International Journal of Sport Nutrition and Exercise Metabolism, 2019, 29, 198-209
https://doi.org/10.1123/ijsnem.2018-0271

Human Kinetics
SCHOLARLY REVIEW

Sports Foods and Dietary Supplements for Optimal Function and Performance Enhancement in Track-and-Field Athletes

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Athletes are exposed to numerous nutritional products, attractively marketed with claims of optimizing health, function, and performance. However, there is limited evidence to support many of these claims, and the efficacy and safety of many products is questionable. The variety of nutritional aids considered for use by track-and-field athletes includes sports foods, performance supplements, and therapeutic nutritional aids. Support for sports foods and five evidence-based performance supplements (caffeine, creatine, nitrate/beetroot juice, β-alanine, and bicarbonate) varies according to the event, the specific scenario of use, and the individual athlete's goals and responsiveness. Specific challenges include developing protocols to manage repeated use of performance supplements in multievent or heat-final competitions or the interaction between several products which are used concurrently. Potential disadvantages of supplement use include expense, false expectancy, and the risk of ingesting banned substances sometimes present as contaminants. However, a pragmatic approach to the decision-making process for supplement use is recommended. The authors conclude that it is pertinent for sports foods and nutritional supplements to be considered only where a strong evidence base supports their use as safe, legal, and effective and that such supplements are trialed thoroughly by the individual before committing to use in a competition setting.

Keywords*:* ergogenic aids, performance nutrition, high performance, athletics

Numerous nutritional products are marketed with claims of optimizing athlete health and function and/or enhancing performance. Products that fall under the banner of "Sports Foods" or "Dietary Supplements," may be used to support performance during training and competition or for enhancing aspects of training adaptation, recovery, immune function, and/or overall athlete health. Effective marketing campaigns and athlete endorsements may convince us that certain sports foods and supplements are fundamental in allowing athletes to reach their sporting goals. However, this approach is naive in understanding the true foundations of athlete success, such as the inherent genetic predisposition for athletic characteristics, the many hours of well-structured/periodized training, appropriate underlying nutrition, adequate sleep and recovery, and of course, good overall physical and mental health. Nevertheless, if these variables are all accounted for, there may be a role for sports foods and dietary supplements in an athlete's training and competition routine, particularly within elite sport where marginal performance gains are pursued. The following review presents general considerations for track-and-field athletes using sports foods and dietary supplements to enhance performance, in addition to exploring the potential therapeutic/prophylactic use of these nutritional aids.

Definition of a Dietary Supplement

Maughan et al. (2018a) recently defined a dietary supplement as:

> A food, food component, nutrient, or non-food compound that is purposefully ingested in addition to the habitually consumed diet with the aim of achieving a specific health and/or performance benefit.

Prevalence

A recent systematic review and meta-analysis of 159 unique studies in athlete populations (Knapik et al., 2016) investigated the prevalence of dietary supplement use (defined using the Federal Drug Administration's Dietary Supplement Health and Education Act of 1994; e.g., sports foods, iron, vitamins, etc.) by sport, sex, and athlete status (i.e., elite vs. nonelite). High variability in supplement use among various sporting groups was reported,

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with the combined group summary prevalence estimate (SPE) ranging from 4 to 62% across various supplement types. When differentiated by athlete status, results showed that elite athlete cohorts (SPE male: ~69% and SPE female: ~71%) presented with greater rates of supplement use than their nonelite counterparts (SPE male: ~48% and SPE female: ~42%). Furthermore, sex differences were apparent, with greater use of supplemental iron reported by female athletes, whereas males used products such as protein, creatine, and vitamin E more often. Although specific supplement use among athlete groups is hard to quantify, these outcomes suggest that service providers (i.e., dietitians, physiologists, sports physicians) working with athlete cohorts should be aware of differences in the incidence and type of supplement use within a given group of athletes, with caliber and sex being discriminating characteristics. For further insights into the prevalence and rationale for use of supplements and sports foods, the reader is directed to recent comprehensive review of the topic (Garthe & Maughan, 2018).

Sports Foods

The term "Sports Foods" generally refers to specifically formulated food products that are commercially developed for use by athletes. The various categories of such foods are outlined in Table 1, with a specific function to target nutritional goals that underpin training adaptation, recovery, and competition performance (Burke & Cato, 2015). Although they often contain nutrients in similar amounts to those found in whole foods and manufactured products in the general food supply (hereafter, called "everyday foods"), sports foods may offer the practical advantage of combining all the nutrients needed for a specific goal in a single source. In addition, the use of novel food and packaging technology can make sports foods easy to transport, store hygienically, prepare, and consume, particularly in situations before, during, or after/between competition events and training sessions. However, although some sports foods resemble "everyday food," they also differ in that they may consist of only a few nutrients compared with the many hundreds of nutrients and phytochemicals found in the former. For that reason, sports foods should not be used as a dietary replacement for athletes, but rather as a supplementary strategy on occasions where a specific combination of key nutrients is required.

