‘Food First’ but not always ‘Food Only’: Recommendations for using dietary supplements in sport

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Abstract

The term ‘food first’ has been widely accepted as the preferred strategy within sport nutrition although there is no agreed definition of this and often limited consideration of the implications. We propose that food first should mean “where practically possible, nutrient provision should come from whole foods and drinks rather than from isolated food components or dietary supplements”. There are many reasons to commend a food first strategy, including the risk of supplement contamination resulting in anti-doping violations. However, a few supplements can enhance health and/or performance and therefore a food only approach could be inappropriate. We propose six reasons why a food only approach may not always be optimal for athletes: 1) some nutrients are difficult to obtain in sufficient quantities in the diet, or may require excessive energy intake and/or consumption of other nutrients, 2) some nutrients are abundant only in foods athletes do not eat/like, 3) the nutrient content of some foods with established ergogenic benefits is highly variable, 4) concentrated doses of some nutrients are required to correct deficiencies and/or promote immune tolerance, 5) some foods may be difficult to consume immediately before, during or immediately after exercise and 6) tested supplements could help where there are concerns about food hygiene or contamination. In these situations, it is acceptable for the athlete to consider sports supplements providing that a comprehensive risk minimisation strategy is implemented. As a consequence, it is important to stress that the correct terminology should be “food first but not always food only”.

Keywords

Supplements, Nutrition, Food, WADA, Ergogenic Aid, Athlete

1. Introduction

Sport nutrition is a fast-growing discipline within sport science with many elite sports teams now employing a sport nutritionist on either a full or part time basis. Many universities now offer degree programs in sport nutrition at both undergraduate and postgraduate level. In the UK, the Sport and Exercise Nutrition register (SENr), which regulates sport nutritionists, has grown dramatically with an 82% increase in its membership between 2017 and 2021. Despite this growth in the sport nutrition discipline, there remains confusion as to the precise role of the sport nutritionist with no universally accepted definition. We would suggest that a working definition could be '*an individual who can work with an athlete or team to reach their performance targets and achieve optimal health through the identification of appropriate sport-specific nutrition goals and the development of an individualised dietary strategy to meet those goals, by the manipulation and periodisation of fluid and nutrient intake, while also considering the strategic use of appropriate dietary supplements and sports foods*'. Although there is no universally accepted definition of what dietary supplements and sports foods are, for the purpose of this manuscript, we support the definition proposed in a recent IOC consensus statement which defines these 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"* (Maughan et al., 2018b).

Implicit in the role of a sport nutritionist is the need to protect the athlete's health and performance by preventing the harmful practices that many follow. It is well recognised that some supplements can be beneficial, and even necessary in some situations (e.g. where an adequate nutrient intake is not easily achieved from food intake), but sports supplements are not without some risks (Burke et al., 2019; Garthe and Maughan, 2018; Maughan et al., 2018a; Maughan et al., 2018b; Thomas et al., 2016). Such risks include contamination of supplements with substances prohibited by the World Anti-Doping Agency (WADA) along with wider safety concerns which will be discussed below. In both the 2018 IOC and 2019 IAAF consensus statements, it was concluded that some dietary supplements may contribute to a successful nutrition support programme, especially when the practicalities of lifestyle or the competition environment make it difficult to consume whole foods (Burke et al., 2019; Maughan et al., 2018b). Furthermore, the Australian Institute of Sport produces a regular sports supplement framework which also recognises the small but important role that sports food and supplements can play in the diet plans of elite athletes (Australian Institute of Sport, 2021).

Despite the widespread acceptance of the potential value of sports supplements, 'food first' has been adopted as the preferred method for nutrition support within elite sport (Burke et al., 2019). Although the term food first has yet to be fully defined, we suggest that it should mean '*where practically possible, nutrient provision should come from standard food and drinks rather than from isolated food components, dietary supplements or sports foods'*. This food first philosophy has many potential advantages. However, with the constant search for 'marginal gains' within elite sport, combined with established research evidence that a small number of sports supplements can enhance health and/or performance (Maughan et al., 2018b), it could be argued that a strict 'food only' approach is inappropriate. Therefore, the purpose of this narrative review is to explore the concept of the food first approach to sport nutrition with specific targeted supplementation. Finally, guidance will be provided as how best to deliver a 'food first, but not always food only' (abbreviated to FFNFO) sport nutrition strategy in a safe and evidence-based manner.

