
153 decreased RPE during a 60-minute submaximal cycle ergometer task performed at 60% of  
154 maximum oxygen uptake ( $VO_{2max}$ ) compared to decaffeinated coffee. However, by focusing  
155 of changes in RPE, this study did not directly measure exercise performance, which  
156 somewhat limits the practical value of these findings.

157

158 Not all studies support a performance-enhancing effect of caffeinated coffee. Graham  
159 et al. (1998) reported no difference between caffeinated coffee (caffeine dose of 4.45 mg/kg)  
160 and decaffeinated coffee in an endurance running task. Marques et al. (2018) found that  
161 caffeinated coffee (providing 5.5 mg/kg of caffeine) did not enhance 800m time trial run  
162 performance when compared to decaffeinated coffee. Lamina and Musa (2009) utilized  
163 caffeine doses of 5, 10 and 15 mg/kg, delivered through powdered coffee dissolved in 200 ml  
164 of water, finding no ergogenic effect of any caffeine dose on 20m shuttle run performance.  
165 This latter result is especially surprising, given the high caffeine doses utilized, and  
166 performance tests that typically show enhancement with acute caffeine consumption  
167 (Goldstein et al., 2010). However, from a practical standpoint the use of very high caffeine  
168 doses, such as 10 and 15 mg/kg, should be avoided given the reported side-effects of caffeine  
169 ingestion, such as gastrointestinal distress, nervousness, jitters, and others, which appear to  
170 increase with caffeine dose (Kaplan et al., 1997). Furthermore, such high acute intakes of  
171 caffeine are above the European Food Safety Authority's general safe acute intake level of  
172 200 mg (EFSA, 2015), and so are potentially unsafe.

173

174 Regarding resistance exercise, Richardson and Clarke (2016) reported no difference  
175 between caffeinated coffee and decaffeinated coffee on a muscular endurance squat and

176 bench press task, whilst Clarke et al. (2016) reported no benefit of caffeinated coffee  
177 compared to a placebo coffee alternative that contained no caffeine on repeated sprint  
178 performance.

179

180 **INSERT TABLE 1 AROUND HERE**

181

182 In summary, when compared to decaffeinated coffee, there is some evidence that  
183 caffeinated coffee, providing a typically ergogenic caffeine dose of 3-6 mg/kg, may enhance  
184 aerobic endurance performance (Wiles et al., 1992; Hodgson et al., 2013; Clarke et al., 2016),  
185 and can lower RPE during exercise (Demura et al., 2007). However, these findings are  
186 equivocal, with some authors reporting no ergogenic effect of caffeinated compared to  
187 decaffeinated coffee (Marques et al., 2018; Graham et al., 1998; Lamina & Musa 2009;  
188 Church et al., 2015; Anderson et al., 2018). The limited research regarding resistance and  
189 high-intensity exercise tentatively suggests no benefits to caffeinated coffee above  
190 decaffeinated coffee (Richardson & Clarke, 2016; Clarke et al., 2016), but this area merits  
191 further research.

192

### 193 **3. Is this ergogenic benefit similar to that of caffeine anhydrous?**

194

195 It appears that caffeinated coffee has the potential to exert ergogenic effects, at least  
196 for endurance performance, even though the somewhat limited studies to date often provide  
197 conflicting results. An important next step is to understand whether caffeinated coffee  
198 provides an ergogenic effect similar in magnitude to that of caffeine anhydrous, requiring  
199 direct comparison of caffeinated coffee and caffeine; this has been explored experimentally  
200 in a number of trials, summarized in table 2. Graham and colleagues (1998) undertook a trial

201 in which nine trained subjects underwent five time-to-exhaustion treadmill trials at 85% of  
202  $\text{VO}_{2\text{max}}$ , comparing differences between placebo, caffeine capsules, caffeinated coffee,  
203 decaffeinated coffee, and decaffeinated coffee with caffeine capsules, consumed ~60 minutes  
204 prior to the exercise trial. The caffeine dose was standardised across trials to deliver 4.45  
205 mg/kg of caffeine, with a total volume of liquid of 7.15 ml/kg. Despite similar changes in  
206 plasma methylxanthines—downstream metabolites of caffeine—in all caffeinated trials, only  
207 the caffeine capsule trial significantly improved performance. These results lead to the  
208 conclusion that coffee is probably inferior to isolated caffeine as an ergogenic aid (Graham,  
209 2001). This study included only nine participants, and has five repeated measures; as such, it  
210 is very possible that it was statistically underpowered. Additionally, it needs to be highlighted  
211 that Graham et al. (1998) used a time to exhaustion test, and these tests generally exhibit poor  
212 test-retest reliability (test-retest coefficient of variation of > 10%) (Currell & Jeukendrup,  
213 2006). These tests appear unsuitable when exploring the acute effects of supplements given  
214 that the overall magnitude of acute improvements with most supplements—including  
215 caffeine—is likely to be small to moderate. For example, the improvements in performance  
216 following caffeine ingestion are generally in the range of 2% to 6% (Grgic et al., 2019);  
217 utilizing tests with poor reliability may, therefore, lead to type II errors. Hodgson and  
218 colleagues (2013) used a cycling time trial test, and these tests generally have a test-retest  
219 variation of < 5%. The results of this study indicated that caffeine (5 mg/kg) and caffeinated  
220 coffee (providing 5 mg/kg of caffeine) enhanced cycle time trial performance compared to  
221 decaffeinated coffee and placebo to a similar extent, suggesting that coffee was as effective  
222 as caffeine anhydrous in enhancing aerobic endurance performance.