The ergogenic properties of sports foods, in general, can be ascribed to four main physiological goals, which they help to support:

a. Hydration: Fluid ingestion for maintaining or restoring hydration status.
b. Fuelling: Carbohydrate provision before, during, and following/between exercise.
c. Anabolism: Protein ingestion to promote amino acid delivery for optimal training adaptation and event recovery.
d. Osmolality: Electrolyte ingestion to replenish loss in sweat.

These goals are generally accepted by the broad sport nutrition scientific community as being determinants of sports performance and training response. Of note, the risk of dehydration and fuel/electrolyte depletion is predominately an issue during longer athletic events, such as distance running and race walking; furthermore, there is ample evidence of the benefits of hydration, carbohydrate fueling, and electrolyte replacements during these events (Burke, 2010; Hoffman et al., 2018). Alternatively, athletic sprint events require a high level of muscle power, and their training-induced muscle hypertrophy relies on adequate protein and amino acids provision around training sessions (Reidy & Rasmussen, 2016). Each sports foods category will contribute to one or more of these physiological goals, yet each in a variable degree. The link between the sports foods categories and their respective goals is summarized in Table 1.

Table 1 Summary of the Roles and Ingredients in Sports Foods

Product	Active ingredient / Physiological goal	Water / Hydration	Carbohydrates / Fueling	Protein / Anabolism	Electrolytes / Osmolality
Isotonic sports drink		✓✓	✓		✓
High-energy sports drink		✓	✓✓		✓
Electrolyte supplement (drink form)		✓			✓✓
Sports gel			✓✓		
Protein supplement (drink form)		✓	✓	✓✓	✓
Sports bars			✓	✓	✓
Sports confectionary			✓✓		
Liquid meal supplements		✓	✓✓	✓	✓
Advantages of sports foods		• Sports foods can contain only those ingredients that are actually needed during exercise. Foods in the general food supply, particularly whole foods, will usually contain other nutrients, such as fat and fibers, which are not needed during a race, and may cause gastrointestinal discomfort. • Sports foods may be manufactured to optimize serving size, convenience, digestibility, storage, and transport.			
Concerns about sports foods		• Sports foods are more expensive than "everyday foods" and may drain an unnecessarily large share of the athlete's budget. It should be noted that many sports nutrition goals can easily be met with the use of everyday foods. A typical example is the protein-rich recovery drinks that can be adequately replaced by the much cheaper dairy products (e.g., skim milk or yogurt). • An overreliance on sports foods as energy sources may lead to poor nutrient intake and limited dietary variety.			

✓ Can contribute to this goal. ✓✓ Is an important contributor to this goal.

Of course, manufacturers want to claim additional benefits of their specific products and proprietary blends, which usually lack any scientific substantiation, beyond the benefits of each compound in isolation. Of note, some manufacturers add performance supplements or other ingredients to sports foods. For instance, protein shakes can contain creatine, sport drinks or sports bars can contain caffeine, and vitamins can be found in the most unexpected places (e.g., in the so-called "sports/fitness waters" that provide a pleasant tasting drink rather than addressing any unique athlete need). This makes the distinction between sports foods and sports supplements more diffuse, and it also greatly complicates the work of sport nutritionists to keep track of the total daily doses of supplements and micronutrients to which athletes are exposed. To track the total ingestion of such ingredients and to reduce concerns around product contamination via raw ingredients that may be considered at higher risk of this problem, athletes are guided to choose brands of sports foods with the simplest formulations to meet the specific goals for which they are designed; in general, they should focus their use of performance supplements to separate protocols, using separate products, which have preferably been third-party batch tested or are manufactured by large (reputable) food companies. The exception to this might be caffeine, which already has a crossover to the food industry, as it is found in the athlete's diet via their intake of "everyday-consumer" products, such as coffee, tea, iced coffee beverages, and "energy drinks.".

In summary, sports foods may provide a valuable contribution to an athlete's nutrition plan, providing nutrients that support training adaptation (e.g., protein) and promote performance (e.g., carbohydrate and fluid/electrolytes). However, their role should not be overestimated, as many of those goals can, to a large extent, be also obtained by carefully selected "everyday" foods.

Performance Supplements

Although countless supplements are marketed with the claims of directly enhancing athletic performance, only a handful are supported by an evidence base that warrants consideration for trial use by athletes (see Figure 1 relevant to the decision-making process). A recent review of this area categorizes the commonly encountered performance supplements in terms of their research support and level of efficacy (Peeling et al., 2018). In addition, the recent International Olympic Committee consensus statement on supplement use by high-performance athletes (Maughan et al., 2018a) proposes that only five performance supplements have an adequate level of evidence to suggest marginal performance gains *may* be possible for elite athletes (a population where such gains are generally harder to obtain) when added to a bespoke and periodized training and nutrition plan. These supplements are summarized with the mechanism of action and the potential application to track-and-field athletics presented in Tables 2 and 3, respectively.

