A meta-analysis on the effects of caffeine ingestion on swimming performance

A meta-analysis on the effects of caffeine ingestion on swimming performance

Abstract

Purpose – Caffeine is a popular ergogenic aid, but its effects on swimming performance are not yet fully clear. Therefore, the aim of this review was to examine the effects of caffeine on swimming performance.

Design/methodology/approach – Crossover placebo-controlled studies that explored the effects of caffeine on swimming performance were included. Six databases were searched to find relevant studies with additional forward and backward citation tracking. The data were pooled in a random-effects meta-analysis.

Findings – Eight studies were included in the review. The main meta-analysis showed a significant ergogenic effect of caffeine ingestion on swimming performance (Cohen's *d*: –0.20; 95% confidence interval: –0.32, –0.08; *p* = 0.0008; –1.7%). In the analysis for short-distance swimming events, caffeine ingestion had a significant ergogenic effect on swimming performance (Cohen's *d*: –0.14; 95% confidence interval: –0.27, –0.01; *p* = 0.03; –1.4%). An ergogenic effect of caffeine was also found in the analysis for moderate-to-long swimming distance events (Cohen's *d*: –0.36; 95% confidence interval: –0.67, –0.05; *p* = 0.02; –2.2%).

Originality/value – The present meta-analysis found that caffeine ingestion decreases the time needed to complete a given swimming event. While these ergogenic effects may be classified as small, they are likely important in swimming, where narrow margins commonly determine placings.

Keywords: supplements; exercise; performance; nutrition

1. Introduction

Caffeine is a highly popular ergogenic aid (Grgic *et al*., 2020). The performance-enhancing effects of caffeine are well-established for various components of exercise performance, including muscular strength and muscular endurance, power, jumping performance, and aerobic endurance (Grgic *et al*., 2020). Most commonly, caffeine is provided in doses from 3 to 6 mg/kg, though even lower doses may be ergogenic (Grgic, 2021). In research, caffeine is frequently provided in caffeine capsules or as caffeine anhydrous mixed in with liquid (e.g., part of an "energy drink") (Guest *et al*., 2020). However, even other forms of caffeine, such as caffeinated chewing gums and gels, may also enhance performance (Venier *et al*., 2019; Wickham *et al*., 2018). Caffeine has a similar molecular structure to adenosine (McLellan *et al*., 2016). After consumption, caffeine binds to adenosine receptors and alleviates feelings of fatigue, which contributes to improvements in exercise performance (McLellan *et al*., 2016). Therefore, it is generally accepted that caffeine exerts its effects by blocking adenosine receptors (McLellan *et al*., 2016).

Competitive swimming is a single-bout event. It includes swimming at varying distances (e.g., 100-m swimming, 200-m swimming) using different styles. In competitive swimming, narrow margins commonly determine final placings (Trewin *et al*., 2004). This notion is illustrated by the results of the finales in the 200-m butterfly stroke at the 2016 Olympic Games, where the difference between first and second place was 0.04 s (1:53.36 vs. 1:53.40-min). Due to the small differences in placings observed in competitive swimming, the use of ergogenic aids in this sport is likely to be of substantial practical importance. Indeed, it is reported that swimmers commonly use a high number of dietary supplements (Shaw *et al*., 2016). One highly popular supplement is caffeine, which is used by athletes from many different sports (Aguilar-Navarro *et al*., 2019). Several reviews concluded that swimmers are likely to benefit from caffeine supplementation (Derave and Tipton, 2014). However, while the ergogenic effects of caffeine on different components of exercise performance (e.g., aerobic and muscular endurance, jumping performance) are well-established, closer scrutiny of the current body of evidence highlights that the effects of caffeine on swimming performance are not yet clear.

One study reported that caffeine ingestion (3 mg/kg) 60 min before exercise reduced the time needed to complete 75-m of swimming by 0.36 s (Goods *et al*., 2017). However, other studies reported no significant difference between the effects of caffeine and placebo on swimming performance (Alkatan, 2020; Pruscino *et al*., 2008). While factors such as caffeine dose and timing of ingestion may explain these contrasting findings, it should also be considered that small sample sizes are a mainstay in studies exploring the effects of supplements on exercise performance (Maughan *et al*., 2018). Indeed, one of the studies that explored the effects of caffeine on swimming performance and did not observe an ergogenic effect included a sample of only six swimmers (Pruscino *et al*., 2008). This might have led to a type II error, especially since the data highly favored the caffeine trial (Cohen's *d*: –0.42; –1.1%).