2. Why a food first approach is important

A food first philosophy is advocated by a number of expert consensus statements and position stands within sport (Collins et al., 2021; Maughan et al., 2018b; Thomas et al., 2016) and is said to be essential for health and performance. The current authors agree that nutritional programs should prioritise food over supplements, as whole food sources offer energy and macronutrients as well as a range of micronutrients, polyphenols, fibre and other bioactive compounds that can have positive benefits through reducing inflammation, promoting immune tolerance and enhanced neuroprotection (Teodoro, 2019). However, despite a food first approach being the preferred strategy, not everyone chooses to eat foods that meet their nutrient requirements and those who do not might benefit from vitamin and mineral supplementation if they are unable or unwilling to modify their food choices (Bender, 2004). The origins of the ‘food first’ philosophy are unclear, but likely stemmed from the over-promotion and unsubstantiated ergogenic claims associated with supplementation in athletic populations. There is a wide array of supplements available and marketed to athletes (Hämeen-Anttila et al., 2011; Timbo et al., 2006), but many of these supplements are associated with questionable claims and little evidence regarding the optimisation of health, muscle function and sporting performance. Despite these questionable claims, the use of supplements within athletic populations is extensive and rising. The use of supplements has been steadily increasing with one report suggesting use has increased in the American general population from approximately 40% in 1988 to 70% in 2016 (Garthe and Maughan, 2018). Huang and colleagues reported that this high prevalence of supplement use was similar within athletic populations, where the estimated use of supplements by athletes competing in the Atlanta (1996) and Sydney (2000) Olympic was 69 and 74% respectively (Huang et al., 2006). In a review of 20 supplement studies within athletic populations, Garthe and Maughan (2018) reported the prevalence to be between 51% (male Norwegian athletes) and 98% (male Canadian athletes). Outram and Stewart estimated that supplement use was slightly lower between 40-70% within Olympic athletes of various nationality, although they suggested that the real figure may be over 90%, dependent upon the sport and the definition of supplement. Our first-hand experience suggests that supplement use may be as high as 100% in some team sports, with many athletes taking multiple supplements daily throughout the calendar year. Taken together, it is clear that athletes across a wide range of sports are using supplements regularly for both perceived health and performance reasons.

Although supplementation may be seen by some as an ‘easy fix’ to food related problems, numerous issues need to be considered prior to using supplements. A risk-benefit analysis must be conducted prior to implementing any sports supplement. Issues that may be considered include the expense of the supplements, false expectations, safety concerns and the risk of consuming (advertently or inadvertently) substances prohibited by WADA. Supplements are deemed a higher risk than medicines given that supplement manufacturing conforms to less rigorous standards than the production of pharmaceutical medicines (Food and Drug Administration in USA; The Medicines and Healthcare Products Regulatory Agency in UK). Supplements may contain undeclared prohibited substances via numerous mechanisms, including but not limited to poor manufacturing practices resulting in contamination of the raw ingredient and deliberate inclusion of ingredients not listed on the label (or labelled under a different name). Evidence suggests that rates of contamination could be as high as 10-25% of all supplements across Europe and USA (Outram and Stewart, 2015), with more recent reports being as high as 38% (Duiven et al., 2021). Indeed, Outram and Stewart (2015) estimated that between 6 and 9% of doping cases may be attributed to supplement use, although it is important to note that these data are taken from reported doping violations in the period 2005-2013. It is difficult to extrapolate these data to the present day: supplement use has increased, but the risk of ingesting contaminated supplements has been reduced by increasing use of third-party batch testing procedures. There is also evidence that often supplements may not contain the actual amount of ingredient stated on the label in the final product, and some do not contain any at all (Harris et al., 2004; Maughan et al., 2018b).