Caffeine

Caffeine shows well-established benefits for enhancing athletic performance across both endurance-based events and short-term, supramaximal tasks. Caffeine dosages of 3–6 mg/kg of body mass (BM), consumed ~60 min prior to exercise in the form of anhydrous caffeine (i.e., pill or powder form), are commonly shown to result in performance gains (Ganio et al., 2009). However, lower caffeine doses (<3 mg/kg BM, ~200 mg), provided both before and during exercise, have also resulted in an ergogenic benefit (Spriet, 2014). Of note, recent research has suggested that the ergogenic effects of caffeine are influenced by the athlete's variant of a number of genes, including the CYP1A2 gene involved in the liver metabolism of caffeine (Guest et al., 2018). This explains the well-known variability in individual responses to the "social" use of caffeine, confirming the need for athletes both to trial their intended performance uses of caffeine prior to implementation in competition and to take into account their personal history of reactions to caffeine intake in "everyday life" (e.g., effects on heart rate, jitteriness, or sleep quality). Interestingly, larger caffeine doses (≥9 mg/kg BM) do not appear to increase the performance effect (Bruce et al., 2000), and are more likely to increase the risk of *negative side effects* such as nausea, anxiousness, insomnia, and restlessness (Burke, 2008). Caffeine habituation seems to have limited impact on the performance effects of this stimulant (Goldstein et al., 2010); high-habitual daily caffeine users tend to encounter similar performance benefits as those with low and moderate intakes (Gonçalves et al., 2017). Furthermore, studies have shown that athletes need not undertake "caffeine withdrawal" over the days prior to competition use to achieve a performance improvement (Irwin et al., 2011). Earlier studies that suggested a larger performance improvement when caffeine supplementation was preceded by a dehabituation period may have been measuring the reversal of the negative effects of caffeine withdrawal (i.e., headache, fatigue, demotivation; Irwin et al., 2011) on top of the normal performance effect rather than a unique benefit.

The caffeine supplementation literature shows strong evidence of improved performance when it is consumed before events varying in duration from 5 to 150 min (Ganio et al., 2009). Furthermore, low–moderate doses of caffeine (100–300 mg) consumed *during* endurance exercise (after 15–80 min of activity) have also been shown to enhance endurance performance by a range of 3–7% (Paton et al., 2015; Talanian & Spriet, 2016). When considering short-term, supramaximal tasks, the ingestion of 3–6 mg/kg BM of caffeine taken 50–60 min preexercise relates to performance gains of >3% for anaerobic activities of 1–2 min in duration (Wiles et al., 2006). Therefore, there is support for high-performance track-and-field athletes in the longer sprints, middle distance, and endurance/ultraendurance events to consider competition use of caffeine. Furthermore, shifting the "social" intake of caffeine to target its effects to training sessions may help to improve the quality of some workouts, particularly if rehearsing competition practices or undertaking sessions in a fuel-depleted state (Lane et al., 2013).

Creatine Monohydrate

Creatine monohydrate (CM) supplementation increases muscle creatine and phosphocreatine stores, sustaining exercise that is otherwise limited by the inability of phosphocreatine resynthesis to keep pace with exercise fuel demands, for example, single and repeated bouts of high-intensity exercise (<150 s duration), with the most pronounced effects evident during tasks <30 s (Branch, 2003; Lanhers et al., 2017). Indeed, creatine supplementation received widespread attention in 1992 when the first report on successful loading protocols (Harris et al., 1992) was published at the same time as anecdotes emerged from the Barcelona Olympic Games regarding its use by gold-medal winning British track-and-field sprinters. In addition, chronic training adaptations, such as lean mass gains and improvements to muscular strength and power, have also been noted with both direct and indirect mechanisms proposed (Table 2). Less commonly, performance advantages for endurance athletes have also been suggested, including such