223

224

**INSERT TABLE 2 AROUND HERE**

225

226 Other studies report no ergogenic effect of either caffeinated coffee or caffeine  
227 anhydrous (3 mg/kg) on performance (Clarke et al., 2016), although these studies often  
228 utilize high-intensity or resistance exercise, modalities in which the ergogenic effects of  
229 caffeine are less pronounced (Grgic et al., 2019). For example, Trexler and colleagues (2016)  
230 reported no beneficial effect of caffeinated coffee or caffeine, standardised to provide an  
231 absolute dose of ~300 mg caffeine (3.8 mg/kg), on a number of resistance training measures  
232 when compared to placebo, although both caffeinated coffee and caffeine maintained  
233 repeated cycle ergometer sprint performance when compared to placebo. This study had a  
234 between-group design, and, thus, the inter-individual variation in responses to caffeine  
235 supplementation were not as well controlled as if the researchers had utilized a cross-over  
236 design (Maclure, 1991). Clarke and colleagues (2016) reported no ergogenic effect of 3  
237 mg/kg caffeine, or coffee providing 3 mg/kg caffeine, on power output or RPE across 18 x 4-  
238 second cycle ergometer sprints. Richardson and Clarke (2016) reported that caffeinated  
239 coffee enhanced muscular endurance performance compared to placebo, whilst caffeine alone  
240 did not, although caffeine in combination with decaffeinated coffee did.

241

242 The results in this area are, therefore, inconsistent. Whilst Graham and colleagues  
243 (1998) reported caffeine offered enhanced ergogenic benefits compared to coffee in an  
244 aerobic endurance task, conflicting findings were reported by Hodgson et al. (2013). This is  
245 potentially due to the type of performance test utilized (as noted previously), or variation in  
246 the composition and preparation of the coffee solutions (Hodgson et al., 2013). Graham et al.  
247 (1998) did not report the coffee brand utilized, limiting detailed between-study comparisons;  
248 future studies should explicitly note the exact brands of coffee within their methodologies. In  
249 terms of resistance and high-intensity exercise, it appears that, in general, caffeine and coffee  
250 perform similarly, although the identified studies report mixed findings regarding the

251 ergogenicity of caffeine on this exercise type (Trexler et al., 2016; Richardson & Clarke,  
252 2016; Clarke et al., 2016). Further research into the coffee versus caffeine conundrum is  
253 therefore required, especially in light of findings suggesting differences in salivary caffeine  
254 concentrations following ingestion of coffee or caffeine anhydrous (Liguori et al., 1997);  
255 might these differences in absorption rates modify the performance-enhancing effects of each  
256 caffeine modality?

257

#### 258 **4. Does decaffeinated coffee block caffeine's ergogenic effects?**

259

260 There remains the possibility that other coffee constituents can modify caffeine's  
261 ergogenic effects. For example, 3,4-dicinnamoyl-1,5-quinides in coffee may raise adenosine  
262 levels (de Paulis et al., 2002). This increase in adenosine levels could subsequently  
263 counteract the ergogenic effects of caffeine on exercise performance. Specifically, after  
264 ingestion, caffeine binds to adenosine receptors, reduces perceived exertion, and ultimately  
265 enhances exercise performance (Graham, 2001). This effect of caffeine on adenosine  
266 receptors is one of the primary mechanisms underpinning its ergogenic effects (Graham  
267 2001). Indeed, in the study by Graham and colleagues (1998), caffeinated coffee, as well as  
268 caffeine capsules consumed alongside decaffeinated coffee, did not enhance endurance  
269 performance versus placebo, whilst caffeine capsules consumed in isolation did—despite the  
270 fact that plasma methylxanthine concentrations increased similarly in the coffee- and capsule-  
271 only trials.

272

273 Historically, researchers added caffeine anhydrous to decaffeinated coffee in caffeine  
274 ingestion trials, allowing them to utilize decaffeinated coffee as a placebo. As a result, there  
275 are a number of research studies, detailed in table 3, allowing us to explore this question.

276 Butts and Crowell (1985) reported that caffeine, when consumed with decaffeinated coffee,  
277 did not significantly improve endurance performance when compared to a decaffeinated  
278 coffee only trial. However, the percentage improvement of 14% (+8.6 min) for females (with  
279 an average caffeine dose of ~5 mg/kg) and 3% (+2.2 min) for males (with an average caffeine  
280 dose of ~4 mg/kg) following caffeine ingestion are indicative of an effect, although this did  
281 not reach statistical significance. Similar results have been reported by Rodrigues et al.  
282 (1990). In this study, ingestion of 5 mg/kg caffeine did not affect total cycling time to  
283 exhaustion; however, this study also included a small sample size of six participants.

