Sports Performance

Overview
Research suggests that caffeine may help to improve physical performance during both endurance and high-intensity exercise[1-12]. Studies have shown that in endurance exercise (i.e. aerobic exercise in sports lasting more than five minutes, such as running, cycling and rowing), caffeine improves time-trial performance and can be associated with a reduction in muscle pain[3-12]. Research also suggests that caffeine can help during short-term, high-intensity (anaerobic) exercise, e.g. athletes performing high-intensity exercises and team sports[13-19].

The European Food Safety Authority (EFSA) concluded that there is an association between caffeine consumption and an increase in endurance performance, endurance capacity and a reduction in the rated perceived effort or exertion during exercise[20].

Although much of the research has been undertaken in trained athletes, studies in sedentary people and those with lower levels of fitness also suggest that caffeine can improve performance in those who are not trained athletes[21,22].

Caffeine may exert its effect through antagonism of the adenosine receptors in the brain – a pathway that leads to an increased production of adrenalin, which stimulates energy production and improves blood flow to the muscles and heart[10,11]. Caffeine may also modulate central fatigue, a type of fatigue caused by neurochemical changes in the brain associated with prolonged exercise, and in turn influence ratings of perceived exertion, perceived pain, and levels of vigour, all of which are likely to lead to improvements in performance[11,12].

Fluid in the body is important: EFSA has concluded that a cause and effect relationship has been established between the dietary intake of water and the maintenance of normal and physical cognitive function[23]. Whilst there is some indication of a short-term diuretic effect of caffeine intake, this effect does not counter-balance the effects of the fluid intake from coffee drinking[24-31]. Drinking caffeinated coffee in moderation can therefore help maintain adequate fluid balance[24-31].

EFSA's Scientific Opinion on the Safety of Caffeine concluded that 'single doses of caffeine up to 200mg (about 3mg/kg bw) from all sources do not raise safety concerns for the general adult population, even if consumed less than two hours prior to intense physical exercise under normal environmental conditions'[32].

The content in this topic was last edited in January 2017. Papers in the Latest Research section and further resources are added regularly.

Background information
It is widely accepted that any effects of coffee consumption on sports performance are linked to the caffeine in coffee. Most of the published work on exercise performance focuses on the effects of caffeine, although more recent research has considered the effect of coffee specifically[7,8].

Caffeine is widely understood to be an ergogenic aid i.e. a substance that improves the capacity to do work or exercise. In 1978, Costill and his co-workers were the first to show that 330mg of caffeine administered an hour before exercise at 80% of maximal oxygen consumption on a bicycle ergometer increased time to exhaustion[33]. Research suggests that performance benefits can be seen with more moderate amounts of caffeine (around 3mg/kg body weight, or 200-300mg caffeine) across a range of sports, including endurance events, stop-and-go events such as team and racquet sports and sustained high-intensity activity such as swimming and rowing[1,2]. In 2015, the European Food Safety Authority (EFSA) published its Scientific Opinion on the Safety of Caffeine, concluding that 'single doses of caffeine up to 200mg (about 3mg/kg bw) from all sources do not raise safety concerns for the general adult population, even if consumed less than two hours prior to intense physical exercise under normal environmental conditions'[32].

Caffeine and performance in endurance (aerobic) exercise

A 2009 review paper focused on endurance performance lasting more than five minutes and measured the time it took to run, cycle or row a set distance, rather than time to exhaustion, which better reflects typical competition conditions. Inclusion criteria were met by 21 papers covering 33 trials[3]. Thirty of these showed a performance improvement with a mean improvement of 3.2 ± 4.3 % with caffeine consumption. The review concluded that overall caffeine ingestion can be an effective ergogenic aid for endurance athletes when consumed in moderate quantities (3-6mg/kg body weight), before and/or during exercise[3]. However, abstaining from caffeine for at least 7 days before an event optimised caffeine's ergogenic effect on performance during the event[3].

In 2011, a study examining caffeine withdrawal and high-intensity endurance cycling performance also suggested that an intake of caffeine of 3mg/kg body significantly improved exercise performance irrespective of whether a 4-day withdrawal period was imposed on habitual caffeine users[4]. Further research published in 2012 concluded that a caffeine intake of 3mg/kg body weight appears to improve cycling performance; although doubling this to (6mg/kg body weight) did not confer additional performance improvement in well-trained athletes[5].

