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Review Article

Does Caffeine Enhance Athletic Performance?

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Abstract

Aim: A plethora of studies have been conducted to examine the effect of caffeine on athletic performance, with conflicting results. The purpose of the study is to investigate the effects of caffeine on muscle activity, physical training, competitive sports events and short-term physical activity.

Methods: For the purpose of the research, a literature review was conducted to determine the optimal dosage of caffeine for athletes, and collected scientific evidence about the caffeine's effect on athletic endurance. The inclusion criteria contain original articles with primary data collection, both quantitative and qualitative published research studies, and studies with athletic subjects. The exclusion criteria comprises review articles without outcome data, incorrect study type, studies with < 10 subjects, and studies with physical inactive subjects.

Results: An issue for dietitians and other sports medicine personnel is that all recommend that exercising athletes should avoid the use of caffeine because it is a diuretic, and that it may exacerbate dehydration and hyperthermia. Evidence indicates that consuming a moderate level of caffeine results in a mild increase of urine production. There is no evidence suggesting that moderate caffeine intake (<456 mg) induces chronic dehydration or negatively affects exercise performance. In addition, pre-exercise feeding may significantly affect plasma caffeine concentrations and the potential for caffeine to improve performance. On the other hand, recent studies suggest that caffeine might indeed have ergogenic potential in endurance events. Also, reports concerning caffeine's effect on $\dot{V}O_2$ max and exercise performance during incremental exercise are not in agreement. However, few caffeine studies have been published to include cognitive and physiologic considerations for the athlete. Furthermore, the effects of different doses of caffeine play important role on endurance. In addition, exercise time to exhaustion seems to be different between users and nonusers with the ergogenic effect being greater and lasting longer in nonusers.

Conclusion: Caffeine consumption may enhance athletic endurance, based on strong evidence, but further research needs to be conducted. High caffeine doses than the optimal, 3-6 mg/kg, before exercise does not confer any additional improvement in athletic performance. Additional, higher caffeine doses may cause side effects in athletes.

Keywords: Caffeine; Exercise; Athletic performance; Sports nutrition

1. Introduction

Caffeine is a pharmacological compound that is extracted on a large scale from the plant coffee Arabica, which originated in Ethiopia. Caffeine and the related substances, theophylline and theobromine, are components of food and drinks, and for most people these substances are part of their daily diet (table 1). Caffeine may be the most prevalent stimulant drug in world. The use is not prohibited for athletes, with a maximum allowable concentration 12 mg/L of urine (International Olympic Committee).

A plethora of studies have been conducted to examine the effect of caffeine on athletic performance, with conflicting results. The fact that caffeine affects the central nervous system, adipose tissue and skeletal muscle, initially led to the hypothesis that caffeine can affect athletic performance. Strong evidence shows that caffeine enhances endurance and provide improvement of performance in a wide range of different physical exercises: short duration, high-intensity events (1-5 minutes), prolonged high-intensity events (20-60 minutes), endurance events (>90 minutes), ultra-endurance events (>4 hours) and prolonged intermittent sprint events (team sports). Caffeine may enhance contractile force in skeletal muscle during submaximal contraction and increase the athlete's threshold for pain or perceived exertion, which could result in longer training sessions [33]. As a powerful antioxidant, caffeine can help combat the muscle damage caused by exercise [39].

For many years, research into caffeine's energy-boosting effects was focused on examining its effects on endurance exercise. As a result, a great deal of data was collected incontrovertibly establishing that caffeine has ergogenic power in exercise situations in which fatigue occurs in 30 to 60 minutes [39]. Caffeine may enhance endurance performance by increasing the release of adrenaline into the blood stimulating the release of free fatty acids from fat tissue and skeletal muscle. Caffeine also does not alter exercise metabolism, and therefore, it appears that alterations in muscle metabolism alone cannot fully explain the ergogenic effect of caffeine during endurance exercise.