284

285         However, contrasting findings were reported by McLellan and Bell (2004). Here, the  
286 authors explored the impact of previous consumption of coffee, both caffeinated and  
287 decaffeinated, on the effects of subsequent caffeine supplementation on exercise performance  
288 across a range of caffeine doses, ranging from 3 mg/kg to 7 mg/kg total caffeine intake.  
289 Coffee was consumed approximately 30 minutes prior to the caffeine capsules, which in turn  
290 were consumed approximately one hour prior to an exhaustive cycle ergometer trial. Time-to-  
291 exhaustion was significantly increased following caffeine capsule ingestion, regardless of  
292 whether caffeinated or decaffeinated coffee was consumed beforehand. Trice and Haymes  
293 (1995) explored the effects of 5 mg/kg caffeine, dissolved in decaffeinated coffee, compared  
294 to decaffeinated coffee alone on intermittent cycling performance, finding that time to  
295 exhaustion was significantly increased in the caffeine compared to decaffeinated coffee trial.  
296 Similar results were reported by Costill et al. (1978), utilizing 330 mg (4.5 mg/kg) of  
297 caffeine dissolved in decaffeinated coffee. Here, caffeine ingestion enhanced total cycling  
298 time to exhaustion by approximately 15 minutes compared to decaffeinated coffee.  
299 Additionally, Richardson and Clarke (2016) found that 5 mg/kg of caffeine, consumed in  
300 combination with decaffeinated coffee, enhanced resistance exercise performance to a greater

301 extent than caffeine anhydrous (5 mg/kg) consumed in isolation. In this study, the mean  
302 difference between the two conditions in the total number of repetitions was 3 (95% CI: 0.1  
303 to 5.2). Such an increase in muscular endurance following acute caffeine ingestion is similar  
304 to improvements noted following eight weeks of regimented resistance training (Mattocks et  
305 al., 2017), highlighting the possible magnitude of caffeine's effects.

306

307

### INSERT TABLE 3 AROUND HERE

308

309 At present, despite the results of Graham and colleagues (Graham et al., 1998) the  
310 majority of results in this area suggest that co-ingestion of caffeine with decaffeinated coffee  
311 does not limit the ergogenic effects of caffeine (Butts & Crowell, 1985; McLellan & Bell,  
312 2004; Trice & Haymes, 1995; Costil et al., 1978), and may serve to enhance resistance  
313 training performance to a greater extent than isolated caffeine (Trexler et al., 2016), although  
314 this latter finding requires further research, especially in a cross-over type design.

315

## 316 5. Practical Considerations

317

318 As compared to caffeine anhydrous, coffee ingestion could provide similar ergogenic  
319 effects (Hodgson et al., 2013). In order to exert these ergogenic effects, the caffeine content  
320 likely needs to be within the commonly considered ergogenic range of 3-6 mg/kg (Goldstein  
321 et al., 2010). This is illustrated by Hodgson and colleagues (Hodgson et al., 2013), in which  
322 coffee was ergogenic at a caffeine dose of 5 mg/kg; here, this represented 600 ml of coffee, a  
323 substantial amount of liquid to have to consume prior to exercise. This is also the case in  
324 other studies; Graham and colleagues (1998) delivered 4.45 mg/kg caffeine through coffee,  
325 requiring ~600 ml of fluid, and Demura et al. (2007) required 4-5 200ml cups of coffee to

326 deliver the required caffeine dose. These examples illustrate a practical issue surrounding  
327 coffee's use as an ergogenic aid, specifically that it potentially requires a large volume of  
328 liquid to be consumed, with an "average" cup of coffee containing approximately 100mg of  
329 caffeine (Desbrow et al., 2007). Caffeine is most reliability shown to be ergogenic at doses of  
330 between 3 – 6 mg/kg (Goldstein et al., 2010), meaning that, for a 70kg athlete, a minimum of  
331 two cups of coffee are required to reliably elicit a performance-enhancing effect at this lower  
332 threshold. Whilst caffeine can be ergogenic at lower doses (Spriet, 2014), there is  
333 considerable variation between individuals when it comes to the optimal caffeine dose  
334 (Pickering & Kiely, 2018), and aspects such as habitual caffeine use can further increase the  
335 caffeine dose required (Pickering & Kiely, 2019), although this latter topic is still  
336 controversial (Goncalves et al., 2017). Accordingly, for habitual caffeine users, caffeine  
337 doses of 6 mg/kg might be required to elicit a performance benefit, which represents over  
338 four cups of coffee for a 70kg athlete, potentially comprising over a liter of fluid.  
339 Consumption of such high amounts of fluid has the potential to lead to increased sensations  
340 of fullness during exercise, increases in body weight—an important consideration for weight  
341 class and weight-bearing sports—and may contribute to an increased risk of hyponatremia,  
342 particularly in endurance athletes (Coyle, 2004). High fluid consumption (900 ml – similar to  
343 the volume utilized by Demura and colleagues) may also divert blood flow from the muscles  
344 activated during exercise to the gastrointestinal system, which may subsequently hinder  
345 running exercise performance (Backes & Fitzgerald, 2016). It is interesting to note that large  
346 fluid intakes appear to hinder running but not cycling performance (Backes & Fitzgerald,  
347 2016; Backx et al., 2003); this difference in exercise modes could be another explanation for  
348 the divergent results reported by Graham et al. (1998), who utilised a running test and  
349 reported no ergogenic effects of coffee, and Hodgson et al. (2013), who employed a cycling  
350 test and found coffee to be ergogenic.