Additionally, a 2013 study considered the potentially enhancing effects of caffeine versus coffee, concluding that caffeine consumed in coffee (5mg/kg body weight) and as a supplement (5mg/kg body weight) one hour prior to exercise can improve endurance exercise performance[6].

A 2016 review concluded that there is an indication that the use of coffee (as opposed to caffeine alone) as an ergogenic aid can improve performance in endurance cycling and running[7]. The authors suggested that coffee providing 3-8.1 mg/kg of caffeine may be used as a safe alternative to anhydrous caffeine to improve endurance performance[7].

Additionally, results from a 2017 study of male runners suggest that 60 minutes after ingesting 0.09 g/kg of caffeinated coffee, one-mile race performance was enhanced by 1.9% and 1.3% compared with a placebo and decaffeinated coffee respectively, in trained male runners[8].

A 2017 meta-analysis suggested that caffeine had a suppressive effect on ratings of perceived exertion, and had no effect on measures of heart rate, respiratory exchange ratio or $\dot{V}O_2$[9]. The authors suggested that whilst the positive effects of caffeine supplementation on sustained high-intensity exercise performance are well accepted, the mechanisms to explain that response remain unresolved[9].

A small number of studies have considered a potential ergogenic effect of low and very low intakes of caffeine taken late in prolonged exercise. A low intake of caffeine (~200 mg) has been shown to improve vigilance, alertness and mood, and improve cognitive processes during and following strenuous exercise, however there is a lack of research on its potential effects on high intensity sprint and burst activities. As the response to caffeine consumption is variable, athletes need to determine whether the ingestion of lower amounts of caffeine before and/or during training and competitions is ergogenic on an individual basis[10].

Summary table of meta-analyses

AUTHOR	INCLUDED STUDIES	RESULTS
Ganio M. S. et al. (2009) Effect of Caffeine on Sport-Specific Endurance Performance: A Systematic Review. *J Strength Cond Res*, 23(1):315-24.	21 studies with a total of 33 identifiable caffeine treatments that measured endurance performance with a time-trial component.	Caffeine ingestion can be an effective ergogenic aid for endurance athletes when taken before and/or during exercise in moderate quantities (3–6 mg.kg body mass). Abstaining from caffeine at least 7 days before use gave the greatest chance of optimizing the ergogenic effect.
Higgins S. et al. (2016) The effects of pre-exercise caffeinated coffee ingestion on endurance performance. *Int J Sport Nutr Exerc Metab*, 26(3):221-39.	Included studies (n = 9) evaluated the effects of caffeinated coffee on human subjects, provided the caffeine dose administered, administered caffeine ≥ 45 min before testing, and included a measure of endurance performance (e.g., time trial).	There is moderate evidence supporting the use of coffee as an ergogenic aid to improve performance in endurance cycling and running. Coffee providing 3–8.1 mg/kg (1.36–3.68 mg/lb) of caffeine may be used as a safe alternative to anhydrous caffeine to improve endurance performance.
Glaister M., Gissane C. (2017) Caffeine and physiological responses to submaximal exercise: a meta-analysis. *Int J Sports Physiol Perform*, 5:1-23.	26 studies met the inclusion criteria of adopting double-blind, randomised, crossover designs that included a sustained (5–30 minutes) fixed-intensity bout of submaximal exercise (constrained to 60–85% VO2max) using a standard caffeine dose of 3–6 mg·kg-1 administered 30–90 minutes prior to exercise.	Relative to placebo, caffeine led to significant increases in submaximal measures of minute ventilation, blood lactate, and blood glucose. In contrast, caffeine had a suppressive effect on ratings of perceived exertion. Caffeine had no effect on measures of heart rate or respiratory exchange ratio.

Caffeine and muscle pain
In 2009 a research paper reported on the effects caffeine had on muscle pain during 30 minutes of high-intensity cycling. Caffeine ingestion (5mg/kg body weight) was statistically significant in reducing the reported intensity of muscle pain and the effect was larger in the group of habitually low caffeine consumers[11].

A 2011 study examined the effect of caffeine on leg pain and rating of perceived exertion during repeated bouts of high intensity exercise. Data revealed no effect of caffeine on leg pain or perceived exertion although caffeine intake improved multiple measures of performance. The authors concluded that it was plausible to suggest that subjects were able to perform better with similar levels of pain and exertion with 5mg/kg of caffeine compared to a placebo[12].

Caffeine and performance in short-term high-intensity (anaerobic) exercise
Research suggests that caffeine can have benefits in some short-term, high-intensity exercises and under certain conditions[13-15].

