

CAFFEINE USE IN SPORTS: CONSIDERATIONS FOR THE ATHLETE

BÜLENT SÖKMEN, LAWRENCE E. ARMSTRONG, WILLIAM J. KRAEMER, DOUGLAS J. CASA, JOAO C. DIAS, DANIEL A. JUDELSON, AND CARL M. MARESH

Human Performance Laboratory, Department of Kinesiology, University of Connecticut, Storrs, Connecticut

ABSTRACT

The ergogenic effects of caffeine on athletic performance have been shown in many studies, and its broad range of metabolic, hormonal, and physiologic effects has been recorded, as this review of the literature shows. 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: 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 performance can provide the same ergogenic effects as acute intake; 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, when an athlete has not slept well. Athletes and coaches also must consider how a person's body size, age, gender, previous use, level of tolerance, and the dose itself all influence the ergogenic effects of caffeine on sports performance.

KEY WORDS ergogenic aid, athletic performance, cognitive, habituation

INTRODUCTION

Caffeine (1,3,7-trimethylxanthine) is the world's most consumed pharmacologic and psychoactive substance. It is found naturally in coffee beans, tea leaves, chocolate, cocoa beans, and cola nuts. In the U.S.A., adults ingest an average of 3 mg·kg⁻¹ of caffeine daily in coffee, tea, caffeinated sodas, and many other drinks and food. The levels of caffeine in foods vary greatly depending on preparation; coffee, tea, and cola (i.e., soft drinks) contain approximately 60 to 150 mg, 40 to 60 mg, and 40 to 50 mg of

caffeine per cup, respectively (42). Caffeine, though having no nutritional value, has attracted the attention of many competitive and noncompetitive athletes as a legal ergogenic aid.

Caffeine has global effects on the central nervous system (CNS) and on hormonal, metabolic, muscular, cardiovascular, pulmonary, and renal functions during rest and exercise (Figures 1 and 2). It stimulates bronchodilation of alveoli, vasodilation of blood vessels, neural activation of muscle contraction, blood filtration in the kidneys, catecholamine secretion, and lypolysis (23,41,50,57,59). These metabolic, physiologic, and hormonal effects of caffeine lower the respiratory exchange ratio, peripheral fatigue, rating of perceived exertion (RPE), and the threshold for exercise-induced cortisol and B-endorphin release; they also increase oxygen uptake, cardiac output, ventilation, circulating levels of epinephrine, metabolic rate, and fat oxidation during endurance exercise in trained and untrained individuals (16,18,23,50,59).

There have been numerous positive reports (Table 1) of the improvements of caffeine on mood, mental alertness, decreased tiredness, and energetic arousal (14,19,21,28,31,40, 43,67). Although the cognitive and mood effects of caffeine may provide a competitive edge in sports performance, few caffeine studies have investigated cognitive and physiologic effects (Table 2). The ergogenic effectiveness and cognitive symptoms of caffeine are represented by an inverted \cap dose-response curve (Figure 3) and a varying time course depending on age, gender, and body size. Also, understanding an individual's caffeine tolerance, habituation, and cessation patterns is critical (Figure 4).

Thus, an intake strategy is crucial for those seeking to improve athletic performance through caffeine use. This article reviews the literature regarding the impact of caffeine form, timing, and dose on exercise performance and suggests practical applications in light of cognitive perception and individual habituation.

PERFORMANCE EFFECTS

Caffeine studies involving endurance exercise have shown increased work output and time to exhaustion (8,16,23,51,58). Caffeine also enhanced performance during intense, short-term cycling and running events of approximately 5 minutes (63). However, positive ergogenic effects were equivocal during sprint and power exercise lasting less than 3 minutes,

Address correspondence to Bülent Sökmen, bsokmen@exchange.fullerton.edu.