351

352           A further complication regarding optimising the caffeine dose from coffee is the large  
353 variability in caffeine concentrations not just between coffee brands, but within the same  
354 brand over time (Desbrow et al., 2007; Desbrow et al., 2012; Desbrow et al., 2019). Desbrow  
355 and colleagues (2007) reported the average caffeine concentrations of 97 espresso samples  
356 collected across the Gold Coast, Australia. Whilst the mean caffeine dose per coffee was 106  
357 mg per serving, it ranged from 25 to 214 mg (Desbrow et al., 2007). In a follow up study, it  
358 was reported that coffees purchased at the same venue at different time points had highly  
359 variable caffeine concentrations, in one case varying from 81 mg to 189 mg of caffeine in the  
360 same product (Desbrow et al., 2012). At-home coffee making fairs no better, with a recent  
361 study (Desbrow et al., 2019) reporting caffeine concentrations of Nespresso coffee pods  
362 varying from 19 to 147 mg. Whilst this issue does not solely plague coffee (Desbrow et al.,  
363 2018), it increases the difficulty of accurate quantification of the caffeine dose ingested,  
364 which may have important implications in the development of caffeine habituation (Pickering  
365 & Kiely 2019), or the experience of negative side-effects, such as increased anxiety and  
366 reduced sleep quality (Pickering & Kiely, 2018).

367

368           Additionally, coffee is often consumed hot, which may affect thermoregulatory  
369 control during exercise, modifying exercise capacity and performance (Wimer et al., 1997;  
370 Mundel et al., 2006). As such, for athletes exercising in warm and/or humid temperatures,  
371 coffee may limit exercise performance, although, to our knowledge, this has yet to be  
372 explored experimentally, and any increase in core temperature may dissipate prior to the  
373 onset of exercise. Furthermore, both caffeine and coffee have the potential to act as gastric  
374 irritants (Boekema et al., 1999). The potential for gastric discomfort is potentially higher with  
375 coffee ingestion, given the multi-ingredient nature of coffee. Accordingly, especially in

376 coffee-naïve individuals, coffee may increase feelings of discomfort during exercise. As with  
377 any nutritional intervention, the use of coffee as an ergogenic aid should be trialed in training  
378 or competitions of lesser importance, and, similar to the “training of the gut” concept with  
379 carbohydrate ingestion (Jeukendrup, 2017), these issues could potentially be alleviated.

380

## 381 **6. Areas for further research**

382

383 Caffeine, and likely coffee, potentially exerts some of its ergogenic effects via  
384 expectancy and placebo (Shabir et al., 2018), such that when individuals believe they have  
385 consumed caffeine, and believe caffeine is ergogenic, their performance is often greater than  
386 if they believe they have not consumed caffeine (Saunders et al., 2017). As caffeine, ingested  
387 via capsules or coffee, may exert negative, performance-limiting side effects such as  
388 increased anxiety (Childs et al., 2008), the use of placebos to exert performance benefits in  
389 these cases may be advantageous, if not ethically challenging. Further research exploring the  
390 expectancy effects of caffeine, potentially using decaffeinated coffee or a coffee-like scent  
391 (Madzharov et al., 2018), may assist in bringing clarity to this area, particularly in situations  
392 where caffeine ingestion may be difficult, such as in the later stages of a prolonged endurance  
393 race.

394

395 Given the observations that lower doses of caffeine (i.e. <3 mg/kg) may be ergogenic  
396 for exercise performance (Lieberman et al., 1987; Spriet, 2014), more work is required to  
397 explore the minimal effective doses of both caffeine and caffeinated coffee. For example, if a  
398 caffeine dose of 2 mg/kg administered in the form of caffeinated coffee is ergogenic—and  
399 the research suggests it potentially is (Spriet, 2014)—it would require the ingestion of a much  
400 more reasonable volume of coffee (e.g. 1-2 espressos for a 70kg individual).

401

402 Future studies should also seek to explore the effects of cold brew or iced coffee  
403 compared to hot coffee on performance. This area might be relevant given the observations  
404 that cold water (4°C) ingestion, compared to water at room temperature (22°C), may result in  
405 different effects on bench press to muscle fatigue performance (Lafata et al., 2012). This  
406 could be especially important during exercise in hot temperatures, where ingestion of hot  
407 coffee may confer a performance limitation.

408

409 Additionally, a recent review (Loureiro et al., 2018) examined whether coffee  
410 components, primarily caffeine, caffeic acid, cafestol, and chlorogenic acid, may exert  
411 beneficial effects on muscle glycogen recovery post-exercise. Whilst the studies  
412 underpinning this review were primarily conducted in vitro or in rats, this is an area worthy  
413 of potential exploration, particularly if coffee outperforms caffeine anhydrous in this regard.  
414 However, a recent study (Nieman et al., 2018), in which participants were randomly assigned  
415 to receive either a high chlorogenic acid coffee or placebo for two weeks reported no  
416 beneficial effect of the coffee on post-exercise inflammation or oxidative stress, although  
417 there were moderate improvements in mood.

418

419 Finally, compared to research on caffeine anhydrous, there is a relative dearth of  
420 studies exploring the efficacy of coffee as the method of caffeine ingestion within exercise  
421 contexts. If active individuals are utilizing coffee as a method of ingesting caffeine—and the  
422 research suggests they are (Desbrow & Leveritt, 2006; Tunnicliffe et al., 2008)—it is  
423 important that we better understand the ergogenic effects, and potential interactions, of coffee  
424 on performance.