The limitation of small sample sizes can be addressed by conducting a meta-analysis, which allows pooling outputs from different studies on a given topic (Maughan *et al*., 2018). While several meta-analyses examined the effects of caffeine on different components of exercise performance, such an analysis for swimming is currently absent (Grgic *et al*., 2018; Polito *et al*., 2016; Shen *et al*., 2019). One meta-analysis examined the effects of caffeine on reducing the time needed to complete different endurance events and reported an ergogenic effect of this supplement (Christiansen *et al*., 2017). However, out of the ten included studies, only one evaluated swimming performance, while all other studies used either running or rowing tasks. Given the outlined limitations in the literature, this review aimed to conduct a meta-analysis examining the effects of caffeine supplementation on swimming performance.

2. Materials and methods

2.1 Search strategy

The search for studies that explored the effects of caffeine on swimming performance was carried out in two phases. Initially, the search was performed through six bibliographic databases, including: Networked Digital Library of Theses and Dissertations, Open Access Theses and Dissertations, PubMed/MEDLINE, Scopus, SPORTDiscus, and Web of Science. The search syntax in all of these databases included the following keywords: (caffeine OR coffee) AND (swim OR swimming OR swimmers). The search in the databases was performed on September 20th 2021. Then, as a part of the second phase, reference lists from all included studies were screened, and forward citation searching was conducted using the Google Scholar database (examining the studies that cited the included studies).

2.2 Inclusion criteria

Studies were included in the review if they satisfied the following criteria: (1) examined the effects of caffeine supplementation on single-bout swimming performance, expressed as the time needed to complete a given swimming event; (2) utilized a placebo-controlled and crossover study design; and (3) included humans as study participants.

2.3 Data extraction

From each included study, the following data were extracted: (1) year of study publication and lead author name; (2) participants characteristics (e.g., sex, training status); (3) caffeine supplementation protocol; (4) swimming performance test; and (5) mean ± standard deviation for the swimming time from the caffeine and placebo trials.

2.4 Methodological quality

The 11-item PEDro checklist was utilized to evaluate the methodological quality of the included studies (Maher *et al*., 2003). This checklist assesses different methodological aspects, including inclusion criteria, randomization, allocation concealment, blinding of participants and assessors, attrition, and data reporting. All items of the PEDro checklist are scored as "1" (criterion is satisfied) or "0" (criterion is not satisfied). Because the first item is not included in the total score, the maximum possible number of points is 10. Studies were classified as poor, fair, good, or excellent quality if they scored ≤3 points, 4–5 points, 6–8 points, and 9–10 points, respectively (Grgic, 2018).

2.5 Statistical analysis

The meta-analysis was performed using effect sizes (Cohen's *d*). In order to calculate Cohen's *d* effect sizes, the following data are needed: (1) mean ± standard deviation swimming time from the caffeine and placebo trials; (2) sample size; and (3) correlation between the trials. As the correlation between the trials was not reported among the included studies, these values were estimated per recommendations provided in the Cochrane Handbook (2011). In the main meta-analysis, data from all studies were pooled. In a sensitivity analysis, the pooled effects were examined after excluding the data from one study that was not published (i.e., thesis) and that provided caffeine supplementation in the form of caffeinated chewing gum (Serpa, 2018). Subgroup meta-analyses explored the effects of caffeine in short-distance swimming tests (25 to 75-m swimming) and in moderate-to-long distance events (200 to 1500-m swimming). The interpretation of effect sizes was based on the following thresholds: trivial (<0.20), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80) (Cohen, 1992). Negative Cohen's *d* values denote favoring of the caffeine (i.e., decrease in the time needed to complete the swimming test). Meta-analyses were performed using the random-effects model. I^2 statistic was used to evaluate heterogeneity. I^2 values were interpreted as low (<50%), moderate (50–75%), and high heterogeneity (>75%). The statistical significance threshold was set at $p < 0.05$. All analyses were performed using the Comprehensive Meta-analysis software, version 2 (Biostat Inc., Englewood, NJ, USA).