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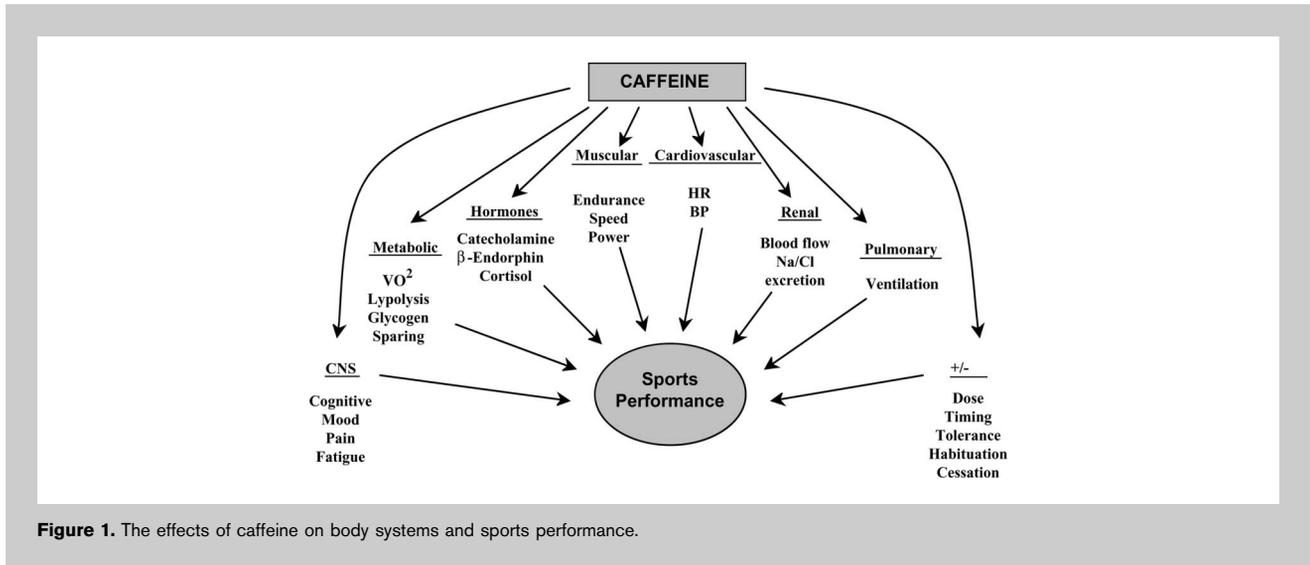


Figure 1. The effects of caffeine on body systems and sports performance.

possibly because of the limited number of investigations and different protocols used (3,9,27,33,35,36,56,64).

In sprint and power events that rely mainly on the phosphogen system (≤ 10 seconds), caffeine improved peak power output, speed, and isokinetic strength (3,36,56); however, in events that heavily rely on the glycolytic system (15 seconds to 3 minutes), no improvements were found with caffeine use, and in fact, it may have been detrimental to performance during repeated bouts of exercise (27,64). One

study showed a 7% increase of peak power output during 6-second Wingate testing with consumption of 250 mg of caffeine (3), whereas another recent study showed improvements of intermittent sprint ability (during 4-second sprints) in soccer players when $6 \text{ mg}\cdot\text{kg}^{-1}$ of caffeine was ingested (56). Caffeine ingestion had no effect on peak power output and total work during 15-second maximal exercise bouts (64) and during 2 repeated exercise bouts that lasted 2 minutes (33). However, during the last of 4 30-second repeated Wingate

tests, significantly lower peak power output was observed with $6 \text{ mg}\cdot\text{kg}^{-1}$ of caffeine ingestion (27). In addition, ingestion of varying levels of caffeine doses exerted no ergogenic effect on maximal strength and endurance during isokinetic strength events of 15 repetitions (35). In tennis, an individual sport requiring concentration and skill, caffeine increased hitting accuracy, running speed, agility, and overall playing success, possibly because it improved reaction time and mental alertness (67). Tennis players also reported higher “energetic drive” during the last hours of play (21).