425

## 426 7. Conclusion

427

428 In summary, based on a small number of studies, it appears that:

429

- 430 1. Caffeinated coffee has the potential to offer ergogenic effects above placebo or  
431 decaffeinated coffee, at least in terms of aerobic exercise (Wiles et al., 1992; Hodgson  
432 et al., 2013; Graham et al., 1998).
- 433 2. There is limited evidence that caffeinated coffee offers a similar magnitude of  
434 ergogenic effect when compared to caffeine anhydrous (Hodgson et al., 2013),  
435 provided the caffeine doses are matched. However, the studies here are both  
436 conflicting and of low sample size, and therefore caution should be exercised with the  
437 interpretation of findings.
- 438 3. Prior or co-ingestion of decaffeinated coffee along with caffeine anhydrous does not  
439 appear to blunt caffeine's ergogenic effects (McLellan & Bell, 2004; Trice & Haynes,  
440 1995), although, from a practical standpoint, it is difficult to identify a situation in  
441 which this ingestion type would occur.

442

443 At present it appears that caffeinated coffee ingestion, approximately 60 minutes prior  
444 to exercise and delivering a typically ergogenic caffeine dose (i.e. 3-6 mg/kg), represents a  
445 potential method of enhancing aerobic endurance performance (Higgins et al., 2016;  
446 Hodgson et al., 2013), with some tentative positive findings for resistance and high-intensity  
447 exercise activities (Trexler et al., 2016; Richardson et al., 2016). However, the low number of  
448 overall studies, along with both low subject numbers and opposing findings, limit the strength  
449 of this conclusion. Additionally, coffee represents a number of practical hurdles regarding its  
450 use pre-exercise, including the ingestion of potentially high volumes of (often hot) liquid, or

451 highly concentrated brews which may irritate the gastrointestinal tract. Accurately  
452 quantifying the caffeine dose from coffee is also difficult (Desbrow et al., 2007; Desbrow et  
453 al., 2012; Desbrow et al., 2019), increasing the potential for negative side effects or a lack of  
454 ergogenic effect due to under-dosing with caffeine. Finally, there is the possibility that other  
455 constituents in coffee modify both performance and recovery, although this is poorly  
456 understood at this point. Accordingly, at present, for athletes who wish to do so, coffee  
457 appears to represent a useful method of caffeine ingestion around regular training, especially  
458 if they are habitual users of caffeine; for most individuals, consumption of ~3 mg/kg of  
459 caffeine (equivalent to approximately 2-3 espressos for a 60-70 kg individual) would likely  
460 be appropriate. However, the utilization of more controlled caffeine doses, requiring less  
461 liquid or concentration, may be advantageous around competitions.

462

### 463 **Novelty Statement & Practical Applications**

464

465 The findings of this review demonstrate that, whilst coffee, may, in some cases, offer  
466 similar ergogenic benefits to caffeine anhydrous (provided the caffeine dose is matched),  
467 these findings are based on a limited number of studies, with a large variability in findings. It  
468 also raises a number of practical issues regarding the use of coffee as a means of obtaining a  
469 pre-exercise dose of caffeine, including the ingestion of large amounts of liquid, variation in  
470 caffeine dose across brands, and within the same brand across time, and the consumption of a  
471 hot drink, which may affect thermoregulatory control; all of these require consideration by  
472 athlete, coach and nutritionist when determining the method of pre-exercise caffeine  
473 ingestion.

474

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## 476 Author Contributions

477 CP conceived of the idea underlying this manuscript, and authored the first draft. JG provided  
478 significant edits and writing assistance. Both authors approved the final manuscript prior to  
479 submission.

## 480 Conflicts of Interest

481 Craig Pickering and Jozo Grgic declare they have no conflicts of interest relevant to the  
482 content of this article.

483

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Study	Subjects	Habitual Caffeine Intake	Experimental Conditions	Coffee Brand	Performance Test	Outcome	Raw Performance Data
Anderson et al. (2018)	9 (7 male) experienced cyclists	316 ± 98 mg/day	Caffeinated coffee (6 mg/kg caffeine) compared to decaffeinated coffee	Starbucks VIA Ready Brew Italian Roast	30-second Wingate test	No significant effect of caffeinated coffee on peak power, mean power, and fatigue index.	<i>Peak power (W)</i> Caffeinated coffee: 942 ± 174 Decaffeinated coffee: 923 ± 168 <i>Mean power (W)</i> Caffeinated coffee: 754 ± 150 Decaffeinated coffee: 755 ± 156
Demura et al. (2007)	10 healthy young adults	Not presented	Caffeinated coffee (6 mg/kg caffeine) compared to decaffeinated coffee	Not specified	60 minutes cycle ergometer sub-maximal exercise @ 60% VO <sub>2max</sub>	RPE was lower in caffeinated vs decaffeinated coffee.	N/A
Wiles et al. (1992)	18 male athletes	Not presented	3g instant coffee (~150-200mg caffeine) vs 3g decaffeinated instant coffee	Not specified	1500m time trial treadmill run	Caffeinated coffee significantly improved performance compared to decaffeinated coffee	<i>Time to run 1500m (sec)</i> Caffeinated coffee: 286 ± 32 Decaffeinated coffee: 290 ± 33
Wiles et al. (1992)	10 male athletes	Not presented	3g instant coffee (~150-200mg caffeine) vs 3g	Not specified	1100m high intensity run, with 400m	Caffeinated coffee significantly (p < 0.05)	<i>Speed of final min (km/h)</i> Caffeinated coffee: 24 ± 2

