Effective Nutritional Ergogenic Aids

Elizabeth Applegate

Athletes use a variety of nutritional ergogenic aids to enhance performance. Most nutritional aids can be categorized as a potential energy source, an anabolic enhancer, a cellular component, or a recovery aid. Studies have consistently shown that carbohydrates consumed immediately before or after exercise enhance performance by increasing glycogen stores and delaying fatigue. Protein and amino acid supplementation may serve an anabolic role by optimizing body composition crucial in strength-related sports. Dietary antioxidants, such as vitamins C and E and carotenoids, may prevent oxidative stress that occurs with intense exercise. Performance during high-intensity exercise, such as sprinting, may be improved with short-term creatine loading, and high-effort exercise lasting 1–7 min may be improved through bicarbonate loading immediately prior to activity. Caffeine dosing before exercise delays fatigue and may enhance performance of high-intensity exercise.

Key Words: dietary supplements, carbohydrate, protein, amino acids, antioxidants, creatine

Athletes of all competitive levels speak about embracing the ideal of sport: the quest for success through hard work and unaided effort, or simply doing the best with what you have. This ideal, however, does not match reality in competitive sports. Beyond genetic endowment and training, many athletes turn to extrinsic methods, such as the use of ergogenic aids, to enhance performance.

The use of performance-enhancing aids has been documented since ancient times (2, 19), and such practices are not reserved for elite or Olympic-level athletes. Back-of-the-pack runners and “weekend warriors” also quest for success at their own levels and look for means of achieving success beyond their own abilities and efforts. Since many athletes are looking for ergogenic aids that do not have side effects and cannot be detected during drug testing, nutritional ergogenic aids, including carbohydrate, creatine, and dietary antioxidants, are promising alternatives.

Nutritional ergogenic aids encompass a broad range of substances that include standard dietary constituents such as carbohydrate and protein as well as atypical dietary constituents such as sodium bicarbonate and creatine. Often, nutritional ergogenic aids must be consumed in amounts that would be unachievable through food consumption alone and thus require users to take supplemental quantities for the purported benefits. For example, creatine, a popular nutritional ergogenic aid among strength athletes, is consumed in powder or pill form. Amounts of

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Creatine shown to be ergogenic would require astronomical daily consumption of raw meat, a source of creatine (49). A brief listing of nutritional ergogenic aids follows:

- Acetyl choline
- Amino acids
  (individual/combinations)
- Bee pollen
- Caffeine
- Carnitine
- Chromium picolinate
- CoQ10
- Creatine
- Eicosanoids
- Ginseng
- Hydroxy methylbutyrate (HMB)
- Inosine
- MCT oils
- Octacosanol
- Omega-3 fatty acids
- Royal jelly
- Spirulina
- Sodium bicarbonate
- Sodium phosphate
- Vitamins (individual/combinations)
- Wheat germ oil

As described by Butterfield (8) and Williams (55), nutritional aids can be divided into four categories: (a) products representing an energy source (e.g., carbohydrate); (b) substances that may enhance anabolism, thereby favorably altering body composition (e.g., amino acids); (c) products that act as cellular components, playing a role in exercise metabolism (e.g., sodium bicarbonate); and (d) products that may enhance recovery or an aspect of recovery from physical exertion (e.g., dietary antioxidants). This discussion focuses on the documented ergogenic potential of several nutritional performance aids: carbohydrate, protein and amino acids, dietary antioxidants, creatine, sodium bicarbonate, and caffeine.

**Evaluation of Ergogenic Aids**

Health food/supplement retail outlets carry numerous nutritional aids purported to enhance performance, and most fitness-related consumer magazines are full of advertisements for such products. Athletes often request fitness professionals to evaluate claims made about ergogenic aids. Several challenges arise when evaluating nutritional ergogenic aids, including the lack of regulation regarding health and performance claims about products. Many athletes fall prey to the colorful advertisements and the testimonials made by successful athletes who “owe” their victories to a particular product. Fitness professionals and others who advise athletes must probe beyond the advertisements and product literature provided by manufacturers.