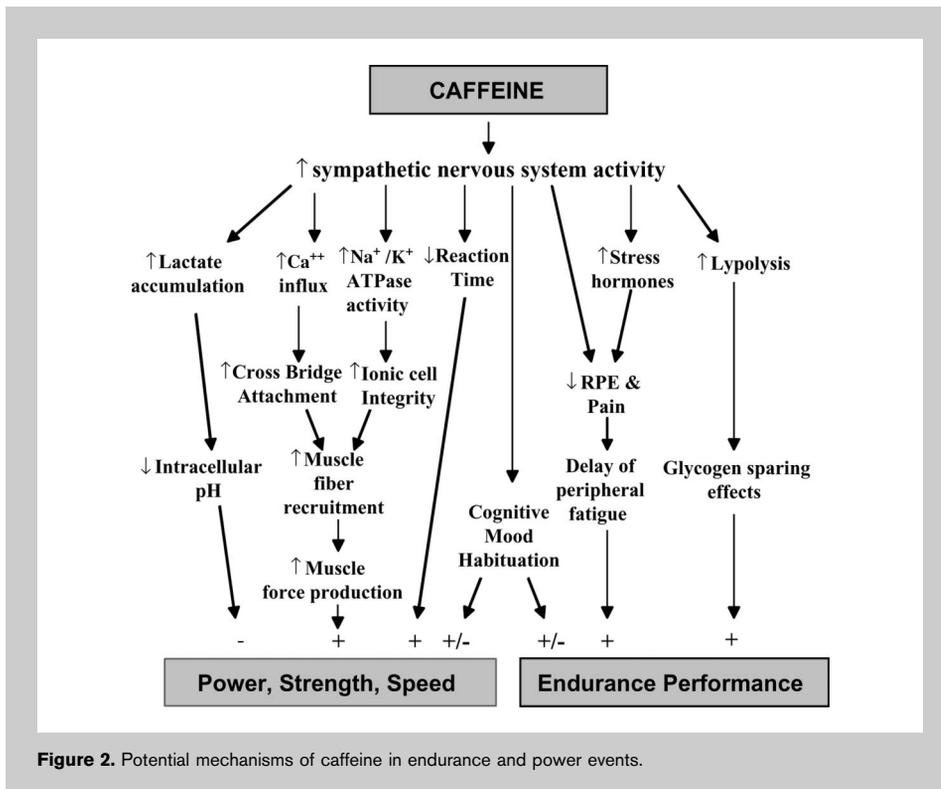


Figure 2. Potential mechanisms of caffeine in endurance and power events.

Mechanism

The mechanism for improved endurance, sprint, and power performance had been previously related to a single biologic

TABLE 1. Effects of caffeine on psychological factors.

Psychological factors	Acute intake	Tolerance	Caffeine cessation	References
Mental alertness	Increases	No change	Decreases	19,31,40,67
Mood	Improves	No change	Degrades	12,15,28,40,43,53,67
Jitteriness	Increases or no change	Decreases	No change	20,26,31,40,46,67
Tiredness	Decreases	No change	Increases	16,20,28,31,57,63, 64
Headache	Decreases	Decreases	Increases	12,15,19,20,26,28,40,67
Nervousness	Increases or no change	Decreases	Decreases	12,15,19,20,26,67
Pain perception	Decreases	No change	Increases	13,15,16,20,48–50,58,64
Sleep	Decreases	Decreases or no change	Prolongs	15,19,20,26,31,41,43,46
Performance accuracy	Increases	No change	No change	21,31,40,43,46,47,67

mechanism, such as glycogen sparing, increased intracellular Ca^{++} concentration, or altered excitation–contraction coupling (11,16,18,23,29,55,59). In fact, a caffeine paradigm for improved athletic performance should be multifactorial, extend beyond any single biologic mechanism, and include cognitive perception and habituation (Figure 2).

The stimulation of the sympathetic nervous system by caffeine acts on multiple metabolic pathways to improve endurance performance. Until recent years, the mechanism for improved endurance performance was considered to be improved lipolysis from adipose and intramuscular triglyceride and conservation of carbohydrate stores (i.e., glycogen-sparing effects of caffeine) for later use during endurance exercise (16,18,23,55,59). Davis et al. (14) proposed a mechanism by which caffeine delays fatigue through its effects on the CNS. Recently, this mechanism has gained popularity because of previously known effects of caffeine as a CNS stimulant, through its action as an adenosine receptor antagonist, and its analgesic effects on CNS.