3. Food first not food only approach to sport nutrition

Whilst the food first approach is the preferred strategy within elite sport, it is crucial to stress that food first does not require a strict food only approach. Indeed, our definition proposed in section 1, makes clear that an important role of the sport nutritionist is to ‘*consider the strategic* *use of appropriate dietary supplements'.* There are situations whereby a food only approach could be detrimental to the athlete both in terms of their overall health and sporting performance. Therefore, whilst the safest approach from an anti-doping perspective is one of a strict food only policy, we would argue that this is not always optimal and/or practical/convenient for the modern athlete. We also need to recognise that foods themselves may also be responsible for adverse analytical findings (Guddat et al., 2012). Specifically, we propose 6 reasons why a food only approach may be problematic, as summarised in Figure 1.

1. Some nutrients are difficult to obtain in sufficient quantities in foods eaten as part of a regular diet, at least without excessive intake of foods containing these dietary components (e.g., creatine and beta alanine in red meat and vitamin D in oily fish).
2. Some essential nutrients are abundant only in foods that some athletes do not consume (e.g., omega 3 found predominantly in oily fish, or a vitamin B12 in meat).
3. It is difficult to establish the precise nutrient content of some foods that have been consistently shown to enhance sporting performance and/or health (e.g., caffeine within coffee, nitrate within vegetables, vitamin D in oily fish).
4. High doses of some nutrients may be required to improve health (e.g., iron supplementation to correct deficiency), and exceeding the reference nutrient intake (RNI) for some nutrients may have beneficial anti-inflammatory (tolerogenic) effects that can reduce the infection burden.
5. Food sources for some nutrients may be difficult to consume close to, during or soon after exercise (e.g., a carbohydrate gel may be more convenient during the 2nd half of a rugby game than eating a banana).
6. Tested supplements could provide a convenient alternative to food, particularly in scenarios where concerns are raised regarding food contamination (e.g., contamination of meat with clenbuterol) and/or food hygiene.

4. Specific situations where performance may be compromised with a strict food only approach

Several supplements have been reported by manufacturers to have beneficial effects on sporting performance. Despite these claims, and with only a few exceptions, there is limited research to substantiate this, and the available evidence is often derived from experimental paradigms that are not relevant to sport (Close et al, 2019). A number of consensus statements (Collins et al., 2021; Maughan et al., 2018b; Tiller et al., 2019) have identified key supplements that are most likely to provide marginal gains in high performance sport. Whilst there are hundreds of supplements with numerous health and/or performance claims, carbohydrate, protein, iron, caffeine, creatine, beta alanine, sodium bicarbonate and nitrate (Table 1) have good evidence of benefits (Maughan et al 2018b) and may be advantageous when consumed in a supplementary form due to the issues highlighted in Section 3 and Figure 1.

4.1 Carbohydrate

It is well established that carbohydrate is required to effectively fuel high intensity exercise (Burke et al., 2011). This includes loading carbohydrates in the days leading to competition, as well as consuming carbohydrate in the acute period prior to (e.g., day of competition) and during competition. Whilst it is possible and preferred to consume sufficient carbohydrate from foods in the days/hours leading into competition, the suggested consumption of 30-60 g of carbohydrate per hour during competition (Baker et al., 2014; Baker et al., 2015; Nicholas et al., 1995) and up to 90 g in cases of ultra-endurance events (Jeukendrup, 2014), can be logistically difficult from whole foods during many sports (point 5 of the FFNFO approach). This is true of both endurance events (such as marathon running or Ironman triathlon), where athletes are not able to eat whilst running or swimming, as well as team sports such as football and rugby, where there is only a short period half-way through the game to consume the carbohydrates required. It is therefore understandable that practitioners may advise carbohydrate drinks and gels.

4.2 Protein

An adequate protein intake is essential for athletes, due at least in part to its role in optimising muscle protein synthesis and net protein accretion for increased lean mass (Collins et al., 2021; Maughan et al., 2018b; Thomas et al., 2016). Despite the evidence that regular ingestion of 20-25 g of protein at intervals across the day can optimise protein synthesis (Koopman et al., 2007; Morton et al., 2015; van Loon, 2013), this can be logistically difficult in some situations, including long haul travel or during prolonged exercise (point 5 of the FFNFO approach). Casein is one particular 'slow-release' protein proposed to benefit overnight protein synthesis (Trommelen and van Loon, 2016), but achieving the recommended 30-60 g prior to sleep may be difficult from whole foods without excessive energy intakes and uncomfortable portion sizes (point 1 of the FFNFO approach). For example, to achieve 40 g of casein-based protein it would be necessary to consume 1025 ml of low fat milk (359 kcal) or 1176 ml of low fat yoghurt (659 kcal) (Trommelen and van Loon, 2016), both of which could be higher in volume and energy than desired by the athlete. A further example of this is supplementary collagen, which is reported to influence tendon and ligament repair (Shaw et al., 2017; Shaw et al., 2019), as well as strength (Lis et al., 2021). Whilst in theory this can be achieved via recipes such as bone broth or concentrated gelatine, this can be impractical at times and can be difficult to control the amount consumed, especially if the athlete is required to take this in close proximity to exercise (points 1, 2, 3, 4 and 5 of the FFNFO approach).