In a recent article, Butterfield (8) described problems and solutions in evaluating performance-enhancing claims made about nutritional ergogenic aids. Three steps can be taken to evaluate claims. The first is to investigate the performance claim based upon a physiological and biochemical understanding of exercise. In essence, does the performance claim make sense? This requires knowledge in a variety of applicable fields such as nutrition, exercise physiology, and biochemistry. The second step is to investigate supportive evidence and use care when the evidence is not published research from peer-reviewed journals. For further reading on this subject, refer to a review by Sherman and Lamb (46). The third step is to determine the safety, ethical, and legal consequences of taking the ergogenic aid.
For example, excessive intake of a nutrient may impair the absorption or action of another nutrient. It is also crucial to examine ethical and legal issues particularly as they relate to the International Olympic Committee (IOC) doping rule, which states that “the use of a physiological substance taken in abnormal quantity . . . with the intention of increasing [performance] in an artificial and unfair manner. . . is to be regarded as doping” (57, p. 122). However, difficulty lies in establishing what constitutes “abnormal quantities” of specific cellular components or energy substrates.

**Nutritional Performance Aids**

**Carbohydrate**

For several decades, carbohydrate has been viewed as an effective ergogenic aid. Scandinavian researchers in the 1930s and 1960s demonstrated that high-carbohydrate diets improved endurance performance (4, 10). Their work became the foundation for the dietary regimen that many athletes use today to modify carbohydrate intake prior to, during, and following prolonged endurance exercise. This dietary regimen boosts muscle glycogen stores, delays fatigue, and enhances recovery. This brief discussion is limited to carbohydrate intake prior to and following exercise as an ergogenic aid.

Because fatigue during prolonged exercise is associated with muscle glycogen depletion, athletes are recommended to consume diets that provide 9–10 g carbohydrate/kg body weight (15). Carbohydrate consumption as a percentage of total caloric intake for an endurance athlete should be at least 60% (52). For several days prior to competition, the literature suggests increasing carbohydrate intake to approximately 70% of total energy intake. Supercompensating muscle glycogen stores by increasing carbohydrate intake and tapering training enhances performance when practiced several days prior to competition or prolonged exercise (31, 45).

Although glycogen loading regimens are considered effective for endurance athletes participating in events longer than 90 min, some research suggests that a similar loading regimen may improve performance in high-intensity, short-duration exercise. In a random crossover design, Pizza et al. (42) compared runners on a mixed diet (4.0 g/kg body weight) to those on a high-carbohydrate diet (8.2 g/kg body weight) consumed for several days prior to an exhaustive run at VO₂max. Subjects completed a 15-min submaximal treadmill run at 75% of VO₂max. Following a 5-min rest, the subjects ran a performance run to exhaustion at their VO₂max workload. Time to exhaustion on the performance run was longer (approximately 23 s) and carbohydrate oxidation greater following the high-carbohydrate diet.

Preexercise feedings of carbohydrate have also been suggested to affect performance, with the timing of intake and possibly the form of carbohydrate (e.g., glycemic index) as determining factors. Carbohydrate ingested 3–6 hr before exercise enhances performance (14, 27, 44) most likely by “topping off” liver and muscle glycogen stores and increasing glucose availability via the circulation. The literature contains mixed findings regarding carbohydrate ingested 30–60 min prior to exercise; it has been shown to improve performance (47), impair performance (22), and have no impact (23).

The glycemic index (GI) of carbohydrate-containing foods consumed prior to exercise has been suggested to affect performance by maintaining blood glucose levels (51). The GI of a food reflects the magnitude of the blood glucose rise
following the ingestion of that food. Low-GI foods (e.g., lentils, milk, apples) may have potential benefits over high-GI foods (e.g., raisins, bagel, or banana) consumed 30–60 min prior to endurance exercise. The literature suggests that low-GI foods may increase fat oxidation and potentially spare glycogen by minimizing hypoglycemia that occurs at the start of exercise following consumption of high-GI carbohydrate (53).

An adequate carbohydrate intake is essential in repleting glycogen stores following prolonged exercise (4, 16). The literature suggests that a carbohydrate intake of 7–10 g/kg body weight within 24 hr after prolonged exercise normalizes muscle glycogen levels. Limited research has been performed that links this rapid normalization of glycogen stores following exercise to improved endurance capacity or exercise time to exhaustion. Fallowfield and Williams (21) reported improved endurance capacity 22.5 hr after a bout of prolonged exercise in runners consuming a high-carbohydrate diet (8.8 g/kg body weight) versus a mixed diet (5.8 g/kg body weight). Burke et al. (7) and others (53) have suggested that high-GI foods are more beneficial than low-GI foods following prolonged exercise, because high-GI foods enhance glycogen resynthesis. To date, however, research does not support the idea that consumption of high-GI foods following exercise provides a performance benefit over low-GI foods in subsequent endurance events.