The proposed mechanisms for relatively short (≤ 10 seconds) sprint and power performance were improved muscular force production that results from increased intracellular Ca^{++} concentration and improved $\text{Na}^{+}\text{-K}^{+}$ ATPase pump activity (11,29). Decreased reaction time could be another factor in relatively brief events (3,34,56). However, in repeated bouts of maximal exercise that last 15 seconds to 3 minutes and thus rely heavily on anaerobic glycolysis, caffeine has been clearly shown to have no effect or to be a negative factor in power and sprint performance, possibly because of an increase in plasma ammonia levels and a decrease in intracellular pH (27,33,64).

COGNITIVE PERFORMANCE AND MOOD EFFECTS

Caffeine affects the CNS by stimulating the secretion of serotonin in the cerebral cortex, enhancing the action of the sympathetic system, and diminishing the activity of inhibitory

neurons (28,41,61) as a result of the binding and blocking of adenosine receptors. Adenosine and caffeine work opposite of one another with respect to cellular regulations. Adenosine, a neuromodulator, binds to adenosine receptors and slows nerve cell activity, whereas caffeine blocks adenosine receptors and speeds up the activity of cells (28,41,61).

This mechanism greatly affects the user's cognition and mood. Several studies show that, depending on timing, quantity of dose, and habituation to caffeine, the positive effects of acute caffeine intake include decreased tiredness, increased mental alertness, mood improvement, and energetic arousal as a result of the effects of caffeine on the CNS (14,19,21,28,31,67). In addition, caffeine significantly enhanced concentration, visual vigilance, choice reaction time, and self-reported fatigue (i.e., after a period of exercise, work, and a long period of sleep deprivation) in a dose-dependent manner (43,46,47). These cognitive effects depended on the quantity of acute caffeine intake, tolerance to caffeine, and cessation from caffeine (Table 1).

Caffeine Considerations: Tolerance and Withdrawal

Habituation to caffeine is important when considering its use as an ergogenic aid. Habituation alters an individual's caffeine sensitivity, tolerance to a given dose, cognitive perception, and mood. These latter 2 effects have been the subject of much scientific research, but few studies have focused on the period of caffeine cessation, the development of tolerance (i.e., repetitive dosing), and the effects of habituation on cognitive perception and mood. These studies merely reported positive and negative effects on cognitive perception or mood during the period of caffeine habituation and experimental trials.

Tolerance. Tolerance (i.e., diminished responsiveness) to caffeine results from repeated exposure. Caffeine tolerance has been associated with increased adenosine receptor activity and a decrease of β -adrenergic activity (13,26,40). Lower caffeine doses are well tolerated by nonusers, who may

TABLE 2. Evidence-based statements regarding caffeine evaluated in terms of the strength of supporting scientific evidence.

	Level of evidence	Evidence category	References
Cognitive effects	Acute caffeine intake decreases tiredness and increases mental alertness, mood, and arousal.	B or C	18,28,31,42,43,67
	Caffeine significantly enhances concentration and choice reaction time and decreases fatigue during work tasks after a period of exercise and a long period of sleep deprivation	B or C	43,46,47
	Consuming caffeine in large quantities may result in dizziness, headache, jitteriness, nervousness, insomnia, and gastrointestinal distress, generally at doses higher than 9 and 13 mg·kg ⁻¹ of caffeine for nonusers and users, respectively.	B or C	12,13,15,18,41,53
	Caffeine has an inverted U dose-response curve regarding side effects.	B or C	8,41,42,52
Exercise performance	Caffeine during endurance exercise increases work output and time to exhaustion.	B	8,16,23,48,49,51,54,58
	Caffeine lowers peripheral pain perception, which results in improved endurance performance.	C	48,49,50,64
	Caffeine cessation decreases endurance exercise performance because of withdrawal symptoms.	C	58
	Caffeine has little or no effect on strength and power performance.	D	9,35,57
Misconceptions	Caffeine does not cause dehydration.	B	4,5,22,44,54
	Caffeine does not increase the risk of cardiovascular disease.	C	38,52,65

These designators reflect strength-of-evidence determinations in the table above.