3. Results

3.1 Search results

In the first phase of the search process (i.e., database searching), there were 815 results. Out of this pool of articles, 14 full-text studies were read, and six studies (Goods *et al*., 2017; Lara *et al*., 2015; MacIntosh and Wright, 1995; Potgieter *et al*., 2018; Pruscino *et al*., 2008; Vanata *et al*., 2014) were included. In the screening of the reference lists, there were 315 search results, but none of these studies were found to satisfy the inclusion criteria. Finally, out of the 324 results in the forward citation searching phase, two studies (Alkatan, 2020; Serpa, 2018) were additionally included (Figure 1). Thus, a total of eight studies were included in the review and meta-analysis (Alkatan, 2020; Goods *et al*., 2017; Lara *et al*., 2015; MacIntosh and Wright, 1995; Potgieter *et al*., 2018; Pruscino *et al*., 2008; Serpa, 2018; Vanata *et al*., 2014).

3.2 Summary of studies

Sample sizes in the included studies ranged from 6 to 30 participants. The pooled number of participants across all studies was 124 (30 female and 94 males). The training status of the participants varied, with studies including national level or Division II collegiate swimmers, distance swimmers, triathletes, or elite swimmers. For the performance events, studies used freestyle swimming distances of 25 m, 45.7 m (50 yards), 50 m, 75 m, 200 m, and 1500 m. For studies that provided supplementation relative to body mass, caffeine doses ranged from 3 to 6 mg/kg. Two studies (Alkatan, 2020; Serpa, 2018) used absolute doses of 250 or 300 mg. Caffeine was most commonly provided 60 min before exercise, even though one study (Serpa, 2018) used caffeine chewing gum provided 5 min before exercise. Timing of ingestion in other studies was 30, 45, or 90-120 min before swimming events (Table 1).

3.3 Methodological quality

Six studies scored 9 points on the PEDro checklist and were classified as having excellent methodological quality (Table 2). Two studies scored 7 points and were classified as having good methodological quality (Table 2).

3.4 Meta-analysis results

In the main meta-analysis, there was a significant ergogenic effect of caffeine ingestion on swimming performance (Cohen's *d*: –0.20; 95% confidence interval: –0.32, –0.08; p = 0.0008; I^2 = 54%; –1.7%; Figure 2). These results remained consistent in the sensitivity analysis. In the analysis for short-distance swimming events, there was a significant ergogenic effect of caffeine ingestion on swimming performance (Cohen's *d*: –0.14; 95% confidence interval: –0.27, –0.01; p = 0.03; I^2 = 39%; –1.4%). An ergogenic effect of caffeine was also found in the analysis for moderate-to-long swimming distance events (Cohen's *d*: –0.36; 95% confidence interval: –0.67, –0.05; $p = 0.02$; $I^2 = 64\%$; –2.2%).

4. Discussion

The main finding of this meta-analysis is that caffeine supplementation has a significant ergogenic effect on swimming performance. Specifically, it was observed that caffeine ingestion reduces the time needed to complete a given swimming event. In addition, subgroup analyses that explored distance-dependent effects found an ergogenic effect in short-distance and moderate-to-long swimming distances. While these ergogenic effects may be classified as small (Cohen's *d*: –0.14 to –0.36; –1.4% to –2.2%), they are likely important in swimming, where narrow margins commonly determine placings. In all included studies, the effects were toward the "favors caffeine" side of the forest plot, which highlights that the data are convincingly suggesting an ergogenic effect of caffeine consumption on swimming performance.

A study by Trewin *et al*., (2004) modeled world-ranking time and best time from the 2000 Olympic Games for top-50 world-ranked swimmers. Analysis of these data reported that improvements in swimming performance as small as 0.6% might have a practically relevant effect on event outcomes (Trewin *et al*., 2004). When comparing these data with the findings observed herein, it seems clear that caffeine may be a worthwhile supplement for swimmers. However, before making such direct generalizations, we first need to consider the characteristics of the participants in the included studies. Studies generally included collegiate or national levels swimmers, but they were not world-ranked swimmers. One study (Pruscino *et al*., 2008) involved elite male freestyle swimmers and did not report an ergogenic effect of caffeine, which might be due to the small sample size ($n = 6$) and not training status *per se*.

This may indeed be the case, given that the data highly favored the caffeine trial (1.35 s reduction in swimming time compared to placebo). Overall, caffeine ingestion improves swimming performance and is likely a worthwhile supplement for swimmers, even though future studies are needed to explore these effects in elite swimmers.