**Protein and Amino Acids**

The lure of protein as a potential ergogenic aid has been documented for several decades. Initially, athletes turned to supplemental dietary protein to enhance muscle mass (33), and in the last 20 years they have focused on protein powders, isolates, and individual amino acid supplements (48). Many athletes look to protein to optimize body composition. For strength athletes such as football players, increased muscle mass may enhance strength and power. Runners and other endurance athletes, on the other hand, want to reduce body fat levels while maintaining lean body mass. Optimizing body composition, or lean body mass, requires sufficient energy and protein intake (36).

The literature suggests that both strength and endurance athletes’ protein needs are greater than the Recommended Dietary Allowance (RDA), which is 0.8 g/kg body weight daily. Lemon (35, 36) and others (56) recommend an intake of 1.5–2.0 g/kg body weight daily for strength athletes. Since protein catabolism may account for 5 to 10% or more of the energy requirements during prolonged exercise, particularly if glycogen stores are low (37), endurance athletes are recommended to consume about 1.2–1.4 g/kg body weight daily provided energy intake is adequate (36).

These protein recommendations for both strength and endurance athletes are easily achieved through dietary intake of typical foods. Athletes are recommended to consume 12–15% of their total energy intake as protein. For a 70-kg runner consuming 14.7 MJ (3,500 kcal) daily, a protein intake of 105–131 g represents 12–15% of the total energy intake and translates to 1.5–1.9 g/kg body weight daily, well within the recommended range.

The ergogenic potential of individual amino acids to stimulate muscle growth, enhance strength, and perhaps delay fatigue is less clear and requires further exploration with well-controlled research studies. While several studies suggest that individual amino acid supplementation may stimulate protein synthesis and in turn
enhance lean body mass gains and muscle strength by elevating human growth hormone and insulin secretion (6, 20), others do not support this effect (for review, see 34 and 36).

Supplementation of branched-chain amino acids (BCAA) during prolonged exercise has been hypothesized to delay fatigue (17). The theory is that an increased serum ratio of free tryptophan to BCAA may cause fatigue through increased production of the brain neurotransmitter serotonin. To date, several studies have shown that BCAA supplementation during exercise may delay fatigue (17), but further research is needed for a conclusive recommendation.

**Dietary Antioxidants**

Antioxidant nutrients including carotenes and vitamins C and E do not appear to directly affect exercise performance. Instead, these and other antioxidants may enhance performance indirectly by enhancing recovery from exercise; enhanced recovery comes from their ability to detoxify free radicals that are produced during strenuous exercise such as intense aerobic exercise or resistance training. There is growing evidence that free radicals mediate skeletal muscle damage, soreness, and/or inflammation following strenuous exercise. As a result of increased oxygen use by mitochondria during exercise, lipid peroxidation increases. These peroxides, according to the literature, are then detoxified by dietary antioxidants, along with antioxidant enzymes (for review, see 13, 18, and 30). In theory, supplemental dietary antioxidants may reduce oxidative stress and skeletal muscle damage associated with strenuous exercise.

Several research studies suggest that supplemental dietary antioxidants, singularly and in combination, reduce indices of oxidative stress, such as lipid and protein peroxidation (18). One group of researchers who employed 5 months of vitamin E supplementation in competitive cyclists found reduced indices of oxidative stress compared to controls following a performance cycling test (43). In a recent study, runners who consumed an antioxidant-fortified (commercially available) food bar for several weeks experienced less oxidative stress following an exhaustive treadmill run compared to the control condition of an unfortified bar (9). In addition to elevated levels of circulating antioxidants, runners also experienced less lipid and protein oxidation. Also, low-density lipoprotein oxidation was reduced following fortified bar consumption. Such protection from oxidative damage may have implications for preventing or reducing the risk of chronic diseases such as vascular disease and cancer.

Several researchers and health professionals have recommended that athletes and active individuals would benefit from supplemental intake of dietary antioxidants (5). Some have made specific recommendations ranging from 600 to 3,000% RDA for vitamins C and E and beta carotene. While further studies are needed for specific recommendations for levels of dietary antioxidant intake, evidence thus far supports that supplemental intake protects against oxidative stress due to exercise and perhaps enhances recovery and minimizes muscle soreness.