Evidence category	Levels of evidence	Definition
A	Randomized controlled trials (rich body of data)	Substantial number of well-designed studies; substantial number of subjects; consistent pattern of findings
B	Randomized controlled trials (limited body of data)	Limited number of studies; includes post hoc, field studies, subgroup, or meta-analyses; pertains when number of randomized controlled trials is small, results are inconsistent, or subject populations differed from the target population
C	Nonrandomized trials Observational studies	Evidence from outcomes of uncontrolled or nonrandomized trials or from clinical observations or case studies
D	Panel consensus judgment	Used when guidance is needed, but literature is lacking; an expert judgment based on a synthesis of published evidence, panel consensus, clinical experience, and laboratory observations

Adapted from National Heart, Lung, and Blood Institute. *Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults. The Evidence Report.* NIH publication 98-4083. Washington, DC: National Institutes of Health, 1998.

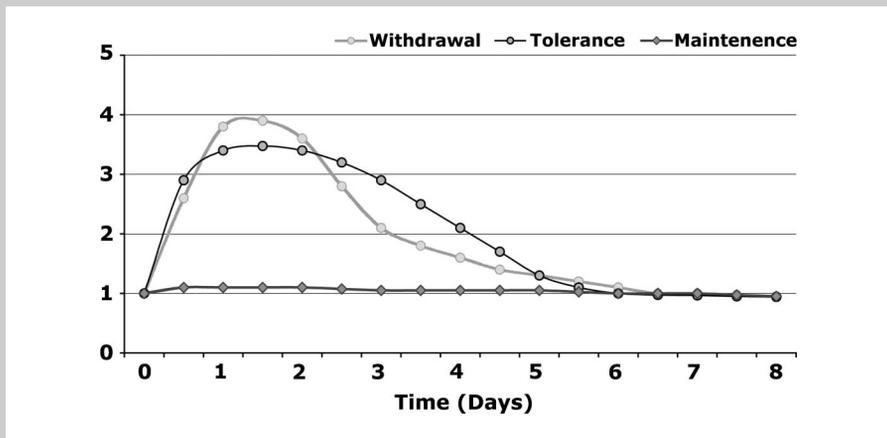


Figure 3. A theory of the predicted symptom intensity and time course, developed from results in references 12, 15, 19, 20, 28, 40, and 41. This model can guide the athlete in determining how controlling caffeine use affects mood and cognitive functions (5,54). The withdrawal line illustrates responses of chronic users to caffeine cessation. The tolerance line depicts the course of symptoms experienced by users who increase their dose and nonusers who begin chronic caffeine intake. The maintenance line represents chronic users who do not alter their intake. On the vertical axis, 5 represents the greatest effect and 1 is negligible.

develop complete tolerance in 5 or 6 days of moderate caffeine intake (Figure 3) (5,19,20,54). If the doses are high and late in the day, jitteriness, nervousness, and insomnia may occur (Table 1).

Caffeine ingestion sustains exercise intensity during heavy and intense endurance training, keeps the athlete mentally focused, and lowers pain perception (16,46,48–50). Thus, an effective strategy for the nonuser may involve 3 or 4 days of consecutive caffeine intake to aid intense workout sessions. The nonuser should begin with a lower dose, such as 1 to 2 mg·kg⁻¹, and then increase the dose progressively during the next few days.

Intentionally reduces caffeine intake may fail to perform well without knowing why. In 1 study, exercise performance significantly decreased 2 to 4 days after caffeine cessation when a placebo was given; however, acute caffeine ingestion after 2 to 4 days of cessation resulted in performance similar to that achieved before withdrawal (58). Resumed or acute caffeine intake almost entirely reverses withdrawal symptoms, including headache.

As a strategy, if the athlete decides to stop consuming caffeine before competition to optimize its benefits during competition, he or she should reduce caffeine consumption at least 1 week before competition to be completely free from

Withdrawal. Caffeine dependency seems to be almost entirely connected to withdrawal symptoms (Table 1), which peak 28 to 48 hours before decreasing to baseline values in 4 to 7 days (19,20,26,28,31,40). These symptoms are different in individuals, and some athletes do not experience them. The main symptom during caffeine withdrawal, frequent and severe headaches, is theoretically caused by vasodilation of cerebral blood vessels (41).