4.3 Iron

Deficiencies of some micronutrients are relatively common in the general population (Bird et al., 2017) and in athletes (Jordan et al., 2020). Iron deficiency, for example, is one of the leading risk factors for disability and death worldwide, affecting close to one third of the world's population, with about half of these cases being the result of inadequate absorption of dietary iron (Murray et al., 2017). It should be noted, however, that the example of iron, as with many other nutrients, is complicated by the interaction of dietary intake and intestinal absorption: the iron content of the diet may be sufficient, but deficiency symptoms will ensue if it is not absorbed in the intestinal tract. Not all food sources of iron are equally bioavailable and some can be poorly absorbed, even when taken in high doses (Young et al., 2018). Simply recommending a high intake of iron-rich foods may therefore not always be an effective treatment for iron deficiency (points 2 and 3 of the FFNFO approach). Further complications arise if iron losses are not also considered, e.g., substantial amounts of iron may be lost from gastrointestinal bleeding and menstrual blood loss. Iron is the functional component of haemoglobin and myoglobin as well as being an essential constituent of mitochondrial enzymes. It is therefore unsurprising that iron deficiencies, even without anaemia, have negative effects on aerobic performance (DellaValle and Haas, 2011). Various stages of iron deficiency have been documented in athletes and it is crucial that if deficiencies are identified these are appropriately corrected to improve both performance and health. Often corrective strategies include supplementation with specific doses and forms of iron and a strict food only approach could be deemed sub-optimal treatment to correct a medical problem.

4.4 Caffeine

Caffeine (mainly found in coffee and tea) is a stimulant that possesses benefits for athletic performance across a range of situations (Grgic et al., 2018; Mielgo-Ayuso et al., 2019; Southward et al., 2018) via antagonism of adenosine receptors. Caffeine intake around exercise can lead to improved neuromuscular function, improved alertness, and reduced perception of exertion during exercise. A dose of 3-6 mg.kg^{-1} body mass (BM) in the form of anhydrous caffeine seems to be sufficient to achieve the benefits to performance. However, it is difficult to control dose of caffeine in food and drink form (point 3 of the FFNFO approach) as the caffeine content of commercially available coffee beverages is extremely varied (15-254 mg per serving) (Desbrow et al., 2007). A strict food only approach could result in either under-consumption or perhaps of more concern, over-consumption of caffeine prior to performance: caffeine in supplementary form with known doses may be the most effective strategy.

4.5 Creatine

Loading of creatine has been documented to increase muscle creatine concentration, a large fraction of which is in the form of PCr, enhancing high-intensity performance (Cooper et al., 2012; Harris et al., 1992; Hultman et al., 1996). When taken chronically alongside a structured training plan, creatine can also aid with gaining lean mass and muscular strength and power (Kreider et al., 2017), something that has clear benefits for many athletes. To achieve these benefits, ~20 $g.day^{-1}$ (divided into four equal daily doses), for 5–7 days, followed by 3–5 $g.day^{-1}$ (single dose) for the duration of the supplementation period has been proposed to be an ideal strategy (Hultman et al., 1996). Despite both supplement and food forms of creatine being readily absorbed, and both raising plasma concentrations of creatine (Harris et al., 2002), it is practically impossible to consume 20 g of creatine via food sources alone (point 1 of the FFNFO approach). For example, foods high in creatine include salmon, pork and steak all of which uncooked contain approximately 3-6 g of creatine per kg and much less when cooked (Balsom et al., 1994). Even carnivorous/omnivorous athletes with high energy needs are unlikely to consume 1 kg of raw meat, four times per day, and therefore supplementation is again the preferred strategy.

