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EFFECTS OF DIETARY CONSTITUENTS ON COGNITIVE AND MOTOR SKILL PERFORMANCE IN SPORTS

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KEY POINTS

- Cognitive and motor skill performance are important determinants of success in many sports.
- Carbohydrate and caffeine are the dietary constituents with the most scientific support to enhance acute cognitive and motor skill performance in athletes.
- Many other dietary constituents have been purported to benefit acute cognitive performance but lack scientific support in athletes or sport-specific cognitive/motor skill tests.
- More research with athletes is needed and it is imperative that valid, reliable and sensitive cognitive and motor skill test batteries are developed and used in future efficacy studies.

INTRODUCTION

Nutrition plays an important role in everyday health and well-being, including optimal brain and cognitive function. Performance in many sports is at least partially dependent on motor control, coordination, decision-making, timing and other cognitive tasks. There has been recent interest in certain nutrients and isolated compounds (hereafter referred to as dietary constituents) that have acute central effects and have been purported to improve cognitive performance in humans. The objective of this Sports Science Exchange article is to review and summarize the available scientific literature on the effects of various dietary constituents on cognitive and motor skill performance in athletes (e.g., stop-and-go or team sport athletes). The nutrients and dietary constituents that will be discussed in more detail are branched chain amino acids (BCAA), caffeine, carbohydrate, cocoa flavanols, ginkgo biloba, guarana, L-theanine, Panax ginseng and tyrosine. Although this list is not exhaustive, these are perhaps the most researched nutrients and dietary constituents.

For the purpose of this article, we will primarily discuss measures of cognition and motor skill thought to be potentially relevant to sport performance, including accuracy, alertness, attention, decision-making, memory, visual acuity, balance, agility, reaction time and sport-specific skills. In addition, the discussion in this article is limited to acute performance effects from a single dose (or multiple doses within a relatively short time frame) of a dietary constituent (as opposed to the chronic effect of several days or weeks of intake).

One of the challenges in interpreting this area of the literature is the methodological differences across studies. Most studies employ tests that are not standardized, making it difficult to compare results.

RESEARCH REVIEW

Branched–Chain Amino Acids

The branched-chain amino acids (BCAA) leucine, isoleucine and valine impact brain serotonin synthesis, and have been implicated as potential nutritional countermeasures to central fatigue during exercise. Changes in brain serotonin are known to affect mood, arousal and sleepiness. Administration of serotonin re-uptake inhibitors (like paroxetine or fluoxetine) has been shown to reduce time to fatigue and increase ratings of perceived exertion in runners and cyclists (Davis et al., 2000). Serotonin synthesis in the brain increases when the ratio of plasma-free tryptophan-to-BCAA rises. Thus, BCAA ingestion has been hypothesized to reduce the concentration of serotonin in the brain and mitigate central fatigue. Only a few studies have tested the effects of BCAA intake on cognitive performance during exercise. Ingestion of a carbohydrate solution with BCAA (total intake of 5.3 g) improved performance during complex but not simple cognitive tasks after a 30-km competitive run compared to runners who drank a carbohydrate solution without BCAA (Hassmen et al., 1994). In a crossover study with endurance-trained cyclists, Blomstrand et al. (1997) reported that ingestion of a solution with 90 mg/kg of BCAA improved cognitive performance and reduced ratings of mental fatigue and perceived exertion compared to a flavored water placebo after a bout of prolonged cycling. However, Cheuvront et al. (2004) recently observed no benefits of a 60 g/L glucose solution with 10 g/L BCAA on performance during a battery of basic and complex cognitive computerized tests or mood after heat-acclimated men cycled in the heat for 90 min. The discrepancy in findings among studies could be attributed to methodological factors. For example, the Cheuvront et al. (2004) study was the only study in which the BCAA beverage and the placebo beverage were calorically-matched (placebo had 60 g/L glucose and 10 g maltodextrin). Despite the plausible mechanism and interesting rationale behind the hypothesis that BCAA ingestion could benefit cognition in athletes, the experimental evidence is currently mixed and no data is available in stop-and-go sports. Moreover, the balance of evidence from many studies with endurance athletes indicates that BCAA do not prevent central fatigue (Davis et al., 2000).