Athletes must take care to avoid unintentional caffeine withdrawal, sometimes experienced during travel or when training in hot weather. A habituated athlete who unintentionally

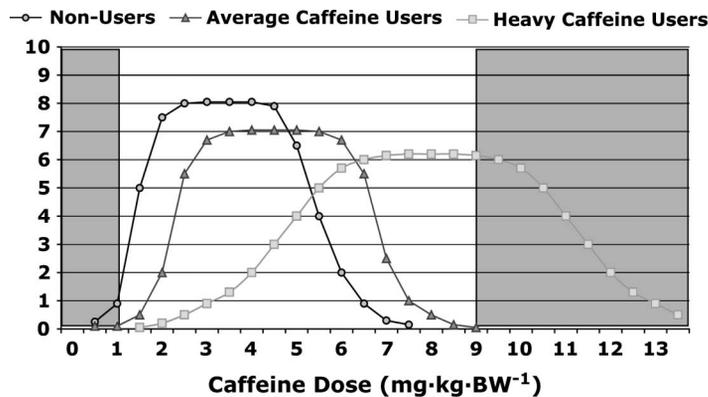


Figure 4. The theoretical responses to caffeine in nonusers, average users (≤ 3 mg·kg⁻¹), and heavy users (≥ 6 mg·kg⁻¹). Dose–response curves are shifted to the right and ergogenic effectiveness is blunted with increased caffeine intake. On the vertical axis, 10 represents the greatest effect and 1 is negligible. For all 3 habituation levels, peak effects may be achieved over a range of doses, rather than at a single dose. The shaded areas represent dose ranges for which negligible positive ergogenic effects are expected; this may be the result of negative cognitive and mood effects at higher doses. The plots are based on references 5, 8, 16, 23, 24, 31, 41, 43, 46, 48–50, 51, 54, 58, and 59.

withdrawal effects. To avoid negative effects on training, the dose should be gradually reduced over 3 or 4 days, instead of quitting abruptly. Resuming caffeine on the day of competition will again provide the desired ergogenic effects, as it would for a nonuser.

PRACTICAL APPLICATIONS FOR ATHLETES: CAFFEINE FORM, TIMING, AND DOSE

Most studies on caffeine in the literature failed to report extensive cognitive effects of caffeine, other than pain perception, during exercise protocols. Across the literature, subjects ingested approximately 3 to 13 mg·kg⁻¹ of caffeine, which is equivalent to 2 to 7 cups of coffee or 4 to 18 cups of tea and soda. The literature still lacks extensive research regarding the effects of caffeine form and dose on habituation and exercise performance.

Caffeine Form

Many investigators have administered caffeine in a capsule form and in regular or decaffeinated coffee. Graham et al. (25) investigated the ergogenic effects of caffeine (4.5 mg·kg⁻¹) in capsule and coffee form on endurance performance. They reported that only capsules improved performance significantly, when compared to placebo, coffee, and decaffeinated coffee plus caffeine. Graham et al. concluded that coffee blunted the ergogenic effectiveness of caffeine. A recent study by McLellan et al. (45) extended the findings by Graham et al. They reported that time to exhaustion was significantly greater in all caffeine trials versus placebo and that previous consumption of coffee did not decrease the ergogenic effect of encapsulated caffeine (45).

Because of their size, easy ingestion, and controlled dose, capsules seem to be an attractive route of administration. However, because of the limited literature regarding kinds of caffeine (e.g., capsule, soda, tea, coffee, and caffeinated energy drinks), this requires further exploration to determine the comparative ergogenic effectiveness of its different forms.

Caffeine Timing

Taken orally, caffeine reaches a peak plasma level between 30 and 75 minutes after ingestion (53). The half-life of caffeine has been reported to be 4 to 5 hours with a modest intake of coffee, but longer when the dose exceeds 300 mg; this value may vary between acute and chronic users (41,42,61). In 6 to 7 hours, 75% of caffeine is cleared from the body because it is quickly absorbed and metabolized by the liver. Bell and McLellan (8) investigated the timing of caffeine effects by taking measurements 1, 3, and 6 hours after ingestion. They observed an increased time to exhaustion during exercise 1 and 3 hours after caffeine ingestion, but not after 6 hours or during placebo trials. These results point to an optimal window of opportunity of less than 6 hours after acute caffeine intake.

The effects of repeated caffeine intake on cognitive task and performance also have been investigated. Hindmarch et al. (31) reported that day-long redosing at low levels of caffeine

(i.e., 75 mg) significantly improved reaction time and alertness. However, repeated day-long redosing had a dose-dependent negative effect on sleep onset, sleep time, and sleep quality, which was independent of the way that caffeine was consumed.