4.6 Beta alanine

Beta-alanine supplementation can increase the intramuscular concentration of carnosine, which acts as an intracellular buffer, reducing the accumulation of protons within the contracting muscle during high-intensity exercise (Harris and Sale, 2012; Hobson et al., 2012; Hobson et al., 2013; Sale et al., 2011), and so enhancing performance. Daily consumption of ~65 $mg.kg^{-1}$ BM of beta alanine is required, typically ingested via a split-dose regimen (0.8-1.6 g every 3-4 hours) over an extended supplement time frame of 10-12 weeks (Saunders et al., 2017). As with creatine, it is difficult to achieve this intake from food alone (point 1 of the

FFNFO approach). Chicken breast (200 g) and turkey breast (150 g) have been shown to result in an increase of plasma bioavailability equivalent to taking 800 mg of beta alanine (Harris et al., 2006; Hoffman et al., 2015). Considering supplementation should be 1.6-6.4 g.day^{-1}, this would require between 0.4-1.6 kg of chicken breast or 0.3-1.2 kg of turkey breast to be consumed on a daily basis, which would increase daily protein intake by ~108-432 g and 81-324 g respectively.

4.7 Nitrate

Nitrate has become one of the most widely used ergogenic aids with extensive research literature to support this practice (Jones, 2014a; Jones, 2014b; Jones et al., 2018; Senefeld et al., 2020). Both acute and chronic doses of nitrate have been shown to enhance prolonged submaximal exercise as well as high-intensity intermittent short-duration efforts (Jones, 2014a), though it is less clear that elite athletes will achieve benefits similar to those seen in laboratory studies of less well-trained participants (Burke and Peeling, 2018). In addition, there is evidence that there is a limited ergogenic effect of nitrate on prolonged exercise (Jones, 2014a; Jones, 2014b). The proposed mechanism of action involves increasing nitric oxide availability via the nitrate-nitrite pathway, leading to enhancement of type II muscle fibre function, increased efficiency of mitochondrial respiration and increased blood flow to the muscle. Both acute (2-3 hours pre-event, 310-560 mg) and chronic (>3 days, 310-560 mg.day^{-1}) doses have been shown to be effective (Senefeld et al., 2020). Whilst there are many foods rich in nitrate including leafy green and root vegetables, and there is evidence that the diets of some athletes often contain foods rich in dietary nitrate (Jonvik et al., 2016) it is difficult to establish the nitrate content of such foods and/or consume enough nitrate from whole foods to achieve the desired ergogenic effects (points 1 and 3 of the FFNFO approach)***.*** Examples of high nitrate foods include spinach (97-426 mg per 100 g fresh weight), rocket lettuce (260 mg per 100 g fresh weight) and beetroot (64-180 mg per 100 g fresh weight) (Lidder and Webb, 2013). Moreover, where targeting nitrate in the pre-competition period (e.g., 3h from game), eating large amounts of leafy vegetables may not be ideal for gastrointestinal reasons and could detract from other key nutrients being consumed with established performance benefits such as carbohydrate. A concentrated nitrate supplement, with a known concentration of nitrate, is therefore the preferred strategy to nitrate load prior to competition.

4.8 Sodium Bicarbonate

The high rates of glycolysis that accompany high-intensity exercise result in the accumulation of hydrogen ions, which contribute to the fatigue that limits performance (Fitts, 2016). Increasing the pH of the extracellular space can accelerate the efflux of hydrogen ions from the active muscle, allowing glycolysis to continue and thus delaying fatigue. Feeding a high carbohydrate, low protein diet for a few days can increase blood and muscle pH (Greenhaff et al., 1988) and can enhance performance in exercise that lasts a few minutes (Maughan and Poole, 1981). Acute or chronic ingestion of sodium bicarbonate at a dose of about 0.2-0.5 g/kg body mass, however, can induce more profound effects on acid-base status and can enhance performance in exercise tasks lasting from about 30 s to 12 min (Grgic et al., 2021).

Table 1. Examples of supplements that may improve performance with a *Food First Not Food Only* (FFNFO) justification.