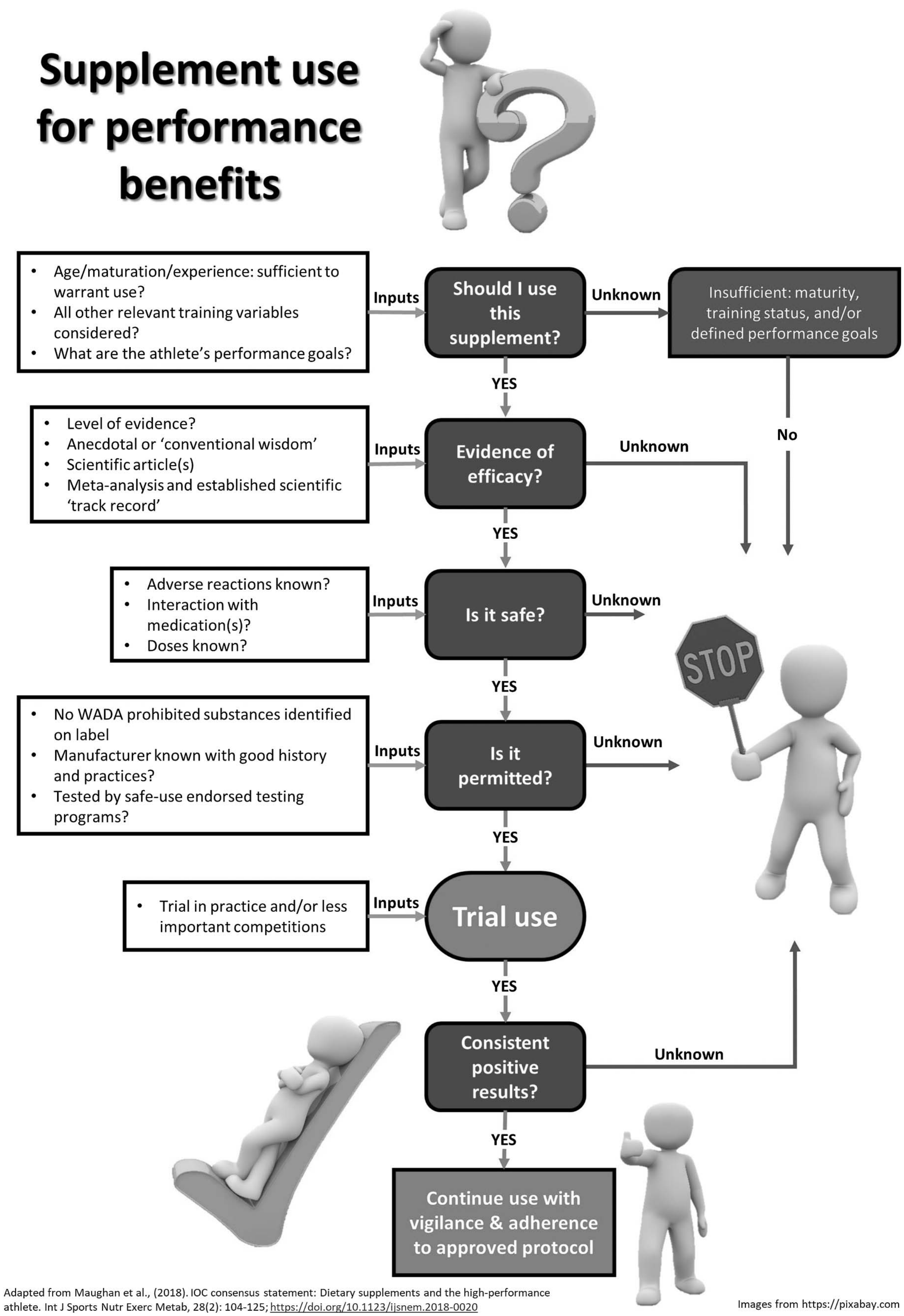

Figure 1 — A pragmatic approach to making decisions about supplement use to optimize function and performance in athletes. Adapted from "IOC consensus statement: Dietary supplements and the high-performance athlete," by R. J. Maughan, L. M. Burke, J. Dvorak, D. E. Larson-Meyer, P. Peeling, S. M. Phillips, … L. Engebretsen, 2018a, *International Journal of Sport Nutrition and Exercise Metabolism, 28*(2), pp. 104–125.

Table 2 Roles and Challenges of Evidence-Based Performance Supplements

Supplement	Mechanism of action	Challenges around use in track-and-field events (Burke, 2017)
Caffeine	Caffeine acts as an adenosine receptor antagonist, with many effects on different organs and systems. Actions include increases in epinephrine release, improvements in neuromuscular function, vigilance and alertness, and a masking of pain and perception of effort during exercise (Burke, 2008; Spriet, 2014).	• High degree of individual variability includes potential for negative response, minimal response, positive response, and super response; thorough practice is needed. • Repeated use for events within the same day (e.g., heptathlon and decathlon) requires careful planning of the timing and amount of doses, including whether a top up dose is even needed. • Use on successive days (e.g., heats and finals of many events in major meets) requires consideration of the effect on sleep and overall recovery, especially when the first event has a late-night schedule. • Interactions with the efficacy or side effects of other supplements used concurrently needs careful consideration and experimentation; this is a likely scenario in many events (see Table 3).
Creatine monohydrate	Supplementation with creatine monohydrate increases muscle creatine stores and augments the rate of PCr resynthesis, thereby enhancing short-term, high-intensity exercise capacity (Buford et al., 2007) and the ability to perform repeat high-intensity bouts. Chronic effects of increased muscle size and strength might be explained by indirect benefits (allowing the athlete to train harder) as well as the direct benefits of upregulation of cellular signaling and protein synthesis due to changes in cellular osmolality (Safdar et al., 2008). Benefits of additional muscle storage of glycogen and water might be of interest to endurance events (Twycross-Lewis et al., 2016).	• Weight gain of 1–2 kg associated with creatine supplementation (Buford et al., 2007) may be counterproductive for weight-sensitive events, such as jumps and distance races. However, a low-dose approach that avoids the CM "loading phase" may avoid such issues (Rawson et al., 2011). • Interactions with the efficacy or side effects of other supplements used concurrently needs careful consideration and experimentation (see Table 3). Indeed, there has been lengthy but unclear speculation that the independently achieved performance benefits of creatine supplementation might be negated by caffeine supplementation (Trexler & Smith-Ryan, 2015).
Nitrate	Nitrate enhances NO bioavailability via the NO_3^-–nitrite–NO pathway, which plays an important role in the modulation of skeletal muscle function (Jones, 2014). This pathway augments exercise performance via an enhanced function of Type II muscle fibers (Jones et al., 2016a), a reduced ATP cost of muscle force production, an increased efficiency of mitochondrial respiration, increased blood flow to the muscle, and a decrease in blood flow to VO_2 heterogeneities (Bailey et al., 2010).	• As for caffeine, responsiveness to nitrate supplementation is individual, and protocols for repeated use within the same day need planning. Furthermore, various research suggests a lack of response for athletes with a well-developed aerobic capacity (i.e., VO_2max >60 ml/kg; Jones, 2014). • Interactions with the concurrent use of other performance supplements require consideration; at present, this has been investigated in relation to use with caffeine with unclear results (Burke, 2017).
β-Alanine	β-Alanine is a rate-limiting precursor to carnosine, an endogenous intracellular (muscle) pH buffer during exercise (Lancha Junior et al., 2015). Chronic, daily supplementation increases skeletal muscle carnosine content (Saunders et al., 2017).	• Concurrent use of β-alanine and sodium bicarbonate supplementation is logical when maximal buffering capacity is needed; however, literature support for combined benefits is premature.
Sodium bicarbonate	Sodium bicarbonate acts as an extracellular (blood) buffer, aiding intracellular pH regulation by raising the extracellular pH and HCO_3^- concentrations (Katz et al., 1984; Lancha Junior et al., 2015). The resultant pH gradient between the intracellular and extracellular environments leads to efflux of H^+ and La^- from the exercising muscle (Katz et al., 1984; Mainwood & Worsley-Brown, 1975).	• Potential for gut disturbances is high risk in running-based events, likely due to the increased sodium content and large fluid intake required to consume the supplement. • Protocols for repeated use within the same day or successive days need planning. • Interactions with the concurrent use of other performance supplements require consideration; concurrent use with caffeine supplementation has been investigated in other sports and often seen to counteract the benefits of the former due to gastrointestinal side effects (Burke, 2017).