**Creatine**

Currently one of the most popular ergogenic aids used by a wide variety of athletes, creatine has been reported to improve performance in certain exercise protocols (25, 50). In the muscle, creatine phosphate (CP) is necessary to maintain adenosine
triphosphate (ATP) levels and thus support muscle contractions during high-intensity exercise. CP depletion has been implicated as a primary factor in fatigue during high-intensity exercise (11). In theory, then, increasing muscle levels of CP via supplementation may delay fatigue and enhance performance in exercise requiring force maintenance, but not during prolonged submaximal exercise.

Studies show that creatine supplementation of approximately 20–25 g/day for several days increases creatine levels in the skeletal muscle by 20% (28). Several studies show that following this brief period of supplementation, work output is increased in exercise protocols involving repeated bouts of short-duration activity such as maximal knee extensions, cycling ergometry, and repeated short treadmill runs (26, 40, 49). However, when protocols involve a single session of maximal-effort exercise, such as a swim or run sprint, creatine supplementation is not beneficial.

To date, few studies have focused on the impact of creatine supplementation on submaximal exercise lasting more than 5 min. In one study, performance time on a 6-km terrain run was impaired following creatine supplementation (3). As suggested by these authors, the longer running time may be a consequence of weight gain experienced by the runners while on creatine supplements. Several other researchers have reported increased body weight following several days of creatine supplementation (26, 50). Most speculate that the increase in body weight is due to greater water content of the muscles following creatine loading. More research is needed that involves longer periods of creatine supplementation to determine if creatine increases protein synthesis and lean body mass.

While anecdotal evidence suggests that muscle cramping and intestinal discomfort are possible side effects of creatine supplementation, published research does not support these effects. Additionally, “field” use of creatine supplementation is often in a cyclic pattern of loading—several days of creatine loading followed by several days of no supplementation. Research is needed to determine if this type of supplementation regimen enhances performance particularly during the periods without supplemental creatine. With the popularity of this ergogenic aid and the broad use of creatine, much more research is needed to determine effective doses, maintenance doses, and possible detrimental side effects. Athletes should also consider that creatine supplementation may be considered a violation of the IOC doping rule.

**Sodium Bicarbonate**

Athletes who engage in high-intensity exercise such as sprint cycling and swimming along with track events in the 400 to 800 m range are interested in ergogenic aids that buffer against lactic acid. Sodium bicarbonate, or baking soda, is a popular buffering agent. During near-maximal exercise efforts lasting more than approximately 60 s, muscles rely on the anaerobic breakdown of glucose to lactic acid. This metabolic by-product, however, increases muscular [H+] . One of the body’s natural buffering agents is bicarbonate, which helps offset this drop in pH that contributes significantly to muscular fatigue. The drop in pH as a result of lactic acid accumulation is thought to inhibit the resynthesis of ATP as well as inhibit muscle contraction (29, 30).

Bicarbonate loading (ingestion of sodium bicarbonate), in theory, would increase the body’s capacity to buffer lactic acid, thereby delaying fatigue during high-intensity exercise. According to the literature, including a meta-analytical review (39), sodium bicarbonate is an effective ergogenic aid during exercise lasting approximately 1 to 7 min, particularly when repeated sprints or an interval-style
exercise protocol is used. In those studies that measured time to exhaustion, performance was enhanced approximately 30% (39). Most studies indicate an effective dose of 300 mg/kg body weight taken 1 to 2 hr prior to high-intensity exercise (29, 38, 39). However, it is not clear whether the ergogenic benefit of sodium bicarbonate is a result of buffering or perhaps the sodium ion itself, which some suggest may be an ergogenic aid (32).

Athletes consume sodium bicarbonate as baking soda mixed with water or take gelatinlike capsules marketed as buffering agents. These sometimes contain other buffering agents such as sodium citrate and sodium phosphate. Athletes are encouraged not to exceed recommended dosages, because severe alkalosis may result. Additionally, side effects may occur such as gastrointestinal discomfort, bloating, and diarrhea, particularly if sufficient water (at least a liter) is not taken with the sodium bicarbonate. While sodium bicarbonate is not currently banned by the IOC, athletes should consider that bicarbonate loading may violate the IOC doping rule.