Scenario	Supplement	FFNFO justification	Supporting evidence	References
Pre- and Post-Competition	**Carbohydrate gels, drinks, powders**	Eating carbohydrate foods at the correct dosage during exercise may not always be practically possible whilst athletes can find it difficult to consume the required carbohydrate volumes from whole foods soon after exercise. **FFNFO: 5**	High carbohydrate intake during exercise 30-60 $g.h^{-1}$ (and possibly up to 90 $g.h^{-1}$) can delay fatigue and enhance intermittent high-intensity exercise. Post-exercise carbohydrate intake of ~1$g.kg^{-1}$ BM for 4h can maximise the restoration of muscle glycogen post-exercise.	(Anderson et al., 2017; Baker et al., 2014; Baker et al., 2015; Bergström et al., 1967; Burke et al., 2017; Holway and Spriet, 2011; Jeukendrup, 2014; Nilsson et al., 1973; Saltin, 1973)
	Caffeine	It is possible to achieve 2-3 $mg.kg^{-1}$ BM from coffee, but the caffeine content of coffee is highly variable. Also, the ideal timing of intake pre-exercise makes a supplement more convenient than taking an espresso, with emerging evidence suggesting benefits of caffeine intake during exercise. **FFNFO: 3,5**	Meta-analysis (n=10 studies) showed increased upper body strength and power. Another meta-analysis (n=5 studies) showed caffeine to improve jump performance, repeated sprint ability and running distance during intermittent team sport situation. A further meta-analysis investigating general exercise performance (n=46 studies) showed improvements to endurance performance, power output and time-trial performance. 3-6	(Grgic et al., 2018; Mielgo-Ayuso et al., 2019; Southward et al., 2018)

			$mg.kg^{-1}$ BM recommended 5-60 min prior to exercise dependent upon activity and form of delivery.	
	Nitrate / Beetroot juice	Nitrate is found in good quantities in foods like beetroot, but eating beetroot pre-competition is not practical and would require portions much higher than typically consumed. Also, it is not possible to know the nitrate concentrations of vegetables. **FFNFO: 1,3,5**	Reduced O_2 cost of exercise observed within 3 h of supplementation of 5-6 mmol of nitrate within a range of exercise such as cycling, running and knee extension. Effect lasts for >15 days of supplementation. Supplementation reported to extend time to exhaustion and time-trial performance in recreationally active and moderately trained participants. Effects may be reduced in elite athletes with higher levels of aerobic fitness.	(Jones, 2014a; Jones et al., 2014b; Jones et al., 2018; Senefeld et al., 2020)
Muscle and connective tissue growth and repair	**Protein powders**	It is possible to achieve sufficient intakes from whole foods, but some situations may benefit from the convenience of a liquid shake, i.e. after exercise where food provision may not be possible or in situations where there are safety concerns regarding meat quality or where energy intake should be restricted.	Increase protein intake is proposed to increase net protein synthesis. Timing of protein intake is important, but the “anabolic window” appears to be >24h. Doses of ~0.4 $g.kg^{-1}$ BM per meal distributed throughout the day. Ingesting larger doses of protein (~0.6 $g.kg^{-1}$ BM per meal) appears to aid overnight muscle protein synthesis.	(Areta et al., 2013; Burd et al., 2011; Koopman et al., 2007; Morton et al., 2015; Res et al., 2012; Trommelen and van Loon, 2016; van Loon, 2013; West et al., 2017)

		FFNFO: 5,6		
	Collagen	Despite being found in food sources such as chicken thighs with skin (20 g.kg^{-1}) and red meat (11 g.kg^{-1}), it is difficult to consume the recommended dose of 20 g in close proximity to exercise. **FFNFO: 1,2,3,4,5**	Supplementation gelatin (15-20 g) enriched with vitamin C (50 mg) 1h prior to exercise increases circulating collagen, that may play a beneficial role in injury prevention/tissue repair. In addition, recent study found that rate of force development in squat and countermovement jumps was improved with collagen supplementation.	(Lis et al., 2021; Shaw et al., 2017; Shaw et al., 2019)
Avoidance of deficiency	**Iron**	Iron is found in abundance in some foods in haem (red meats) and non-haem (leafy green vegetables) forms. Despite adequate intake in the diet, absorption of the nutrient may be an issue and if deficiencies are identified supplementation with high doses is often the optimal strategy. **FFNFO:1,2,3,4**	Study screened female collegiate rowers (n=165) for iron deficiency. Those deemed iron depleted (n=60) had 2-km times ~21 s slower than non-deplete counterparts with adequate iron status. Important to address deficiency not only for health, but also for performance.	(DellaValle and Haas, 2011)
Muscle Buffers	**Creatine**	Although found in meat-based products, it is difficult to achieve >5 g.day^{-1} within the diet, especially within plant-based diets.	Effect of dietary creatine and supplementation investigated in male participants (n=31). Muscle creatine concentration increased ~20% following 6 days of creatine	(Harris et al., 1992; Hultman et al., 1996)