Note. PCr = phosphocreatine; CM = creatine monohydrate; NO = nitric oxide; ATP = adenosine triphosphate.

benefits as enhanced glycogen storage and thermoregulation secondary to the changes in the cellular environment associated with the additional storage of creatine and water (Cooper et al., 2012; Kreider et al., 2017); however, the potential negative influence of minor weight gain from such mechanisms should be considered in the context of event-specific performance requirements (see Table 2).

Effective supplementation protocols generally encompass a "loading phase" of ~20 g/day (divided into 4 equal 5 g doses/day), for 5–7 days, followed by a "maintenance phase," typically involving a single daily CM dose of 3–5 g for the duration of the supplementation period (Hultman et al., 1996). Alternative approaches propose lower doses of CM (2–5 g/day), consumed for approximately 4 weeks (Rawson et al., 2011), based on the concept that low doses of CM provided over an adequate time period can increase muscle creatine levels (Hultman et al., 1996). Of note, consuming CM concurrently with a mixed protein/carbohydrate source (~50 g of protein and carbohydrate) may enhance muscle creatine uptake via insulin stimulation (Steenge et al., 2000), while it takes ~4–6 weeks following the cessation of supplementation for muscle stores to return to baseline levels.

No negative health effects have been noted with the long-term use of CM (up to 4 years) when appropriate loading protocols are followed (Schilling et al., 2001), and in some instances, potential anti-inflammatory effects are proposed (Deminice et al., 2013). Therefore, creatine supplementation consumed according to the previously mentioned protocols shows strong efficacy for both

Table 3 Performance Supplements That May Achieve a Marginal Performance Gain in Track-and-Field Events as Part of a Bespoke and Periodized Training and Nutrition Plan

Event	Caffeine	Creatine	Nitrate	β-Alanine	Bicarbonate
Sprints: 100 m, 100-m hurdles, 110-m hurdles, and 200 m	✓	✓			
Sustained sprints: 400 m and 400-m hurdles	✓	✓		✓	✓
Middle distance: 800 m, 1,500 m, 3,000 m, and steeple chase	✓		✓	✓	✓
Long distance: 5,000 m, 10,000 m, cross-country, 20-km race walk, half marathon, marathon, 50-km race walk, and mountain/ultra running	✓		✓		
Jumps and throws: high jump, long jump, triple jump, pole vault, discus throw, hammer throw, javelin throw, and shot put	✓	✓			
Multievents: heptathlon and decathlon	✓	✓	✓	✓	✓

Readers are referred to Burke et al. (2019), da Costa et al. (2019), Slater et al. (2019); Stellingwerff et al. (2019), and Sygo et al. (2019).

acute and chronic performance gains, where power, strength, and short-repeated bouts of high-intensity exercise are encountered.

Nitrate

Nitrate supplementation has been shown to promote improvements in exercise tasks that predominately stress the aerobic energy system, such as time to exhaustion (4–25% increased performance) and sport-specific events (1–3% increased performance) lasting <40 min (Jones, 2014; McMahon et al., 2017). In addition, nitrate supplementation is proposed to enhance Type II muscle fiber function (Bailey et al., 2015) resulting in the improvement (3–5%) of high-intensity exercise efforts (Thompson et al., 2015; Wylie et al., 2016). Current evidence is equivocal for such benefit to exercise tasks lasting <12 min (Reynolds et al., 2016; Thompson et al., 2016), although more work is needed in this area.