Caffeine

Caffeine (1, 3, 7-trimethylxanthine) is found naturally in coffee, tea and chocolate and is added to some soft drinks and sports nutrition products. Several studies have tested the impact of caffeine on sports-related measures of motor skill performance during simulated team-sport activity. Foskett et al. (2009) examined the impact of 6 mg/kg caffeine ingested 1 h before simulated soccer activity. The players displayed significantly better passing accuracy and countermovement jump height after ingesting caffeine compared to placebo. Duncan et al. (2012) tested the effect of caffeine (5 mg/kg) ingestion on field hockey skill performance after a bout of total body fatiguing exercise in competitive hockey players. They found that post-exercise dribble times and ball handling scores were significantly better in the caffeine vs. the placebo trial. Furthermore, caffeine ingestion resulted in lower ratings of perceived exertion and higher ratings of readiness to invest physical and mental effort compared to placebo (Duncan et al., 2012). Similarly, Stuart et al. (2005) concluded that compared to placebo, 6 mg/kg caffeine improved passing accuracy by 10% in high-level male rugby players during a simulated game (Figure 1). In another study, Duvnjak-Zaknich et al. (2011) fed amateur and semiprofessional team sport athletes a caffeine dose (6 mg/kg) or placebo 1 h before a simulated team game. Qualitative results suggested that caffeine ingestion likely enhanced decision-making accuracy and reactive agility time compared to placebo.

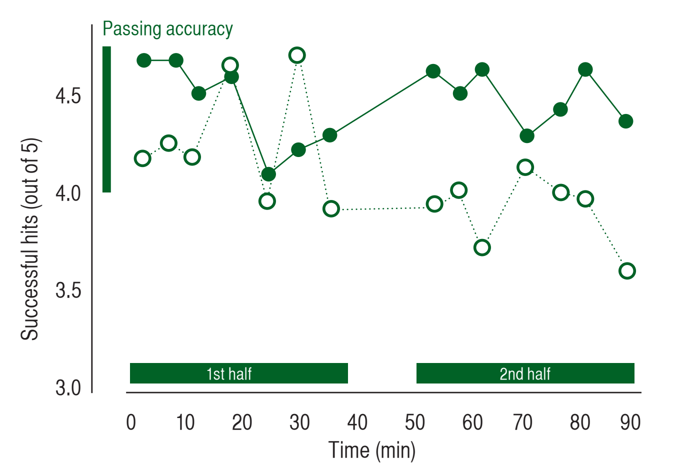

Figure 1. Passing accuracy of male rugby union players following caffeine (•) and placebo (o) ingestion. Compared to placebo, caffeine (6 mg/kg) ingestion 70 min prior to a simulated rugby game resulted in a 10% improvement in passing accuracy. This was observed early in the test and even more so in the second half (i.e., when the subjects were fatigued). Values are means; bar is between-subject SD. (From Stuart et al., 2005).

A few of the exercise/sport-related studies have reported no benefit of caffeine on hitting accuracy in tennis players' (Ferrauti et al.,1997), reactive agility performance in male team-sport athletes (Pontifex et al., 2010) or a proagility run test in college-aged men (Lorino et al., 2006). The difference in results between these studies and others finding a benefit of caffeine on athletic agility and skill is unclear, as the doses used were similar in all studies. It could, however, be due in part to some methodological differences. All of the studies that found a performance-enhancing effect of caffeine on sports-related motor skill performance administered the tests interspersed within or after a period of exercise to induce fatigue and/or simulate game play, while others (Lorino et al., 2006) did not. Perhaps this provides support to the notion that caffeine is more likely to benefit motor skill performance of athletes when they are physically/mentally fatigued (e.g., toward the end of practice or a game). This finding also illustrates the importance of using sport-specific tests in realistic athletic situations/environments to determine caffeine's impact on sport performance.

It is noteworthy that some studies have found a negative effect of caffeine ingestion on fine motor coordination (hand steadiness), anxiety and tenseness. These negative effects have occurred mostly in individuals who are not caffeine users or when the caffeine dose was ≥ ~300 mg (Smith, 2002). However, it is important to keep in mind that this level of caffeine has also benefited motor skill performance, including in the previously described studies with athletes.