An ergogenic effect of caffeine was found in the analysis for short-distance swimming events (Cohen's *d*: –0.14) and moderate-to-long distances (Cohen's *d*: –0.36). Based on this comparison of results, it seems that the overall effects of caffeine are greater in longer distance events. This notion has support from a physiological perspective, given that caffeine primarily improves performance by attenuating exercise-induced fatigue (Glade, 2010). Indeed, data also indicate that the effects of caffeine on endurance performance in cycling and running increase along with the increasing duration of the time-trial event (Shen *et al*., 2019). Nevertheless, it also needs to be considered that the 95% confidence intervals reported in the different subgroup analyses overlapped, which does not allow us to make firm conclusions about the distance-specific effects of caffeine. Therefore, this gap should be addressed in future studies, which may consider using multiple distances in the same cohort of athletes to evaluate swimming performance. Another option to explore the distance-specific effects of caffeine is to use a long-distance event (e.g., 1500-m swimming) and analyze the splits for each distance (e.g., every 500 m). Such an approach was adopted by one study (MacIntosh and Wright, 1995) where caffeine reduced the time to complete 0–500-m, 500–1000-m, and 1000–1500-m swimming by 5 s, 6 s, and 12 s, respectively. Based on these results, it seems caffeine may indeed have greater effects in longer distance events, even though a limitation with this approach is the use of different pacing strategies (i.e., all-out effort might not occur at each split) (Lara and Del Coso, 2021).

The present meta-analysis only explored the effects of caffeine on single-bout swimming. This approach was adopted given that competitive swimming is a single-bout event. However, these data do not provide insights into the effects of caffeine on interval swimming, which is relevant for the interval-based training practices of swimmers (Sperlich *et al*., 2010). One of the included studies explored the effects of caffeine on swimming performance in 6 × 75-m swimming events interspersed with 10-min rest intervals (Goods *et al*., 2017). This study reported that caffeine ingestion was ergogenic in interval swimming, with the largest effect sizes observed in intervals 3 and 4 (Cohen's *d*: 0.84–1.02), likely owing to the caffeine-induced attenuation of fatigue with repeated intervals. Therefore, it seems that caffeine ingestion enhances single-bout and interval swimming performance, highlighting that this supplement may be used both in competition and training.

It is reported that swimmers commonly use a high number of dietary supplements. For example, one study reported an average use of 9 different dietary supplements among 39 elite Australian swimmers (Shaw *et al*., 2016). Given the high number of supplements ingested by swimmers, future studies are needed to explore the effects of caffeine in combination with other supplements on swimming performance (Burke, 2017). A recent meta-analysis (Grgic and Mikulic, 2021b) reported that sodium bicarbonate ingestion reduces the time needed to complete 200 to 400-m swimming (Cohen's *d*: –0.22; –1.3%). When ingested in isolation, both caffeine and sodium bicarbonate seem to have similar effects on swimming performance (Grgic *et al*., 2021). Therefore, future studies may consider exploring if their combined ingestion has any additive effects. Besides sodium bicarbonate, future studies may consider exploring the effects of caffeine combined with creatine, taurine, beta-alanine and other ergogenic aids (Karayigit *et al*., 2021; Maughan *et al*., 2018).

Chronic caffeine consumption has been associated with an upregulation of adenosine receptors (Svenningsson *et al*., 1999). Due to these effects, it is suggested that caffeine's ergogenic effects may attenuate over time (Guest *et al*., 2021). Indeed, some studies have reported an absence/attenuation of caffeine's ergogenic effects among habitual caffeine users, even though the evidence base on the topic is equivocal (Bell and McLellan, 2001; Grgic and Mikulic, 2021a; Karayiğit *et al*., 2021). Among the included studies, an ergogenic effect of caffeine was observed among low and high habitual caffeine users (Lara *et al*., 2015; Potgieter *et al*., 2018). However, the included studies also varied in other methodological aspects that could impact the treatment effect independent of habitual caffeine intake (e.g., caffeine dose, swimming test). Therefore, future studies should consider directly comparing the effect of caffeine among swimmers with varying habitual caffeine intakes. Finally, as the included studies differed in caffeine doses provided to the participants, future dose-response studies are needed to establish the optimal dose of caffeine on swimming performance.