	FFNFO: 1,2,3,4	supplementation of 20 g.day^{-1}. Maintenance dose >2 g.day^{-1} maintained concentration. Review of available literature showed this level of creatine may enhance post-exercise recovery, injury prevention, thermoregulation, rehabilitation and concussion. Also showed that long-term supplementation (<30 g.day^{-1} for 5 years) is safe and well-tolerated in healthy individuals.	
Beta alanine	Whilst found in small quantities in some meats, it is not practically possible to eat enough beta alanine to get the performance enhancing effects e.g. sustained high intensity effort. **FFNFO: 1,2,3,4**	Meta-analysis (n=1461 participants, n=40 studies) found a significant positive effect of beta alanine supplementation (>1.6 g.day^{-1}) on performance. Greatest benefits to performance are seen in exercise lasting 0.5-10 min with smaller effect sizes observed in trained individuals.	(Harris et al., 2006; Hobson et al., 2012; Hobson et al., 2013; Lancha Junior et al., 2015; Saunders et al., 2017)
Sodium Bicarbonate	Whilst feeding a high carbohydrate, low protein diet for a few days can increase blood and muscle pH, the ingestion of supplemental sodium bicarbonate at a dose of about 0.2-0.5 g.kg^{-1} body mass can induce more profound effects and does not involve athletes following a	Meta-analysis (n=192 participants, n=20 studies) found a significant positive effect of sodium bicarbonate supplementation (0.3-0.4 g.kg^{-1}, 60-180 min prior to exercise) on muscular endurance but not strength. Another meta-analysis (n=108 participants, n=10 studies) showed no	(Fitts, 2016; Greenhaff et al., 1988; Grgic, 2020; Grgic et al., 2020; Grgic et al., 2021; Maughan and Poole, 1981).

	diet that may not be optimal for wider aspects of their athletic performance, i.e. low protein. **FFNFO: 1,2,3,4**	improvement of sodium bicarbonate supplementation (0.2-0.5 g.kg^{-1}, 60-180 min prior to exercise) on a single Wingate bout but did report improved performance during repeated Wingate tests.	

5. Specific situations where immune health may be compromised with a strict food only approach

Infections affecting the respiratory and gastrointestinal tracts pose a serious problem for elite athletes, second only to injury in surveys of factors that limit athlete availability to train and compete (Engebretsen et al., 2013; Palmer-Green et al., 2013; Soligard et al., 2015). Prominent risk factors for infection in elite athletes and military personnel are broadly similar to those in the wider population; including, the common cold season and foreign travel, when pathogen exposure may increase (Simpson et al., 2020; Svendsen et al., 2016), and factors that can compromise immunity via activation of the hypothalamic-pituitary-adrenal axis and the sympathetic nervous system including psychological stress, anxiety, depression and poor sleep (Drew et al., 2017; Walsh, 2018; Wentz et al., 2018). For over 25 years exercise immunologists have sought nutritional countermeasures to reduce the illness burden in athletes. Nutrient availability influences immunity because macro- and micro-nutrients are involved in a multitude of immune processes e.g., macronutrients are involved in immune cell metabolism and protein synthesis and micronutrients in antioxidant defences. For a more comprehensive account on nutrition and athlete immunity interested readers are directed to a consensus statement (Bermon et al., 2017) and a new perspectives review on the topic (Walsh, 2019).