Caffeine's effect on cognitive and motor skill performance is likely mediated by its inhibition of adenosine receptor sites. Adenosine is a neurotransmitter-inhibitor with sedative-like properties, thus blocking the action of adenosine results in central effects, which can positively impact pain perception, fatigue, perceived exertion, cognition, alertness and mood during exercise (Davis & Green, 2009). The optimal dose of caffeine is unknown. Only moderate doses (5-6 mg/kg) have been used in the sport-specific studies, but lower doses (~100-250 mg) have also been efficacious in endurance studies (Pasman et al., 1995) as well as civilian and military studies (Lieberman, 2003). Finally, contrary to popular belief, caffeine intake (< ~450 mg) does not have a negative impact on fluid/electrolyte balance or thermoregulation when consumed before exercise and/or exposure to environmental heat stress (Armstrong et al., 2007). Based on the available data, it is likely that 5-6 mg/kg (2.3-2.7 mg/lb) of caffeine consumed before and/or during practice or competition has the ability to improve cognitive and motor skill performance in sports. Perhaps lower doses may also have an effect, but more studies, with standardized and validated protocols, are needed to elucidate optimal dose and timing of caffeine intake.

Carbohydrate

It is well established that carbohydrate feedings can improve endurance performance (Jeukendrup, 2004). The literature suggests that carbohydrate may also enhance performance in tests that simulate the skills and cognitive demand of various team/ skill sports. For instance, carbohydrate (5-8% drink) ingestion throughout exercise has improved athletes' performance during sport-specific skill tests, such as passing and dribbling precision in male semiprofessional and professional soccer players (Ali & Williams, 2009; Ostojic & Mazic, 2002), dribbling, agility and shooting in university soccer players (Currell et al., 2009), stroke quality in tennis players (Vergauwen et al., 1998) and shooting accuracy in boy basketball players (Dougherty et al., 2006). In addition, consumption of a 6% carbohydrate electrolyte solution significantly improved performance during a whole-body motor skills test and decreased ratings of fatigue during an intermittent exercise protocol similar to team sports (Welsh et al., 2002; Winnick et al., 2005, Figure 2). Collardeau et al. (2001) found that reaction time during a complex cognitive test at the end of a 100-min run was improved with a 5.5% carbohydrate electrolyte solution compared to placebo.

However, not all studies have been positive. Hitting accuracy during a ball-machine test in male and female tennis players (Ferrauti et al., 1997), motor skills in male Rugby players and shooting accuracy in male high school and college basketball players (Baker et al., 2007b) were not different when athletes consumed a 6% carbohydrate drink compared to placebo. Moreover, several studies have found no benefit of carbohydrate intake on cognitive performance during exercise. According to Roberts et al. (2010), Winnick et al. (2005) and Welsh et al. (2002), ingestion of a 6% carbohydrate electrolyte solution had no impact on team sport athletes' ability to concentrate and make quick decisions.

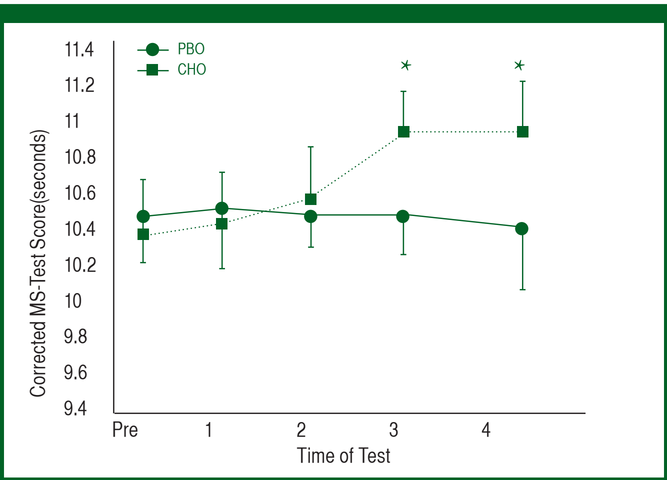

Figure 2. Motor skill performance with a 6% carbohydrate solution (CHO, ~41 g/h) and a flavored placebo (PBO) ingested before and during an intermittent high-intensity exercise protocol simulating a team game (four 15-min quarters and 20-min halftime). The athletes' performance during the motor skill test (which required a combination of speed and agility) was significantly improved with CHO vs. PBO, but only in the 3rd and 4th quarters of the simulated game (i.e., when the subjects were fatigued). Values are mean ± SEM; * P < 0.05 for CHO compared with PBO. (From Winnick et al., 2005).

Also, Baker et al. (2007a) found that a 6% carbohydrate electrolyte solution did not improve vigilance-related attention compared to placebo in male basketball players. Overall, the effects of carbohydrate on cognition and skill performance are less consistent than the effects on endurance capacity. However, it may be that the tests used to measure motor skills and cognition in athletes are not sensitive enough to detect possible improvements conferred by carbohydrate intake. To alleviate this issue, it would be helpful to design protocols that are not only valid (sport-specific and relevant to actual performance), but also are highly sensitive (high signal to noise ratio) for use in future studies.