4.1 Methodological quality

The included studies were classified as good or excellent methodological quality. Therefore, the findings presented herein are not confounded by the inclusion of studies with poor methodological quality. Of the eight included studies, six used a double-blind design, while two used a single-blind design (Goods *et al*., 2017; Vanata *et al*., 2014). However, these differences in blinding did not likely influence the results as the pooled effects in the two single-blind studies (Cohen's *d*: 0.06 and 0.36) were very similar to the effects reported in double-blind studies (Cohen's *d*: 0.06 to 0.57). Even though the participants were blinded to the treatments in all studies, only three studies (Goods *et al*., 2017; Lara *et al*., 2015; Pruscino *et al*., 2008) explored the effectiveness of this blinding. These studies reported that 36% to 66% of the participants correctly identified the caffeine and placebo trials, suggesting a moderate success in blinding. Future studies also need to incorporate this procedure, given that correct supplement identification may influence exercise outcomes and lead to bias in the results (Saunders *et al*., 2016).

5. Conclusion

The present meta-analysis found that caffeine ingestion has a significant ergogenic effect on swimming performance. Specifically, this analysis found that caffeine ingestion decreases the time needed to complete a given event. In addition, an ergogenic effect of caffeine was found on swimming performance in short distances and moderate-to-long distances. While these ergogenic effects may be classified as small, they are likely important in swimming, where narrow margins commonly determine placings.

Conflict of interest: no potential conflicts of interest in the development and publication of this article.

References

Aguilar-Navarro, M., Muñoz, G., Salinero, J.J., Muñoz-Guerra, J., Fernández-Álvarez, M., Plata, M.D.M., and Del Coso, J. (2019), "Urine caffeine concentration in doping control samples from 2004 to 2015", *Nutrients*, Vol. 1 No. 2, pp. 286.

Alkatan, M. (2020), "The effect of caffeine on swimming speed", *Journal of Physical Education Research,* Vol. 7 No. 4, pp. 24-29.

Bell, D.G. and McLellan, T.M. (2002), "Exercise endurance 1, 3, and 6 h after caffeine ingestion in caffeine users and nonusers", *Journal of Applied Physiology*, Vol. 93 No. 4, pp. 1227-1234.

Burke, L.M. (2017), “Practical issues in evidence-based use of performance supplements: supplement interactions, repeated use and individual responses”, *Sports Medicine,* Vol. 47 No. 47, pp. 79-100.

Christensen, P.M., Shirai, Y., Ritz, C., and Nordsborg, N.B. (2017), “Caffeine and bicarbonate for speed. A meta-analysis of legal supplements potential for improving intense endurance exercise performance”, *Frontiers in Physiology,* Vol. 8, pp. 240.

Cohen, J. (1992), “A power primer”, *Psychological Bulletin,* Vol. 112 No. 1, pp. 155-159.

Derave, W., and Tipton, K.D. (2014), “Dietary supplements for aquatic sports”, *International Journal of Sport Nutrition and Exercise Metabolism,* Vol. 24 No. 4, pp. 437-449.

Domínguez, R., Jesús-Sánchez-Oliver, A., Cuenca, E., Jodra, P., Fernandes da Silva, S., and Mata-Ordóñez, F. (2017), “Nutritional needs in the professional practice of swimming: a review”, *Journal of Exercise Nutrition & Biochemistry,* Vol. 21 No. 4, pp. 1-10.

Glade, M.J. (2010), “Caffeine-Not just a stimulant”, *Nutrition,* Vol. 26 No. 10, pp. 932-938.

Goods, P.S., Landers, G., and Fulton, S. (2017), “Caffeine ingestion improves repeated freestyle sprints in elite male swimmers”, *Journal of Sports Science and Medicine,* Vol. 16 No. 1, pp. 93-98.

Grgic, J. (2018), “Caffeine ingestion enhances Wingate performance: a meta-analysis”, *European Journal of Sport Science,* Vol. 18 No. 2, pp. 219-225.

Grgic, J. (2021), “Effects of caffeine on resistance exercise: a review of recent research”, *Sports Medicine*, Vol. 51 No. 11, pp. 2281-2298.

Grgic, J., and Mikulic, P. (2021a), “Acute effects of caffeine supplementation on resistance exercise, jumping, and Wingate performance: no influence of habitual caffeine intake”, *European Journal of Sport Science,* Vol. 21 No. 8, 1165-1175.