			decaffeinated instant coffee		“finishing burst”	improved performance compared to decaffeinated coffee	Decaffeinated coffee: 23 ± 2
Wiles et al. (1992)	6 male middle-distance athletes	Not presented	3g instant coffee (~150-200mg caffeine) vs 3g decaffeinated instant coffee	Not specified	1500m high intensity run at predetermined speed	Caffeinated coffee significantly ( $p < 0.025$ ) improved performance compared to decaffeinated coffee	N/A
Clarke et al. (2018)	13 trained middle-distance runners	171 ± 250 mg/day	0.09 g/kg coffee (~3 mg/kg caffeine), decaffeinated coffee, or placebo	Nescafé Original, Nestlé	Competitive one-mile run	Race time was significantly faster in the caffeinated vs decaffeinated ( $p = 0.018$ ) and placebo ( $p = 0.006$ ) trials.	<i>Race completion time (min:s.ms)</i> Caffeinated coffee: 04:35:37 ± 00:10:51 Decaffeinated coffee: 04:39:14 ± 00:11:21 Placebo: 04:41:00 ± 00:09:57
Marques et al. (2018)	12 well-trained adult males	Average intake of 91 mg/day	Caffeinated coffee (5.5 mg/kg caffeine) vs decaffeinated coffee	Nescafé, Nestlé.	800m running time trial	No difference in time trial performance between treatments.	<i>Time trial performance (min)</i> Caffeinated coffee: 2.39 ± 0.09 Decaffeinated coffee: 2.38 ± 0.10
Lamina and Musa (2009)	20 male young adults	Not presented	Caffeinated coffee (5, 10 and 15 mg/kg caffeine)	Capra Nescafe	20-meter shuttle run test	No significant effect of caffeine on performance	Not presented

			compared to placebo				
Church et al. (2015)	Twenty subjects (10 females)	277 ± 183 mg	Turkish coffee (providing 3 mg/kg caffeine) or decaffeinated coffee	Strauss Coffee	5km running time trial, reaction to visual stimuli tests, and object tracking	Upper body reaction performance was significantly higher in the caffeinated vs decaffeinated coffee trials. No differences were reported in other performance tests.	<i>Time trial performance (seconds)</i> Caffeinated coffee: 1685 ± 217 Decaffeinated coffee: 1717 ± 256
Graham et al. (1998)	9 (8 male) young adult (21-47 y) trained endurance runners	One participant with no caffeine intake, two “light” users (<100 mg/day) and the remaining were “moderate” users (<500 mg/day)	4.45 mg/kg, as either caffeine capsules, caffeinated coffee, or decaffeinated coffee + caffeine	Not specified	5 treadmill trials to exhaustion @ 85% VO <sub>2max</sub>	Caffeine capsule ingested significantly enhanced endurance performance compared to other trials.	<i>Total running time (min)</i> Decaffeinated coffee: 34 ± 12 Decaffeinated coffee + caffeine: 34 ± 11 Caffeinated coffee: 34 ± 12 Placebo: 30 ± 12 Caffeine: 40 ± 12
Richardson & Clarke (2016)	9 resistance trained males	241 ± 122 mg	Caffeinated coffee (0.15 g/kg; ~5 mg/kg caffeine),	Nescafé Original coffee	Squat and bench press repetitions to	Caffeinated coffee enhanced performance	<i>Bench press (repetitions)</i>

			caffeine (5 mg/kg), caffeine (5 mg/kg) + decaffeinated coffee, and decaffeinated coffee		failure @ 60% 1RM	compared to placebo, but not compared to decaffeinated coffee. Decaffeinated coffee and caffeine consumed in combination significantly enhanced performance compared to decaffeinated coffee, placebo, and caffeine alone.	Caffeinated coffee: 13 ± 2 Caffeine: 13 ± 2 Decaffeinated coffee + caffeine: 12 ± 3 Decaffeinated coffee: 12 ± 2 Placebo: 12 ± 2 <i>Squat (repetitions)</i> Caffeinated coffee: 17 ± 5 Caffeine: 15 ± 5 Decaffeinated coffee + caffeine: 18 ± 5 Decaffeinated coffee: 14 ± 5 Placebo: 13 ± 4
Hodgson et al. (2013)	8 trained male cyclists/triathletes	≤300 mg	Caffeine (5 mg/kg), compared to caffeinated coffee (providing 5 mg/kg caffeine), decaffeinated coffee, and placebo.	Nescafé Original coffee	30 minutes steady state cycling, followed by 45-minute time trial	Performance in the time trial was significantly faster for both caffeine and caffeinated coffee trials compared to decaffeinated coffee and placebo, with no real difference	<i>Time trial finishing time (min)</i> Caffeine: 38 ± 1 Caffeinated coffee: 38 ± 2 Decaffeinated coffee: 40 ± 2 Placebo: 40 ± 1 <i>Mean power output (W)</i> Caffeine: 294 ± 17 Caffeinated coffee: 291 ± 20

						between the two.	Decaffeinated coffee: 276 ± 20 Placebo: 277 ± 11
Clarke et al. (2016)	12 recreationally active males	Not presented	Caffeine (3 mg/kg) compared to coffee (providing 3 mg/kg caffeine), placebo, and control	Nescafé Original coffee	18 x 4-second cycle ergometer sprints	No significant differences in peak or mean power output, or RPE, between all experimental conditions.	<i>Peak power (W)</i> Caffeinated coffee: 949 ± 174 Placebo: 971 ± 149 Caffeine: 949 ± 199 Control: 975 ± 170 <i>Mean power (W)</i> Caffeinated coffee: 862 ± 44 Placebo: 887 ± 119 Caffeine: 873 ± 172 Control: 892 ± 143

827 Table 1 - Studies comparing caffeinated coffee compared to placebo/decaffeinated coffee; VO<sub>2max</sub> maximum oxygen uptake; RPE rating of  
 828 perceived exertion, 1RM one-repetition maximum.