Nitrate-rich foods include leafy green and root vegetables (i.e., spinach, rocket, celery, beetroot, etc.), although *beetroot juice* is the more popular supplement choice for exercise settings (McMahon et al., 2017). Acute performance benefits are generally seen within 2–3 hr following a NO_3^- bolus of 5–9 mmol (310–560 mg) (Hoon et al., 2014; Peeling et al., 2015); however, chronic periods of NO_3^- intake (>3 days) also appear beneficial to performance (Thompson et al., 2015, 2016).

There appears to be few side effects or limitations to nitrate supplementation other than the potential for minor gastrointestinal upset in some gut-sensitive athletes. In addition, an upper limit to the benefits of NO_3^- consumption has been shown (i.e., no greater benefit from 16.8 mmol [1,041 mg] vs. 8.4 mmol [521 mg]; Wylie et al., 2013), and it might also be considered that performance gains appear harder to obtain in elite athletes, with limited to no benefits generally seen in athletes with a maximal oxygen uptake (VO_2max) > 60 ml/kg (Jones, 2014). Therefore, individual trials of this supplement prior to use in competition are recommended to ensure its use is effective.

β-Alanine

β-Alanine supplementation is associated with the improved tolerance for maximal exercise in the range of 30 s to 10 min (Saunders et al., 2017), with small but potentially meaningful performance benefits (~0.2–3%) shown during both continuous and intermittent exercise tasks of this duration (Baguet et al., 2010; Chung et al., 2012). β-Alanine supplementation increases the muscle content of carnosine, an intracellular dipeptide with buffering, antioxidant, and anti-inflammatory properties. Of these effects, enhanced buffering is believed to explain the main performance benefit. β-Alanine dosing strategies typically involve the consumption of 3.2–6.4 g/day, ingested via a split-dose regimen (i.e., 0.8–1.6 g every 3–4 hr) over an extended supplement time frame of 4–12 weeks (Saunders et al., 2017). Regardless, a positive correlation between the magnitude of muscle carnosine change and performance benefit remains to be established (Saunders et al., 2017). Of note, the effectiveness of this supplement has also been shown in well-trained athletes (Bex et al., 2014; Saunders et al., 2017), although the performance margins for improvement are evidently smaller (Bellinger, 2014). A possible negative side effect of skin paresthesia should be considered, although sustained release tablets are noted to prevent this outcome and are reported to result in lower urinary loss of the supplement, possibly resulting in improved whole-body β-alanine retention (Decombaz et al., 2012). Finally, large interindividual variations in muscle carnosine synthesis have been reported with the use of β-alanine (Stautemas et al., 2018), and therefore, an individualized approach to supplementation must be considered.

Sodium Bicarbonate

Sodium bicarbonate ($NaHCO_3$) supplementation is proposed to enhance the performance (~2%) of short-term, high-intensity sprints lasting ~60 s in duration, with a reduced efficacy as the effort duration exceeds 10 min (Carr et al., 2011a). In contrast to β-alanine supplementation, which achieves a chronic elevation in intracellular buffering capacity, $NaHCO_3$ ingestion (consumed at a dose of 0.2–0.4 g/kg BM) achieves an acute increase in extracellular/blood buffering (Carr et al., 2011a) with peak blood bicarbonate levels occurring after 75–180 min (when consuming 0.3 g/kg BM $NaHCO_3$), which appear to decrease by 3-hr postsupplementation (Jones et al., 2016b). However, split doses (i.e., several smaller doses) taken over a 30- to 60-min time period (Krustrup et al., 2015) or serial loading with three to four smaller doses per day for two to four consecutive days prior to an event (Burke, 2013) has been proposed as methods to overcome the well-established gastrointestinal distress associated with this supplement. Further strategies used to minimize gastrointestinal distress include the coingestion of $NaHCO_3$ with a small carbohydrate-rich meal (~1.5 g/kg BM CHO; Carr et al., 2011b) or the use of the less effective but more gut-friendly sodium citrate as an alternative (Requena et al., 2005).

In summary, despite the relatively robust evidence base to support the consideration for use of these five supplements by well-trained athlete populations, the potential side effects and negative individual tolerance must be considered, and therefore, any supplement use should be thoroughly trialed in training before competition. Notwithstanding, as can be seen in Table 2, there are potential challenges for the use of these supplements within track-and-field events, including issues of repeated use and the potential for interaction when several potentially useful supplements are used together (Burke, 2017). The current literature relevant to such use is not well understood and requires more research.

Therapeutic Nutritional Supplements and Prophylactic Aids

In the context of this review, "therapeutic/prophylactic supplements" are considered as nutritional aids that can be used either to (a) correct a deficiency, (b) assist in the *possible* prevention of illness and/or injury, or (c) help in the recovery from the stress of physical workloads via an anti-inflammatory effect. For instance, it is well known that iron deficiency can impair hematologic adaptation, which left untreated can negatively impact on athletic performance (Garvican et al., 2011). However, nutritional correction of this issue via various intervention strategies has been regularly shown to have a positive impact on correcting the underlying deficiency and enhancing athlete performance (Dawson et al., 2006; Garvican et al., 2011; Woods et al., 2014).