Redosing at low levels after a morning dose, over 2 or 3 consecutive days, may be helpful if the athlete competes in an all-day event. Maintaining good sleep habits is important for the events of the following day, so doses should not extend into the late afternoon.

Caffeine Dose

A large part of the literature on caffeine has focused on dose-response effects, to determine ergogenic effectiveness in endurance and power events. As little as 1 (i.e., approximately 70 mg) and as much as 13 (i.e., approximately 900 mg) mg·kg⁻¹ had positive effects on time to fatigue, endurance events, sports, and sprint or power events (23,51,54,67). Pasman et al. (51) showed significantly improved time to fatigue in endurance cycling performance with a dose of 5, 9, and 13 mg·kg⁻¹ in trained individuals, but observed no dose-response relationship. Similar improvement was reported in rowing performance with 6 or 9 mg·kg⁻¹ of caffeine (2,10). Graham and Spriet (24) reported that low to moderate doses (i.e., 3 and 6 mg·kg⁻¹) showed superior ergogenic effectiveness than higher doses (9 mg·kg⁻¹) during a running event. Another dose-response study reported gender-specific pain perception during moderate cycling exercise. Caffeine ingestion (5 vs. 10 mg·kg⁻¹) greatly reduced leg muscle pain in men and women. There was no dose-response effect in women, but the 10-mg dose resulted in significantly less leg muscle pain compared to the 5-mg dose in men (48-50).

Studies by Van Soeren and Graham (58,59) showed that improved endurance performance after a single dose of caffeine was not related to previous caffeine habituation. A recent study, however, reported that the duration and magnitude of ergogenic effects with 5 mg·kg⁻¹ of caffeine were greater in nonusers than in users, because of dampened sympathetic responses in users (8,12,13).

Acute consumption of caffeine affects some symptoms, depending on the dose. Caffeine may result in dizziness, headache, jitteriness, nervousness, insomnia, and gastrointestinal distress, generally at doses greater than 9 and 13 mg·kg⁻¹ of caffeine for nonusers and users, respectively (12,19,41,53). These signs and symptoms at high doses may be linked to decreased performance in some athletes (24,28,54).

It would not be wise to recommend the same absolute doses for men, women, users, and nonusers. Generally, users have higher caffeine tolerance than nonusers, and men tolerate higher doses than women. But there is no evidence of greater ergogenic effects with more than 9 mg·kg⁻¹. Instead, the higher caffeine concentrations may blunt cognitive performance (20,41,42). Figure 4 serves to guide athletes, depending on their caffeine habituation. Nonusers, moderate, and heavy caffeine users have a wide range of peak values, but

the ranges may differ according to group. Within one's own range, an individual may find that the dose at the lower end of the range could be as effective for enhancing performance as moderate and higher doses of caffeine.

Caffeine and Other Ergogenic Substances: Carbohydrate, Creatine, and Amino Acids

Combining caffeine with nutritional supplements and other ergogenic compounds has recently become popular with the general public and in the scientific research community. Caffeine coingested with a carbohydrate (CHO) solution has been shown to have no additive effects on substrate use and exercise performance in 3 studies (32,37,62). However, caffeine has also been shown to improve 1-hour time trial cycling performance in a dose-dependent manner, when added to a 7% CHO-electrolyte drink, without having any effects on fat oxidation (39). A recent study showed that caffeine may exert ergogenic properties during exercise, when ingested in combination with a CHO solution, perhaps by increasing exogenous CHO oxidation or intestinal absorption (66). Before a conclusive statement can be made, further research is required.

Besides studying the effects of the interaction of caffeine CHO on exercise performance, many studies have also investigated the combination of caffeine with creatine and amino acids to identify potential ergogenic effects on exercise performance. It has been previously reported that caffeine interferes with creatine loading, and ergogenic, torque-related effects of creatine loading were eliminated during repeated bouts of intermittent isometric and isokinetic knee extensions (60). These decreases in muscular torque production with caffeine intake may be reasons for prolonged muscle relaxation time or decreased phosphocreatine resynthesis during the recovery period that overrides the creatine-facilitated recovery (30,60). Doherty et al. (17), however, reported that a 5 mg·kg⁻¹ acute caffeine ingestion after 6 days of creatine loading was significantly associated with increased time to exhaustion during treadmill running at an exercise intensity equivalent to 125% of $\dot{V}O_2\text{max}$ compared to creatine loading alone.