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Study	Subjects	Habitual caffeine intake	Experimental Conditions	Coffee Brand	Performance Test	Outcome	Raw Performance Data
Graham et al. (1998)	9 (8 male) young adult (21-47 y) trained endurance runners	One participant with no caffeine intake, two “light” users (<100 mg/day) and the remaining were “moderate” users (<500 mg/day)	4.45 mg/kg, as either caffeine capsules, caffeinated coffee, or decaffeinated coffee + caffeine	Not specified	5 treadmill trials to exhaustion @ 85% VO <sub>2max</sub>	Caffeine capsule ingested significantly enhanced endurance performance compared to other trials.	<i>Total running time (min)</i> Decaffeinated coffee: 34 ± 12 Decaffeinated coffee + caffeine: 34 ± 11 Caffeinated coffee: 34 ± 12 Placebo: 30 ± 12 Caffeine: 40 ± 12
Trexler et al. (2016)	54 resistance trained males	33 ± 60 mg	300 mg caffeine (3-5 mg/kg) compared to 8.9g coffee (303 mg caffeine) and placebo.	Nescafé House Blend	1 RM and repetitions to fatigue @ 80% 1RM on bench press and leg press, alongside 5 x 10-second cycle ergometer sprints	No beneficial effect of coffee or caffeine on strength performance, and no difference between the two, except for leg press 1RM, where coffee outperformed caffeine, but not placebo. Total work in	<i>Leg press 1RM (kg) pre</i> Caffeine: 284 ± 63 Coffee: 309 ± 86 Placebo: 279 ± 69 <i>Leg press 1RM (kg) post</i> Caffeine: 291 ± 64 Coffee: 324 ± 86 Placebo: 293 ± 68 <i>Bench press 1RM (kg) pre</i> Caffeine: 93 ± 19 Coffee: 96 ± 18 Placebo: 87 ± 17

						the sprint test decreased with placebo ingestion, but not with caffeine or coffee.	<i>Bench press 1RM (kg) post</i> Caffeine: 95 ± 19 Coffee: 97 ± 18 Placebo: 89 ± 17
Richardson & Clarke (2016)	9 resistance trained males	241 ± 122 mg	Caffeinated coffee (0.15 g/kg; ~5 mg/kg caffeine), caffeine (5 mg/kg), caffeine (5 mg/kg) + decaffeinated coffee, and decaffeinated coffee	Nescafé Original coffee	Squat and bench press repetitions to failure @ 60% 1RM	Caffeinated coffee enhanced performance compared to placebo, but not compared to decaffeinated coffee. Decaffeinated coffee and caffeine consumed in combination significantly enhanced performance compared to decaffeinated coffee, placebo, and caffeine alone.	<i>Bench press (repetitions)</i> Caffeinated coffee: 13 ± 2 Caffeine: 13 ± 2 Decaffeinated coffee + caffeine: 12 ± 3 Decaffeinated coffee: 12 ± 2 Placebo: 12 ± 2 <i>Squat (repetitions)</i> Caffeinated coffee: 17 ± 5 Caffeine: 15 ± 5 Decaffeinated coffee + caffeine: 18 ± 5 Decaffeinated coffee: 14 ± 5 Placebo: 13 ± 4
Hodgson et al. (2013)	8 trained male cyclists/triathletes	≤300 mg	Caffeine (5 mg/kg), compared	Nescafé Original coffee	30 minutes steady state	Performance in the time trial	<i>Time trial finishing time (min)</i>

			to caffeinated coffee (providing 5 mg/kg caffeine), decaffeinated coffee, and placebo.		cycling, followed by 45-minute time trial	was significantly faster for both caffeine and decaffeinated coffee trials compared to decaffeinated coffee and placebo, with no real difference between the two.	Caffeine: 38 ± 1 Caffeinated coffee: 38 ± 2 Decaffeinated coffee: 40 ± 2 Placebo: 40 ± 1 <i>Mean power output (W)</i> Caffeine: 294 ± 17 Caffeinated coffee: 291 ± 20 Decaffeinated coffee: 276 ± 20 Placebo: 277 ± 11
Clarke et al. (2016)	12 recreationally active males	Not presented	Caffeine (3 mg/kg) compared to coffee (providing 3 mg/kg caffeine), placebo, and control	Nescafé Original coffee	18 x 4-second cycle ergometer sprints	No significant differences in peak or mean power output, or RPE, between all experimental conditions.	<i>Peak power (W)</i> Caffeinated coffee: 949 ± 174 Placebo: 971 ± 149 Caffeine: 949 ± 199 Control: 975 ± 170 <i>Mean power (W)</i> Caffeinated coffee: 862 ± 44 Placebo: 887 ± 119 Caffeine: 873 ± 172 Control: 892 ± 143

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Table 2 - Studies comparing caffeine with caffeinated coffee; RPE rating of perceived exertion; 1RM one-repetition maximum;  $VO_{2max}$  maximum oxygen uptake.