A 2009 review looking at the effects of caffeine on anaerobic exercise performance considered 29 studies, finding that 17 of the studies revealed caffeine to have a significant effect[13]. It was also observed that there was significant variation between the studies. Several factors in the various studies were highlighted as potential explanations for the variation: trained vs. untrained participants, caffeine-habituated vs. non-habituated participants, slow vs. fast caffeine-metabolizers amongst the participants, different dosing regimens (fixed amount of caffeine vs. mg per kg body weight), as well as different types of tests.

Results of a 2017 meta-analysis indicated a significant difference between the placebo and caffeine trials on mean power output and peak power output on a cycle ergometer. This meta-analysis adds to the current body of research that suggests that caffeine ingestion can enhance components of anaerobic performance[15].

The overall results suggest that caffeine can have benefits in some short-term, high-intensity exercises particularly under certain conditions, such as trained athletes who had abstained from caffeine before power-based sports and team sports events following ingestion of a moderate amount of caffeine[13-15].

Summary table of meta-analyses

AUTHOR	INCLUDED STUDIES	RESULTS
Astorino T.A. et al. (2009) Efficacy of acute caffeine ingestion for short-term high-intensity exercise performance: a systematic review. *J Strength Cond Res*, 24(1):257-65.	29 studies that measured alterations in short-term performance after caffeine ingestion.	Eleven of 17 studies revealed significant improvements in team sports exercise and power-based sports with caffeine ingestion, yet these effects were more common in elite athletes who do not regularly ingest caffeine. Six of 11 studies revealed significant benefits of caffeine for resistance training. Some studies show decreased performance with caffeine ingestion when repeated bouts are completed.
Grgic J. (2017) Caffeine ingestion enhances Wingate performance: a meta-analysis. *Eur J Sport Sci*, 31:1-7.	Following a search through PubMed/MEDLINE, Scopus, and SportDiscus®, 16 studies were found meeting the inclusion criteria (pooled number of participants=246).	Results of the meta-analysis indicated a significant difference (p=.005) between the placebo and caffeine trials on mean power output with standardized mean differences (SMD) values of small magnitude (0.18; 95% confidence interval: 0.05, 0.31; +3%). The meta-analysis performed for peak power output indicated a significant difference (p=.006) between the placebo and caffeine trials (SMD=0.27; 95% confidence interval: 0.08, 0.47 [moderate magnitude]; +4%).

Caffeine and carbohydrates

A 2010 paper looked at the effect of caffeine (3.7mg/kg body weight) in addition to a carbohydrate-electrolyte supplement in a simulated football performance[16]. The authors found that the caffeine group better maintained, and improved, short distance sprinting and jumping performances, compared to the no-caffeine group[16]. A 2011 review of the research suggests that the ingestion of carbohydrates with caffeine provides a significant but small improvement in endurance performance compared with carbohydrates alone[17]. However, the magnitude of the performance benefit that caffeine provides was less when added to carbohydrate than when added to placebo[17].

Short-term effects of caffeine

A 2010 paper[18] reported that caffeine intake of 6mg/kg body weight in trained women resulted in an improvement in an "all at once" test but not in a repeated test[18].

A further paper[19] tested two different caffeine intakes (2mg/kg body weight and 5mg/kg body weight) in active participants[19]. The ingestion of the higher caffeine amount, but not the lower, resulted in an improvement in knee extension/flexion exercise performance. This effect disappeared in the second bout, meaning any benefits of caffeine were short-term only[19].

Caffeine and fluid balance during physical activity

Fluid balance is a particularly important topic amongst athletes, as dehydration is always a concern since it is associated with reduced performance. Caffeine may exert a short-term diuretic effect but research suggests that this does not counter-balance the effects of the fluid intake from coffee drinking[24-31]. Drinking caffeinated coffee in moderation can help to maintain adequate fluid balance[24-31].

A comprehensive review concluded that a daily intake of 300mg of caffeine (the amount found in approximately 3 regular cups of coffee) induces only a mild, short-term diuretic effect, similar to that of water, with no significant effect on overall fluid balance[24]. The authors stated that there is no evidence that caffeine is detrimental during exercise in hot climates when fluid losses are maximal[24]. The study further confirmed that statements suggesting the avoidance of caffeinated beverages before and during exercise are unfounded[24].

A 2014 meta-analysis considering the role of caffeine in fluid balance in adults during rest and exercise concluded that although caffeine produced a minor diuretic effect this was negated by exercise. The authors also suggested that concerns regarding unwanted fluid loss associated with caffeine consumption are unwarranted particularly when ingestion precedes exercise[29].