The mechanism for improved motor skill performance reported in some studies is not entirely clear. Emerging research indicates that a mouth rinse with a carbohydrate-containing drink is associated with improvements in endurance performance (Jeukendrup & Chambers, 2010). This has led researchers to hypothesize that carbohydrate's ergogenic effect during high-intensity exercise lasting less than ~1 h may be mediated by carbohydrate-sensitive receptors in the mouth affecting the central nervous system and improving central command (Jeukendrup & Chambers, 2010). In fact, the oral exposure to a 6.4% glucose or maltodextrin solution has been shown in functional magnetic resonance imaging studies to activate regions of the brain associated with reward and motor control during exercise (Chambers et al., 2009). The mechanism by which carbohydrate improves exercise/sport performance, including cognitive performance and motor skills in stop-and-go sports may be due in part to activation of carbohydrate-sensitive receptors in the mouth and subsequent effects on the brain and motor control. However, given that the benefits of carbohydrate seem to be more apparent toward the end of competition (i.e., when the athlete is getting fatigued) it is possible that carbohydrate improves performance through nutritional mechanisms (maintenance of blood glucose concentration and/ or carbohydrate oxidation rates, see Jeukendrup, 2004 for review). Further research is needed to better understand the mechanisms involved in skill improvements with carbohydrate intake.

The overall body of evidence suggests that consumption of carbohydrate (e.g., in a 5-8% carbohydrate drink) before and/ or during practice or competition may improve skill performance. However, future investigations with standardized and validated sport-specific protocols are needed to determine the optimal dose and timing of carbohydrate intake

Cocoa Flavanols

Flavanols are a type of polyphenol antioxidant found in high concentrations in cocoa beans. The literature on acute intake is sparse, but two human studies suggest that a single dose of cocoa may have beneficial effects. Scholey et al. (2010) found that compared to placebo, 520 and 994 mg cocoa flavanol significantly improved cognitive performance and attenuated self-reported fatigue (520 mg dose only). Field et al. (2011) fed healthy young adults dark chocolate (720 mg cocoa flavanol) or white chocolate (trace amount of flavanol) in a crossover study and found that subjects experienced improved visual (contrast sensitivity and reaction time) and cognitive (memory and reaction time) performance in the dark chocolate trials relative to the white chocolate trials. The biological mechanism by which cocoa flavanol (primarily epicatechin) improved performance may be related to increased brain perfusion induced by nitric oxide-dependent vasodilation (Francis et al., 2006; Fisher et al., 2006). However, these positive results and putative mechanism for improved performance with cocoa flavanol intake should be viewed with caution because few human studies have been conducted.

Ginkgo biloba

Ginkgo biloba is an herbal extract from the leaves of the maidenhair tree and has been widely used in traditional Chinese medicine for its purported benefits on memory and other aspects of cognitive function. However, studies have found conflicting results on the acute effects of Ginkgo biloba intake (120-600 mg) (Gorby et al., 2010). In fact, a recent meta-analysis concluded that Ginkgo biloba had no significant positive effects on memory, executive function or attention in healthy individuals (Laws et al., 2012). It is also important to note that the effects of Ginkgo biloba intake have not been tested in athletes.

Ginseng

Ginseng is commonly touted to have stimulating effects in individuals who are fatigued and under stress. There are several ginseng species, including Panax ginseng (Korean ginseng), Panax quinquefolius (American ginseng), Panax notoginseng (Sanchi ginseng), Panax japonicas (Satsuma-ninjin) and Eleutherococcus senticosus maxim (Siberian ginseng). The most commonly researched type of ginseng is Panax ginseng. The primary active components of Panax ginseng are ginsenosides, which are triterpene saponins that modulate hypothalamic-pituitary-adrenal axis activity (Gorby et al., 2010). However, the cognitive performance literature has shown mixed results after ingestion of 200-600 mg of Panax ginseng (Gorby et al., 2010). Moreover, some studies have reported detrimental effects on performance, including impaired response time (Gorby et al., 2010). Only one ginseng study has involved athletes. In 1966, Dalinger found that Siberian ginseng improved ratings of fatigue and motor skills (significantly higher number of target hits in the shooting event for the treatment vs. the control group) in skiers during a biathlon. Exercise-induced mental/physical stress and fatigue is an important factor involved in sports performance, but there is currently not enough evidence to support a cognition-enhancing effect of ginseng (Geng et al., 2010).