Study	Subjects	Habitual caffeine intake	Experimental Conditions	Coffee Brand	Performance Test	Outcome	Raw Performance Data
Butts & Crowell (1985)	28 active subjects (15 female)	Not presented	300 mg caffeine + decaffeinated coffee, compared to decaffeinated coffee	Not specified	Time to exhaustion cycle ergometer test @ ~75% $VO_{2max}$	Caffeine increased time to exhaustion, although these changes were not significant	<i>Time of exercise (min)</i> <i>Females</i> Caffeine + decaffeinated coffee: 69 ± 23 Decaffeinated coffee: 60 ± 27 <i>Males</i> Caffeine + decaffeinated coffee: 70 ± 32 Decaffeinated coffee: 68 ± 33
Graham et al. (1998)	9 (8 male) young adult (21-47 y) trained endurance runners	One participant with no caffeine intake, two "light" users (<100 mg/day) and the remaining were "moderate" users (<500 mg/day)	4.45 mg/kg, as either caffeine capsules, caffeinated coffee, or decaffeinated coffee + caffeine	Not specified	5 treadmill trials to exhaustion @ 85% $VO_{2max}$	Caffeine capsule ingested significantly enhanced endurance performance compared to other trials.	<i>Total running time (min)</i> Decaffeinated coffee: 34 ± 12 Decaffeinated coffee + caffeine: 34 ± 11 Caffeinated coffee: 34 ± 12 Placebo: 30 ± 12 Caffeine: 40 ± 12

Richardson & Clarke (2016)	9 resistance trained males	241 ± 122 mg	Caffeinated coffee (0.15 g/kg; ~5 mg/kg caffeine), caffeine (5 mg/kg), caffeine (5 mg/kg) + decaffeinated coffee, and decaffeinated coffee	Nescafé Original coffee	Squat and bench press repetitions to failure @ 60% 1RM	Caffeinated coffee enhanced performance compared to placebo, but not compared to decaffeinated coffee. Decaffeinated coffee and caffeine consumed in combination significantly enhanced performance compared to decaffeinated coffee, placebo, and caffeine alone.	<p><i>Bench press (repetitions)</i>  Caffeinated coffee: 13 ± 2  Caffeine: 13 ± 2  Decaffeinated coffee + caffeine: 12 ± 3  Decaffeinated coffee: 12 ± 2  Placebo: 12 ± 2</p> <p><i>Squat (repetitions)</i>  Caffeinated coffee: 17 ± 5  Caffeine: 15 ± 5  Decaffeinated coffee + caffeine: 18 ± 5  Decaffeinated coffee: 14 ± 5  Placebo: 13 ± 4</p>
McLellan and Bell (2004)	13 subjects (9 male)	608 ± 446 mg	Decaffeinated coffee + placebo, decaffeinated coffee + caffeine (5 mg/kg), coffee (1.1 mg/kg caffeine) + caffeine (5 mg/kg), coffee +	Royal Blend	Cycle ergometer time to exhaustion @ 80% VO <sub>2max</sub>	Prior consumption of coffee did not reduce the subsequent ergogenic effect of anhydrous caffeine.	<p><i>Time to exhaustion (min)</i>  Decaffeinated coffee + placebo: 22 ± 8  Decaffeinated coffee + caffeine (5 mg/kg): 29 ± 7</p>

			caffeine (3 mg/kg), coffee + caffeine (7 mg/kg), placebo + caffeine (5 mg/kg).				Coffee (1.1 mg/kg caffeine) + caffeine (5 mg/kg): $28 \pm 11$ Coffee + caffeine (3 mg/kg): $25 \pm 8$ Coffee + caffeine (7 mg/kg): $26 \pm 8$ Placebo + caffeine (5 mg/kg): $27 \pm 8$
Trice and Haymes (1995)	8 trained male subjects	Non regular caffeine users	5 g decaffeinated coffee + 5 mg/kg caffeine, compared to 7g decaffeinated coffee	Sanka	3 x 30-min cycle ergometer trials @ 70 rpm	Time to exhaustion was significantly longer in the caffeine compared to no caffeine trial	<i>Time to exhaustion (min)</i> Caffeine + decaffeinated coffee: $78 \pm 15$ Decaffeinated coffee: $61 \pm 6$
Costill et al. (1978)	9 competitive cyclists (7 males)	Not presented	Coffee + 330 mg caffeine anhydrous, compared to decaffeinated coffee	Not specified	Cycle ergometer time to exhaustion task @ 80% $VO_{2max}$	Subjects were able to perform significantly more work in the caffeine vs decaffeinated coffee trial	<i>Time to exhaustion (min)</i> Caffeine + decaffeinated coffee: $90 \pm 22$ Decaffeinated coffee: $76 \pm 15$

851 Table 3 – Studies comparing the ergogenic effects of caffeine added to decaffeinated coffee, compared to decaffeinated coffee alone, or placebo;  
852  $VO_{2max}$  maximum oxygen uptake; 1RM one-repetition maximum