Grgic, J., Grgic, I., Pickering, C., Schoenfeld, B.J., Bishop, D.J., and Pedisic, Z. (2020), "Wake up and smell the coffee: caffeine supplementation and exercise performance—an umbrella review of 21 published meta-analyses", *British Journal of Sports Medicine,* Vol. 54 No. 11, pp. 681-688.

Grgic, J., and Mikulic, P. (2021b), "Ergogenic effects of sodium bicarbonate supplementation on middle-, but not short-distance swimming tests: a meta-analysis", *Journal of Dietary Supplements*, 2021. doi: 10.1080/19390211.2021.1942381

Grgic, J., Pedisic, Z., Saunders, B., Artioli, G.G., Schoenfeld, B.J., McKenna, M.J., Bishop, D.J., Kreider, R.B., Stout, J.R., Kalman, D.S., Arent, S.M., VanDusseldorp, T.A., Lopez, H.L., Ziegenfuss, T.N., Burke, L.M., Antonio, J., and Campbell, B.I. (2021), "International Society of Sports Nutrition position stand: sodium bicarbonate and exercise performance", *Journal of the International Society of Sports Nutrition,* Vol. 18 No. 1, pp. 61.

Grgic, J., Trexler, E.T., Lazinica, B., and Pedisic, Z. (2018), "Effects of caffeine intake on muscle strength and power: a systematic review and meta-analysis", *Journal of the International Society of Sports Nutrition,* Vol. 15, pp. 11.

Guest, N.S., VanDusseldorp, T.A., Nelson, M.T., Grgic, J., Schoenfeld, B.J., Jenkins, N.D., Arent, S.M., Antonio, J., Stout, J.R., Trexler, E.T. Smith-Ryan, A.E., Goldstein, E.R., Kalman, D.S., and Campbell, B.I. (2021), "International society of sports nutrition position stand: caffeine and exercise performance", *Journal of the International Society of Sports Nutrition*, Vol. 18 No. 1, pp. 1-37.

Higgins, J.P.T., Deeks, J.J., and Altman, D.G., on behalf of the Cochrane Statistical Methods Group, editors. (2011), "Chapter 16.1.3.2. Imputing standard deviations for changes from baseline", In: Higgins, J.P., Green, S., editors. Cochrane handbook for systematic reviews of interventions. Version 5.1.0 (updated March 2011). Cochrane Collaboration, Chichester, UK.

Karayigit, R., Naderi, A., Saunders, B., Forbes, S.C., Coso, J.D., Berjisian, E., Yildirim, U.C., and Suzuki, K. (2021), "Combined but not isolated ingestion of caffeine and taurine improves wingate sprint performance in female team-sport athletes habituated to caffeine", *Sports*, Vol. 9 No. 12, pp. 162.

Karayiğit, R., Yıldız, H., Şahin, M.A., Şişman, A., Sarı, C., Ersöz, G. and Büyükçelebi, H. (2021), "The effects of low-dose caffeinated coffee ingestion on strength and muscular endurance performance in male athletes." *Progress in Nutrition*, Vol. 23 No. 1, pp. 2021001.

Lara, B., and Del Coso, J. (2021), "Pacing strategies of 1500 m freestyle swimmers in the World championships according to their final position", *International Journal of Environmental Research and Public Health*, Vol. 18 No. 14, pp. 7559.

Lara, B., Ruiz-Vicente, D., Areces, F., Abián-Vicén, J., Salinero, J.J., Gonzalez-Millán, C., Gallo-Salazar, C., and Del Coso, J. (2015), "Acute consumption of a caffeinated energy drink enhances aspects of performance in sprint swimmers", *British Journal of Nutrition*, Vol. 114 No. 6, pp. 908-914.

MacIntosh, B.R., and Wright, B.M. (1995), "Caffeine ingestion and performance of a 1,500-metre swim", *Canadian Journal of Applied Physiology*, Vol. 20 No. 2, pp. 168-177.

Maher, C.G., Sherrington, C., Herbert, R.D., Moseley, A.M., and Elkins, M. (2003), "Reliability of the PEDro scale for rating quality of randomized controlled trials", *Physical Therapy*, Vol. 83 No. 8, pp. 713-721.