A further study published in 2014 found no significant differences in measures of hydration status between those who drank coffee or those who drank water, concluding that coffee consumed in moderation by regular male coffee drinkers had similar hydrating qualities to water[30].

In 2004 the International Olympic Committee (IOC) officially removed caffeine from its list of banned substances stating that historical suggestions that caffeine's mild, short-term diuretic effect may impair physical performance are unfounded.

Further information on fluid balance can be found here.

Potential mechanisms

Caffeine's ergogenic effects were once thought to be explained by caffeine's stimulation of free fatty acid oxidation and, as a result, sparing of muscle glycogen[34], however several other mechanisms such as are now also under investigation.

Endurance exercise

Any suggested improvement in sports performance is strongest for endurance sports. Research and reviews conclude that caffeine affects endurance performance largely through its antagonist effect on the adenosine receptors in the brain i.e. via a pathway that leads to an increased production of adrenalin, which stimulates energy production and improves blood flow to the muscles and heart[6]. Caffeine modulates central fatigue and influences ratings of perceived exertion, perceived pain and levels of vigour, all of which may lead to performance improvements[6].

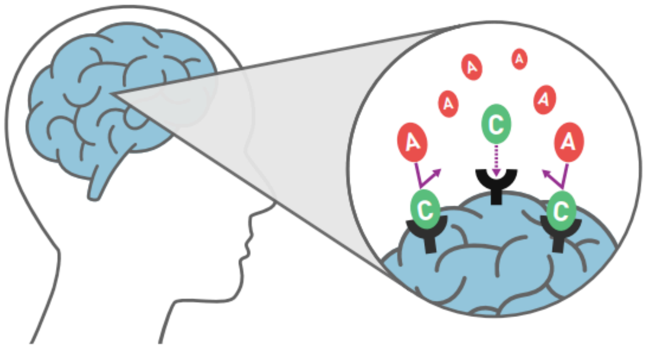

Fig. 1 Illustration of caffeine binding to the adenosine receptor, which may enhance the central nervous system[6]

Short-term high-intensity exercise

For short-term anaerobic exercise, the fatty acid oxidation and glycogen sparing is not a realistic model for the mechanism behind performance improvement because, for example, the time frames do not fit. A 2009 review on anaerobic mechanisms of action discussed current options and demonstrated that it is not yet clear how caffeine improves short-term high-intensity exercise performance[13].

Some of the areas under investigation include: lactic acid, blood glucose, potassium – for peripheral mechanisms; caffeine as an adenosine antagonist, pain perception and ratings of perceived exertion – for a central mechanism. This caffeine-related central model is the most promising to date.

It is interesting that the models for the mechanisms of action to explain the benefits of caffeine for performance in both types of exercise – endurance and short-term, high- intensity – seem to be moving in the same direction[17-19]. As a consequence the recommendations for sports people also show more and more similarities[17-19].

Genetic variability

Researchers have suggested that the impact of caffeine consumption on performance may differ between individuals, possibly mediated by polymorphisms within two genes, CYP1A2 and ADORA2A, as well as environmental factors. A clearer understanding of the factors underpinning inter-individual variation may facilitate customisation of caffeine ingestion guidelines, specific to an individual's biology, history, and competitive situation[35].

Summary

The current body of research supports the International Society of Sports Nutrition's position statement on caffeine supplementation and sports performance, summarised as follows[2]:

1. Caffeine is effective for enhancing sport performance in trained athletes when consumed in low to moderate dosages (~3-6mg/kg) and, overall, does not result in further enhancement in performance when consumed in higher dosages (≥ 9mg/kg).
2. Caffeine exerts a greater ergogenic effect when consumed in an anhydrous state* as compared to coffee.
3. It has been shown that caffeine can enhance vigilance during bouts of extended exhaustive exercise, as well as periods of sustained sleep deprivation.
4. Caffeine is ergogenic for sustained maximal endurance exercise, and has been shown to be highly effective for time-trial performance.
5. Caffeine supplementation is beneficial for high-intensity exercise, including team sports such as soccer and rugby, both of which are categorized by intermittent activity within a period of prolonged duration.
6. The literature is equivocal when considering the effects of caffeine supplementation on strength-power performance, and additional research in this area is warranted.
7. The scientific literature does not support caffeine-induced diuresis during exercise or any harmful change in fluid balance that would negatively affect performance.

*in a capsule, tablet or powder form.

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