Short-term exercise has received much less attention. In the last two decades, researchers have deliberated the effects of caffeine on short-term exercise with progressive work tests, in which athletes undertake high-intensity exercise that results in rapid exhaustion. Researches suggest that caffeine ingestion improves performance during short-term exercise, lasting approximately 5 minute at 90-100 % of maximal oxygen uptake. This exercise intensity requires maximal provision of energy from both aerobic and anaerobic systems. The reasons for the performance improvement may be direct positive effect of caffeine on muscle anaerobic energy provision and contraction or a central nervous component related to the sensation of effort, leading

Food/Drink	Portion	Caffeine (mg/cup)
Filter coffee	200 ml	90
Espresso	60 ml	80
Tea	220 ml	40–60
Plain chocolate	50 g	20–25
Milk chocolate	50 g	~10
Soft Drinks (coca cola, etc.)	355 ml	40
Energy Drink	250 ml	~80

Table 1: EFSA, 2015.

to a reduction in perception of effort during exercise and therefore influencing the motivational factors to sustain effort during exercise [29].

Studies on caffeine use in strength training, is less prevalent than in endurance training. However, evidence strongly suggests that caffeine has direct effects on the strength of muscle performance that are independent of caffeine's metabolic effects. According to Graham [19], caffeine may increase strength by changing the environments of active muscles in a way that can "facilitate force production" by the muscle's cells.

Additionally, it is well known that caffeine use has several side effects. Blood pressure is increased both at rest and during exercise, heart rate is increased, gastrointestinal distress can occur and insomnia can result [33]. At high levels, caffeine has the potential to cause impairments or alterations in fine motor skills and techniques, and it can interfere with recovery and sleep patterns, more likely in athletes who are not regular caffeine users. Since dehydration is a concern of every athlete, series of studies occur for decades, in order to examine the possible effect of caffeine on dehydration. For several years, athletes avoid consumed caffeine, because of the myth that caffeine may cause dehydration [39]. In the past few years, researchers have proven that caffeine does not dehydrate athletic people and has no diuretic effects at all on people who exercise. There is no evidence that caffeine ingestion before exercise leads to dehydration, or other side effects such as ion imbalance and stomach irritation. However, athletes must consume caffeine in the optimal dose 3-6 mg/kg, in order to avoid side effects. In addition, handful of studies has failed to find any further improvement on athletic performance, in very high doses.

The purpose of the study is to investigate the effects of caffeine to muscle activity, physical training, competitive sports events and short-term physical activity. The optimal dose of caffeine for athletes and possible side effects, will be also discussed.

For the purpose of the research, a literature review was conducted to determine the optimal dosage of caffeine for athletes and collect scientific evidence about the caffeine's effect on athletic endurance. The literature search held through electronic databases and articles in scientific journals such as Sports Medicine and Journal of Medicine and Science in Sports, etc. The main databases used were: PubMed, World Health Organization (WHO), International Olympic Committee (IOC) and National Center for Biotechnology Information (NCBI). The following words – keys, used during the search: caffeine, athletes, performance, endurance, strength, side effects, dosage, exercise.

The inclusion criteria of the literature review contain original articles with primary data collection, both quantitative and qualitative research published studies, and studies with athletic subjects. The language of publication was narrowed to English and publication date from November 2015, with no longer limit date was chosen. The exclusion criteria comprise review articles without outcome data, incorrect study type, studies with < 10 subjects, and studies with physical inactive subjects.

2. Discussion

An issue for dietitians, exercise physiologists, athletic trainers, and other sports medicine personnel all recommend that exercising athletes should avoid the use of caffeine because it is a diuretic, and it may exacerbate dehydration and hyperthermia. Evidence indicates that consuming a moderate level of caffeine results in a mild increase of urine production. Although this diuresis may (240-642 mg of caffeine) or may not (<240 mg) be significantly greater than a control fluid (0 mg of caffeine), there is no evidence suggesting that moderate caffeine intake (<456 mg) induces chronic dehydration or negatively affects exercise performance, temperature regulation, and circulatory strain in a hot environment. Caffeinated fluids contribute to the daily human water requirement in a manner that is similar to pure water. It is possible that urinary Na^+, but less likely that urinary K^+, excretion is increased somewhat by caffeine consumption. However, an affluent Western diet provides Na^+ and K^+ in amounts that exceed these losses. Furthermore, no evidence supports the contention that caffeine increases heat storage during exercise or that caffeine affects exercise performance in a hot environment negatively. Finally, not enough research where done about the efficacy of caffeine administration regarding large doses of caffeine (>600 mg) that are consumed at one time and differences between modes of caffeine delivery, for instance via capsules, tablets, coffee, tea, soft drinks, sport drinks, and solid food [25].