Maughan, R.J., Burke, L.M., Dvorak, J., Larson-Meyer, D.E., Peeling, P., Phillips, S.M., Rawson, E.S., Walsh, N.P., Garthe, I., Geyer, H., and Meeusen, R. (2018), "IOC consensus statement: dietary supplements and the high-performance athlete", *International Journal of Sport Nutrition and Exercise Metabolism,* Vol. 28 No. 2 pp. 104-125.

McLellan, T.M., Caldwell, J.A., and Lieberman, H.R. (2016), "A review of caffeine's effects on cognitive, physical and occupational performance", *Neuroscience & Biobehavioral Reviews*, Vol. 71, pp. 294-312.

Polito, M.D., Souza, D.B., Casonatto, J., and Farinatti, P. (2016), "Acute effect of caffeine consumption on isotonic muscular strength and endurance: a systematic review and meta-analysis", *Science & Sports*, Vol. 31 No. 3, pp. 119-128.

Potgieter, S., Wright, H.H., and Smith, C. (2018), "Caffeine improves triathlon performance: a field study in males and females", *International Journal of Sport Nutrition and Exercise Metabolism,* Vol. 28 No. 3, pp. 228-237.

Pruscino, C.L., Ross, M.L., Gregory, J.R., Savage, B., and Flanagan, T.R. (2008), "Effects of sodium bicarbonate, caffeine, and their combination on repeated 200-m freestyle performance", *International Journal of Sport Nutrition and Exercise Metabolism,* Vol. 18 No. 2, pp. 116-130.

Saunders, B., de Oliveira, L.F., da Silva, R.P., de Salles Painelli, V., Gonçalves, L.S., Yamaguchi, G., Mutti, T., Maciel, E., Roschel, H., Artioli, G.G., and Gualano, B. (2017), "Placebo in sports nutrition: a proof-of-principle study involving caffeine supplementation", *Scandinavian Journal of Medicine & Science in Sports,* Vol. 27 No. 11, pp. 1240-1247.

Serpa, M.C. (2018), “Efeitos da suplementação de cafeína na natação: desempenho em 50m e durante o exercício intervalado”, *Universidade Federal de Santa Catarina*. Thesis.

Shaw, G., Slater, G., and Burke, L.M. (2016), “Changes in the supplementation practices of elite Australian swimmers over 11 years”, *International Journal of Sport Nutrition and Exercise Metabolism,* Vol. 26 No. 6, pp. 565-571.

Shen, J.G., Brooks, M.B., Cincotta, J., and Manjourides, J.D. (2019), “Establishing a relationship between the effect of caffeine and duration of endurance athletic time trial events: A systematic review and meta-analysis”, *Journal of Science and Medicine in Sport,* Vol. 22 No. 2, pp. 232-238.

Sperlich, B., Zinner, C., Heilemann, I., Kjendlie, P.L., Holmberg, H.C., and Mester, J. (2010), “High-intensity interval training improves VO(2peak), maximal lactate accumulation, time trial and competition performance in 9-11-year-old swimmers”, *European Journal of Applied Physiology,* Vol. 110 No. 5, pp. 1029-1036.

Svenningsson, P., Nomikos, G.G., and Fredholm, B.B. (1999), “The stimulatory action and the development of tolerance to caffeine is associated with alterations in gene expression in specific brain regions”, *The Journal of Neuroscience,* Vol. 19 No. 10, 4011-4022.

Trewin, C.B., Hopkins, W.G., and Pyne, D.B. (2004), “Relationship between world-ranking and Olympic performance of swimmers”, *Journal of Sports Sciences,* Vol. 22 No. 4, pp. 339-345.

Vanata, D.F., Mazzino, N., Bergosh, R., and Graham, P. (2014), “Caffeine improves sprint-distance performance among Division II collegiate swimmers”, *The Sport Journal,* Vol. 17, pp. 1-8.

Venier, S., Grgic, J., and Mikulic, P. (2019), “Acute enhancement of jump performance, muscle strength, and power in resistance-trained men after consumption of caffeinated chewing gum”, *International Journal of Sports Physiology and Performance,* Vol. 14 No. 10, pp. 1415-1421.

Wickham, K.A. and Spriet, L.L. (2018), “Administration of caffeine in alternate forms”, *Sports Medicine*, Vol. 48 No. 1, pp. 79-91.