Guarana

The guarana seed comes from plants (Paullinia cupana) local to the Amazon. Only two studies have investigated the independent effects of guarana on cognitive performance. Kennedy et al. (2004) found that 75 mg guarana improved speed during an attention task compared to placebo in healthy young adults, but at the expense of reduced accuracy. In addition, Haskell et al. (2007) found that 37.5, 75, 150 and 300 mg guarana improved memory performance and subjective alertness and mood ratings compared to placebo. The positive study results may be attributed to the presence of caffeine in guarana seeds, although there is only ~36 mg of caffeine in 300 mg guarana. The effects of guarana ingestion on sport-specific performance are unknown. Thus, there is insufficient evidence at present to suggest guarana intake benefits athletes' cognitive or motor skill performance.

L-theanine

L-theanine is a nonprotein amino acid that is found almost exclusively in tea, especially green tea. An increase in alpha brain waves, the brain waves often associated with a relaxed, yet alert state, has been found with administration of 50 to 250 mg of L-theanine (Bryan, 2008). L-theanine purportedly exerts its effects on anxiety and brain function by influencing the concentrations of the neurotransmitters dopamine, serotonin and γ-aminobutyric acid (Bryan, 2008). Decreased anxiety and increased tranquility scores have been reported after administration of 200 mg of L-theanine. However, others have not found an effect of L-theanine on mood (Bryan, 2008). The effect of L-theanine on various cognitive tasks has been tested in healthy young adults; however, improvements have typically only been reported when L-theanine is combined with caffeine (Bryan, 2008). No study to date has tested theanine in a sports setting. Thus, there is not enough evidence at present to suggest L-theanine intake improves alertness or any other aspect of cognition during sports.

Tyrosine

Tyrosine, a large amino acid found in many animal and plant protein foods, is a dietary precursor for catecholamine synthesis and is thought to be an effective treatment for mitigating some adverse behavioral, cognitive and physiological effects of acute stress. It has been hypothesized that central catecholamine neurons are unable to synthesize sufficient neurotransmitter (particularly norepinephrine) during acutely stressful situations. Administration of tyrosine enhances the ability of neurons to release neurotransmitters, thus preventing the cognitive deficits that typically occur with stress (Lieberman, 2003). Many of the studies demonstrating the stress-mitigating effects of tyrosine have been conducted in animals. However, the potential use of tyrosine as an acute cognitive performance enhancer has also been explored in humans, especially during military operations. The results of the human studies have generally been in agreement with that of the animal studies. For example, tyrosine intake (100-300 mg/kg across six different studies) has mitigated the performance decrements in memory, logical reasoning, map/compass reading, pattern recognition, reaction time, visual vigilance and psychomotor function during acute environmental stress and/or sleep deprivation in healthy young adults (Lieberman, 2003). Only one study has examined acute tyrosine ingestion and cognition in an athlete population.

In a crossover study, Watson et al. (2012) compared the effect of 150 mg tyrosine [total given in two 250-mL (8.5 oz) aliquots before and 150 mL (5 oz) aliquots every 15 min during exercise] vs. placebo on cognition in eight physically active, unacclimated men after cycling (70% VO2 peak) to exhaustion (~60 min) in the heat. Tyrosine had no effect on concentration, decision-making, memory and rapid visual information processing. Tyrosine has not been tested in a skill or team sports setting. Thus, there is no data to suggest that the success of tyrosine in military operations (with extreme stresses and sleep deprivation) translates to improved performance on the field of play.

Others

Other dietary constituents that have been suggested to impact mood, cognition and/or motor skill performance include theobromine, quercetin, vitamins and minerals, polyphenols, polyunsaturated fatty acids, herbs and spices, Rhodiola rosea, sage, soy isoflavones, choline precursors, acetyl-L-carnitine, creatine, huperzine A and phosphatidylserine. There is a lack of supporting evidence in young healthy adults that these dietary constituents alter cognitive performance. For many of these dietary constituents, there are few human studies and/or they have primarily been tested in chronic intake studies, usually related to mitigation of age- and disease-related cognitive impairments.

Summary

The dietary constituents with the most scientific support to benefit cognitive aspects of sports performance are caffeine and carbohydrate. At this time, there is insufficient evidence to substantiate the use of any other dietary constituents to benefit sports-related cognition or motor skill performance. More work is needed to determine optimal dosage/timing of caffeine and carbohydrate intake and it is imperative that valid, reliable and sensitive batteries of cognitive and motor skills tests are developed for use in future efficacy studies.

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