Regarding illness, there is strong evidence to suggest that immunodepression can occur as a result of strenuous exercise (Castell et al., 2019; Peake et al., 2017), and a high incidence of upper respiratory tract illness is frequently reported (Drew et al., 2018; Nieman, 1994), before and particularly after endurance events. Low-energy availability has been identified as a key nutritional factor in such illness (Drew et al., 2018; Heikura et al., 2018); however, the provision of nutritional supplements to alleviate exercise-induced immunodepression and to aid more rapid recovery in athletes has also been well studied. Sometimes certain supplements initially appear promising, but further intensive investigation fails to provide sufficient evidence of consistent beneficial effects on some aspects of exercise-induced immunodepression. As different nutritional supplements become unfashionable, whether targeting immunodepression or performance, others take their place; however, the pros and cons of these need to be carefully studied. For instance, probiotic supplementation has been investigated in recent years (as have prebiotics), with preliminary evidence of positive effects on immune function (Cox et al., 2010) that might support the consistency of training and competition. However, the effects of such supplementation are dependent on appropriate doses of live bacteria of specific strains (e.g., *Lactobacillus, Bifidobacterium*), and larger studies are still needed to provide definitive evidence that probiotics benefit the immune function of athletes. Glutamine and branched chain amino acids, which are often marketed to support bodybuilding and postexercise recovery, also have an unclear role in supporting immune function in athletes (Bermon et al., 2017). Clearly, immunonutrition is an emerging and important area for consideration in the use of dietary supplements for athlete populations, and as such, the reader is directed to recent reviews in this area (Bermon et al., 2017; Castell et al., 2019), in addition to the comprehensive paper on feeding the immune system (Calder, 2013).

With respect to the inflammatory response, there is a growing body of work that is investigating anti-inflammatory and antioxidant aspects of various foods and supplements. For instance, food polyphenols possess strong antioxidant and anti-inflammatory properties (Tsao, 2010) that may be beneficial to exercise recovery. Specifically, the high-anthocyanin content of tart Montmorency cherries is proposed to reduce the inflammatory and oxidative stress responses to strenuous exercise, such as a marathon (Dimitriou et al., 2015; Howatson et al., 2010), or consecutive days of intermittent high-intensity activity (Bell et al., 2014). This may be particularly relevant to the heavy training loads of many high-performance athletes, as well as the competition recovery in multievents in track-and-field athletics or the programs of middle-distance runners with heats and finals across several events at major competition. Other anti-inflammatory nutrients include flavonoids such as quercetin and green tea extract, plus fish oil, each of which may have a beneficial effect on delayed onset muscle soreness (Ranchordas et al., 2018). Consumption of highly colored vegetables/fruit is often advised; this advice is appropriate for elite athletes (previously mentioned), as these flavonoids (including blueberries, blackcurrants, and cherries) have a beneficial effect on exercise-induced inflammation, muscle damage, and illness (Bermon et al., 2017). In addition, it is proposed that some of these foods may also have the ability to reduce exercise-induced oxidative stress; however, there is currently some controversy about whether high-dose antioxidant supplementation (in the form of pills, powders, and tablets) is advisable to alleviate exercise-induced generation of reactive oxygen/nitrogen species. Emerging evidence suggests that antioxidant supplementation mitigates important exercise-induced adaptations, which may also extend to the immune system (Bermon et al., 2017).

In summary, there are various roles for nutritional supplements for what may be considered "therapeutic applications"; however, much more work is needed in this area to assess the efficacy of these supplements and to determine their true effect on athletic performance.

Disadvantages of Sports Foods and Dietary Supplements

The decision to take a supplement will always involve an attempt to gain a functional advantage, in most cases being health protection/improvement, physique management or enhanced recovery, or a direct performance enhancement. Contrary to these potential benefits, is the consideration that the supplement inherently possesses certain risks against its use; such risks can be divided into three categories.

Risks of Labeled Content

All supplements worldwide are legally bound to be sold in packages that contain a listing of the ingredients. Some national legislations may be stricter than others in setting and enforcing the list of permitted ingredients in supplements, but any consumer, and certainly, athletes who consider taking supplements to support their athletic performance should not consume a product with ingredients that cannot be recognized in a basic Internet search. A so-called "proprietary-blend" listing exotic names and claiming commercial Intellectual property cannot be considered a transparent listing of ingredients.

Even when supplement contents are clearly listed, they cannot necessarily all be considered safe. In many countries, the regulations covering supplements do not require specific testing before going to market but rely on notification of adverse events to remove unsafe products from sale. This has led to the inclusion of toxic substances in highly popular products, for example, the bodybuilding and weight loss supplement OxyELITE Pro (USPlabs, Hermosa Beach, CA) was found to be associated with at least one death and a cluster of serious liver complications, attributed to the ingredient 1,3-dimethylhexanamine (also known as DMAA; Johnston et al., 2016). This was subsequently removed from the list of ingredients that may be included in supplements across many countries. Even where some ingredients might have been considered to be "safe use," basic toxicology laws dictate that any substance has the potential to lead to health-deteriorating effects when used by some individuals in specific scenarios or doses. For athletes, this is often preceded by decreased performance.