The enhanced endurance performance observed in athletes consuming coffee containing 330 mg of caffeine 60 minutes before the exercise had similar effects of caffeine on lipolysis and has positive influence on nerve impulse transmission [8]. Skinner, T. L., et al, [34] agrees that individual characteristics need to be considered when administering caffeine for performance enhancement. In addition, pre-exercise feeding may significantly affect plasma caffeine concentrations and the potential for caffeine to improve performance. On the other hand, recent studies suggest that caffeine might indeed have ergogenic potential in endurance events (e.g. marathon running). It is hypothesized that it is related to the increased availability of free fatty acids for muscle metabolism, which has a glycogen-sparing effect. Also, reports concerning caffeine's effect on $\dot{V}O_2$ max and exercise performance during incremental exercise are not in agreement [31].

An interesting study, Lorino, A. J. [26], suggested that a 6 mg [middle dot] kg-1 dose of caffeine does not impact agility as measured by the proagility run test or power output as measured by the 30-second Wingate test in recreationally active young adult males who are not habituated to caffeine.

An important aspect is the ergogenic effect of caffeine on athletic performance that has been discussed in many studies. However, few caffeine studies have been published to include cognitive and physiologic considerations for the athlete. The following practical recommendations consider the global effects of caffeine on the body resulted that lower doses can be as effective as higher doses during exercise performance without any negative coincidence after a period of cessation, restarting caffeine intake at a low amount before exercise performance can provide the same ergogenic effects as acute intake. Basically, caffeine can be taken gradually at low doses to avoid tolerance during the course of 3 or 4 days, just before intense training to sustain exercise intensity and caffeine can improve cognitive aspects of performance, such as concentration, for instance when an athlete has not slept well. [35]. A similar recent study was done and stated that, lower caffeine doses ($\leq$3 mg/kg bm, ~200 mg) taken before exercise increases athletic performance. Low caffeine doses do not alter exercise-induced changes in peripheral whole-body responses to exercise and are associated with few side effects. Low doses of caffeine (~200 mg) have also been shown to improve awareness, alertness and mood and improve cognitive processes during and following strenuous exercise. Therefore, the ergogenic effect of low caffeine doses appears to result from alterations in the central nervous system [25].

Many studies indicate that, during aerobic exercise a nutritionally-enriched coffee beverage appears to enhance time to exhaustion, whereas, it does not provide an ergogenic benefit during anaerobic exercise [21].

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Furthermore, the effects of different doses of caffeine play important role on endurance cycling time trial performance. Desbrow, B. [10] concluded that a caffeine dose of 3 mg·kg−1 body mass appears to improve cycling performance in well-trained and familiarized athletes. Whereas, doubling the dose of caffeine to 6 mg·kg−1 body mass does not confer any additional improvements in performance. A similar came to the same conclusion that high caffeine dose had the greatest effect on epinephrine and blood-borne metabolites yet had the least effect on performance. While, low caffeine dose had little or no effect on epinephrine and metabolites but did have an ergogenic effect. These results are not compatible with the traditional theory that caffeine mediates its ergogenic effect via enhanced catecholamines [17].