Caffeine with amino acids and CHO has been the subject of a limited number of studies. Alford et al. (1) investigated the impact of a combination drink (i.e., caffeine plus amino acid [taurine] plus CHO) on time to exhaustion and cognitive functions (i.e., 5-choice reaction time). Time to exhaustion and cognitive function (i.e., reaction time) improved with the combination energy drink compared to those with water and no-water trials. A study (7) investigated the effects of CHO, caffeine plus CHO, and caffeine plus taurine plus CHO on cardiac parameters and reported increases in postexercise stroke volume that may be the result of inotropic effects of taurine. Taurine itself was shown to increase depolarization-induced force responses by augmenting sarcoplasmic reticulum calcium accumulation in an in vitro study (6), which may explain why energy drinks with taurine enhance

postexercise stroke volume. Because there are so few studies on this subject and because there is the likelihood of an economic significance, whether amino acids have any beneficial effects when combined with caffeine and carbohydrate supplements should be examined.

Misconception: Caffeine Effects on Hydration Status

The common belief that caffeine leads to dehydration and causes poor athletic performance (i.e., its reputed diuretic effect) apparently is not factual (4,5,22,44,54). A recent study observed no changes in body fluid indices during 11 days of controlled caffeine ingestion and during exercise on the 12th day (5,54). In chronic consumers (3 and 6 mg·kg⁻¹·d⁻¹), acute caffeine ingestion did not alter fluid-electrolyte and physiologic responses during exercise in heat (37.7° C), when compared to a placebo (54).

Misconception: Health Effects

Similarly, a recent review article reported that caffeine does not promote ventricular arrhythmia, contrary to popular belief (38). One large Danish study with 48,000 participants yielded no association between caffeine consumption and atrial fibrillation. Another recent meta-analysis included 17 studies and concluded that there is a decreased risk for myocardial infarction in moderate caffeine users (52). These recent studies show that claims of adverse effects of caffeine on the cardiovascular system are inconclusive.

Caffeinated and decaffeinated coffee are rich sources of antioxidants, which have been linked to a number of potential health benefits, including protection against heart disease and type 2 diabetes mellitus (38,52,65).

PRACTICAL APPLICATIONS

Nonusing athletes who are considering caffeine as an ergogenic aid will be unaccustomed to its cognitive and physiologic effects. Nonusers therefore should test its effects before implementing a caffeine strategy for training or competition.

Because caffeine cessation decreases exercise performance, habituated athletes may consider ingesting lower doses (≤ 3 mg·kg⁻¹) of caffeine to avoid the undesirable withdrawal symptoms associated with complete cessation.

If an athlete decides to stop consuming caffeine before competition to increase its ergogenic effects during competition, he or she should reduce caffeine consumption at least 1 week before competition to be completely free from withdrawal effects. To avoid potential negative symptoms, the dose should be gradually reduced over 3 to 4 days, instead of quitting abruptly. Resuming caffeine on the day of competition will again provide the desired ergogenic effects, as it would for a nonuser.

Caffeine ingestion can benefit high-volume or intense endurance training. Three or four days of consecutive low levels of caffeine intake, during the period of heavy training days, can serve as an ergogenic aid in preparing for competition.

The half-life of caffeine is approximately 4 to 6 hours, and plasma concentration has been shown to peak in 30 to 60 minutes. Therefore, caffeine should be ingested, at the latest, 3 hours before power, sprint, and short endurance events or 1 hour before prolonged endurance events.

Acute redosing with caffeine does not necessarily improve performance; however, if the events are more than 6 hours apart, it may be beneficial.

Because caffeine increases plasma lactate levels and decreases intracellular pH, it may be contraindicated for athletes in sprint events that last 30 seconds to 3 minutes. Further research is warranted.

The effects of ingesting caffeine with a carbohydrate solution, with an amino acid solution, and during creatine loading require further study.

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