Caffeine

Perhaps because of caffeine's availability and social acceptance, it has become the most casually and widely used ergogenic aid by a wide variety of athletes ranging from elite competitors to weekend warriors. Caffeine occurs naturally in several foods, such as chocolate, coffee, and tea, and is added to others, such as soft drinks and medications. The ergogenic potential of caffeine has been noted for some time, and currently caffeine is on the IOC's list of restricted substances. Yet the legal limit of 12 μg/ml of urine allows athletes to consume caffeine without fear of disqualification. In fact, doses of caffeine of 3–9 mg/kg body weight enhance athletic performance without exceeding the "legal" limit (12, 24). Although generally thought to be of value in endurance events, caffeine has recently been suggested to improve anaerobic, high-intensity efforts.

Caffeine is theorized to improve performance in two ways. As a central nervous system stimulant, caffeine affects perception of effort, wards off drowsiness, and increases alertness. Most likely these effects involve stimulation of the sympathetic nervous system (41). Caffeine is also thought to improve performance through altering fuel utilization, specifically, increasing fat oxidation and reducing carbohydrate use. This effectively spares glycogen and helps delay fatigue during prolonged exercise sessions (24).

Well-controlled studies have demonstrated that 3–13 mg caffeine/kg body weight taken 1 hr prior to exercise improves endurance performance (12, 24) by prolonging time to exhaustion. Exercise protocols typically involve cycling or running at approximately 80% VO₂ max. Although the ergogenic potential of caffeine has been demonstrated in laboratory settings, few well-controlled studies have assessed the effectiveness of caffeine in the field. Anecdotal, countless runners and other athletes, elite and recreational, ritualistically drink coffee or other caffeinated beverages prior to exercise.

Recently, caffeine has been touted as an ergogenic aid during high-intensity exercise. One study investigated the effect of a moderate caffeine dose on run time for a 1,500-m simulated race. Ingestion of caffeine improved run time and the speed of the “finishing burst” (54). The ability of caffeine to enhance short-term exercise performance does not appear to be related to glycogen sparing but perhaps is due to direct action on the muscle or the central nervous system (1).
More research is needed to establish if the ergogenic effect of caffeine is gender specific, because most studies have included only male subjects. Additionally, since caffeine also acts as a diuretic, hydration status following caffeine use should be explored more fully, particularly in older recreational athletes, on whom very few studies have been performed.

Summary

Athletes use several effective nutritional ergogenic aids to enhance performance. Included in this discussion are standard dietary constituents, such as carbohydrate and protein along with atypical dietary aids such as bicarbonate and creatine. Use of these nutritional ergogenic aids has proven effective under certain conditions. In the search for a competitive edge, however, athletes and coaches must consider both ethical and legal issues when using a substance in abnormal quantities with the expressed intent to improve performance. Additionally, one must consider safety issues surrounding use of dietary ergogenic aids. Insufficient research exists on the safety of many of theses dietary aids.

References


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**Wander Award on Biochemistry of Exercise**

**Honour Award on Biochemistry of Exercise**

The Wander Award, presented every 3 years by Isostar Sport Nutrition Foundation and the Research Group on Biochemistry of Exercise (ICSSPE-UNESCO), is given in recognition of the best study (in English) on (a) muscle energy metabolism and exercise or (b) sports and nutrition. Potential participants are currently invited to submit unpublished papers or those published between January 1, 1997 and June 30, 1999. For a subscription form, contact the Isostar Sport Nutrition Foundation, Attention: Rien Peeters, P.O. Box 1350, NL-6201 BJ Maastricht, The Netherlands (Fax: +31 43 367 06 76; E-mail: ISNF@novartis.unimass.nl).

The Honour Award, also presented every 3 years by ICSSPE-UNESCO, is designed to honor a scientist who had made substantial contributions to the development of research on the biochemistry and nutrition of exercise. Nominations must be submitted by December 31, 1999. Candidates can be nominated by writing to Martina Brouns, P.O. Box 1350, NL-6201 BJ Maastricht, The Netherlands (Fax: +31 43 367 06 76; E-mail: M.Brouns@novartis.unimass.nl).

The 2000 Awards will be presented during the 11th International Biochemistry of Exercise Conference in Little Rock, AK, June 3–7, 2000.