As stated before, caffeine is a common substance used by most athletes, and it is now found as well in many new products, including energy drinks, sport gels, alcoholic beverages and diet aids. It can be a powerful ergogenic aid at levels that are considerably lower than the acceptable levels of the International Olympic Committee and could be beneficial in training and in competition. Caffeine does not improve maximal oxygen capacity directly, but could permit the athlete to train at a greater power output and train longer time. It is indicated that intake of caffeine increase speed and power output in simulated race conditions. These effects have been found in activities that last as little as 60 seconds or as long as 2 hours. Not enough research was done in order to see if caffeine affects the strength of the athlete. However, a study claimed that there was no effect on maximal ability, but enhanced endurance or resistance to fatigue. Also, not further research was done to see if caffeine ingestion before exercise leads to dehydration, ion imbalance, or any other adverse effects. Due to that ingestion of caffeine as coffee appears to be ineffective compared to doping with pure caffeine. It appears that male and female athletes have similar caffeine pharmacokinetics, for instance a given dose of caffeine, the time course and absolute plasma concentrations of caffeine and its metabolites are the same. So, exercise or dehydration does not affect caffeine pharmacokinetics. Limited studies suggest that caffeine non-users and users respond similarly and that withdrawal from caffeine may not be important [19].

In addition to this, exercise time to exhaustion seems to be different between users and nonusers with the ergogenic effect being greater and lasting longer in nonusers, according to Bell & McLellan [4]. For the nonusers (8 subjects), exercise times 1, 3, and 6 h after caffeine ingestion, <50 mg caffeine/day were significantly greater. But, for caffeine users (13 subjects), exercise times 1, 3, and 6 h after caffeine ingestion (>300 mg caffeine/day) were respectively. Only exercise times 1 and 3 h after drug ingestion were significantly greater. The study concluded that 5 mg/kg dose of caffeine were greater in the nonusers compared with the users.

A lot of studies aimed to see the effect of caffeine on exercise performance in habitual caffeine users. A study suggested that habitually high caffeine users acquire a tolerance to caffeine, which reduces its effects during prolonged exercise. Furthermore, to magnify the effect of caffeine, habitual users should withdraw from caffeine use for about 4 days [15].

Another study aimed was to examine the effects of caffeine ingestion on exercise performance at low and high altitudes. The effect of caffeine on exercise time over a specified distance (approx. 21 km) was investigated in well-trained cross-country skiers (14 subjects) both at low (300 m above sea level) and high (2900 m above sea level) altitudes. Each subject participated in two races at both altitudes - one after caffeine ingestion (6 mg/kg body weight) and one after placebo on a double-blind basis. They concluded that caffeine induces had an increased in performance capacity for cross-country skiers at low altitudes [5].

Sung, et al., [37] present study examined the effects of caffeine on blood pressure regulation in hypertensive men during exercise. Twenty unmedicated, mild hypertensives (HT, BP = 140/90 to 160/105 mm Hg) and 12 age-matched, normotensives (NT, BP < 130/80 mm Hg) performed 30 min of extended bicycle exercise following a single dose of caffeine (3.3 mg/kg, equivalent to 2 to 3 cups of coffee) and placebo in a double-blind, cross-over design. He claimed that during exercise, heart rate was greater on caffeine day than placebo day in hypertensives only. Systolic blood pressure was consistently elevated on caffeine day compared to placebo day in both groups. Diastolic blood pressure was elevated in hypertensives for 30 min of exercise on caffeine day, but this disappeared at 15 min of exercise in normotensives. As a result, rate-pressure products were significantly higher on caffeine days in hypertensives at post drug and during exercise. On caffeine day, 7 hypertensives and 1 normotensive showed an excessive blood pressure response during exercise. This study assumed that caffeine has significant hemodynamic effects on mild hypertensives at rest and during exercise. The increased rate-pressure products following caffeine during exercise place a greater workload on the heart, and abstinence from caffeine, especially before exercise, may be effective for persons with hypertension.

3. Conclusion

The purpose of the study was to collect information on caffeine's benefits to muscle activity, physical training, competitive sports events and short-term physical activity, which aims to examine the hypothesis that caffeine enhance athlete's endurance. It appears that, caffeine consumption may enhance athletic endurance in both short duration activities and long endurance exercises, based on strong evidence. As the result seems controversial on ergogenic effect on caffeine, further research needs to be conducted. The optimal dose of caffeine for athletes and possible side effects were considered during the research. High caffeine doses than the optimal, 3-6 mg/kg, before exercise does not confer any additional improvement in athletic performance. Additional, higher caffeine doses may cause side effects in athletes, such as increased blood pressure and heart rate.

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