Risks of Undeclared or Unlabeled Content

Despite existing legislations, some supplements have been found to contain contaminants or health hazards, such as molds, glass, or animal feces (Benedict et al., 2016; Katz, 2013). A specific risk for competitive athletes is the undeclared presence of substances that are banned under the World Anti-Doping Agency (WADA) anti-doping code. Of course, these substances are sometimes identified on product labels, but athletes are either unaware that they are banned or are confused by technical/chemical names. For example, DMAA is a banned substance and has been included in supplements under a variety of other names including geranium oil/extract or geranamine; this no doubt contributed to many publicized and less well-known cases of anti-doping rule violations.

This risk of inadvertent doping from supplement use has been known for at least 30 years but is still very much present (de Hon & Coumans, 2007; Geyer et al., 2004; Martinez-Sanz et al., 2017). Indeed, the list of prohibited substances that have been detected in supplements includes stimulants, anabolic agents, selective androgen receptor modulators, diuretics, anorectics, and β2 agonists (Martinez-Sanz et al., 2017). When the amounts of banned substances in supplements are large enough to generate a direct effect (e.g., stimulant symptoms), this is an obvious sign of potential contamination to a consumer and sometimes an indicator of intentional but undeclared manufacturing practices (Geyer et al., 2008; Parr et al., 2007, 2008). But the risks of unintentional contamination from adulterated raw ingredients or cross-contamination of machinery, even by the most careful manufacturers, should not be underestimated and will never be zero (Judkins et al., 2010; Maughan et al., 2018b). Because of the ever-improving analytical capabilities in antidoping laboratories, trace amounts of prohibited substances can be found in biological samples taken at doping control. As a result, it cannot be stressed enough that athletes need to be aware that the WADA rules of strict liability mean that the detection of a prohibited substance in an athlete's specimen will be treated as an anti-doping rule violations, irrespective of the intentions behind it (Abbott, 2004; Hughes, 2015). Furthermore, it should also be understood that coaches, support personnel, parents, friends, and anyone else involved in the life of an athlete can also be implicated in an anti-doping rule violations, with WADA imposed sanctions (i.e., suspensions from sport) applicable. Using only products that have been audited by a third-party testing program and found to be free of banned substances will help to lower, but not completely eliminate, this risk. However, the general avoidance of the high-risk multi-ingredient supplements promoted as preworkouts or weight loss and bodybuilding products is recommended.

Noncontent-Related Risks

Some final concerns or issues regarding use of supplements and sports foods need to be considered. First, athletes should realize that any benefit of legal supplementation is bound to be small. Expecting too much of an intervention that addresses only the top end of one aspect of athletic performance may lead to disappointments and distract from other, more powerful, aspects of elite athletic training. Second, expense must also be considered, especially when finite resources could have been used in other areas of the preparation of an elite athlete's life. Finally, concerns have been raised that supplement use may be a stepping stone to taking other substances, including those prohibited by antidoping regulations (Backhouse et al., 2013). With this in mind, attention should be directed toward the ethical challenges of athlete product marketing and the influence of such approaches on encouraging undue supplement use, especially on young/developing athletes.

In summary, the very real risks of taking supplements should be carefully considered by competitive athletes. Of note, Castell et al. (2015) published an A–Z Guide on 140 nutritional supplements in exercise and health; this includes efficacy tables ranging from those supplements shown to be ergogenically effective to those banned by WADA as being harmful or illegal. Readers might find it useful to consult this book prior to embarking on a course of supplements.

Conclusion: A Pragmatic Approach to Making Decisions about Supplements

In the past, athletes and coaches often worked in a parallel universe to their expert groups (e.g., governing bodies of sport) and service teams (e.g., sports scientists, dietitian, and physicians) with regard to performance supplements, with the former favoring supplement use based on their interest in performance gains and the latter being risk averse and dismissive of such products. The modern landscape, at least for high-performance athletes, has seen a unification of effort and intent, with many parties now working together to take a pragmatic approach to managing a risk:benefit audit around the use of sports foods, therapeutic/prophylactic supplements, and performance supplements. This has been led by organizations such as the International Olympic Committee and the Australian Institute of Sport, that have produced expert statements (Maughan et al., 2018a) and education resources (Burke & Cato, 2015) to guide a proactive but evidence-based consideration of the use of these products. In the case of sports foods, track-and-field athletes are guided to seek the expertise of an appropriately qualified sports nutrition professional who can help them balance the expense of using these specialized products with the scenarios in which they offer genuine performance benefits. Therapeutic/prophylactic supplements should involve the expertise of a sports physician, especially when a diagnosis of medical issues and nutrient deficiencies is needed. A decision-tree approach to the use of performance supplements (Figure 1), especially in collaboration with sports science/nutrition experts, will help to ensure that any products that are used are appropriate to the athlete's age and maturation in their event, integrated into the athlete's plan according to evidence-based protocols and appropriate scenarios, and chosen on the basis of being at low risk of contamination with banned or harmful ingredients. Ultimately, it is pertinent that sports foods and nutritional supplements should only be considered where a strong evidence base supports their use as safe, legal and effective and that such supplements are trialed thoroughly by the individual before committing to use in a competition setting.

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