In accordance with a food first strategy, athletes are recommended to follow a varied diet that avoids deficiencies of any of the macro- or micro-nutrients that are required for proper immune function, irrespective of their dietary preference/requirements, such as carnivorous, omnivorous and vegetarian diets as well as those with medical conditions such as lactose intolerances. Currently in the spotlight is whether athletes with low energy availability (LEA) and those following plant-based diets have lowered immunity due to dietary insufficiencies (FFNFO points 1 and 2): interest has been stoked by reports of increased illness symptoms in elite female athletes with LEA and the increasing popularity of plant-based diets amongst athletes (Drew et al., 2017; Schoenfeld, 2020). Protein deficiency is widely considered to be responsible for the clinical features of immune suppression and infection in severe malnutrition and starvation, supported by numerous animal studies and the observation that well preserved immunity and infection resistance in anorexia nervosa patients is likely because protein intake is adequate (carbohydrate and fat are typically reduced) (Nova et al., 2001; Taylor et al., 2013; Woodward, 1998). In female athletes with LEA protein intake appears to be sufficient to support immunity, typically exceeding recommendations for endurance athletes (1.2-1.7 $g.kg^{-1}$ per day) (Heikura et al., 2018; Phillips, 2012). It is conceivable that poor mental health (e.g., stress, anxiety and depression), highly prevalent in female athletes with LEA, plays a role in reports of increased illness symptoms (Ackerman et al., 2019; Drew et al., 2018; Mountjoy et al., 2014). The quantity and quality of protein in a vegan athlete's diet, although reportedly lower than in an omnivorous diet (Śliż et al., 2021), should also be adequate to support immunity, assuming the athlete chooses a wide variety of foods *viz*., the diet is "…not made up of say, just cookies, crackers, potato chips and juice" (Gardner et al., 2019). The food first approach for athlete immune health also applies to micronutrient intake; a vegetarian diet made up of diverse foods can provide the key micronutrients for immunity (e.g., zinc in fortified breakfast cereals, legumes and wholegrain) (Saunders et al., 2013). Fortified foods and supplements can mitigate against shortfalls in micronutrients such as vitamin B12, the only natural source for which is from animal origin. One of the first studies on nutrition and immunity in athletes, published 30 years ago, showed no difference in various measures of immune function in male endurance athletes following a mostly plant-based diet (lacto-ovo vegetarian) or omnivorous diet for 6 weeks (Richter et al., 1991). A contemporary view is that dietary restriction and/or following a plant-based diet without malnutrition elicits a healthy phenotype (Heianza et al., 2021; Most et al., 2017).

A recent review presented a new paradigm for exercise immunology that considers 'resistance' (the strength of the immune weaponry) and 'tolerance' (the ability to endure microbes and dampen defence activity) (Walsh, 2019). Key to effective tolerance is a proportionate immune response that facilitates homeostatic regulation: an overly exuberant immune response can cause excessive tissue damage and unnecessarily allocate energy resources away from vital functions; conversely, a weak immune response increases susceptibility to damage from the pathogen (Ayres and Schneider, 2012). It is clear that nutritional supplements can improve immune resistance in those with impaired immunty, such as the frail elderly and clinical patients; particularly in those with poor nutritional status (Calder, 2013). Evidence supporting clinical immunosuppression in athletes is lacking (Campbell and Turner, 2018), so it is not surprising that studies providing athletes with supplemements targeted towards improving immune resistance have shown little if any benefit ("if it ain't broke, don't fix it") (Walsh, 2019). With the new paradigm in mind, arguably the targets are nutritional supplements with tolerogenic properties that can blunt an overly exuberant immune response (e.g. through anti-inflammatory and/or antioxidant effects) and reduce the infection burden: tolerogenic supplements may reduce how sick the athlete gets. Indeed, evidence supports the premise that for some nutrients, in scenarios where athletes are at increased risk of illness (Table 2), exceeding the RNI using supplements may be beneficial (FFNFO point 4). For example, nutritional supplements with beneficial tolerogenic properties that can reduce illness in athletes during the common cold season include vitamin D, vitamin C and probiotics (Bermon et al., 2017; Walsh, 2019). Although supplements may offer athletes a convenient and practical solution, particularly when concerns are raised over limited food choices, poor food hygiene and safety (e.g., during foreign travel), as will be discussed in section 6, athletes should use only supplements from reputable suppliers (Maughan et al., 2018b).

Table 2. FFNFO scenarios where nutritional supplements may benefit athlete immune health.

Scenario	Supplement	FFNFO justification	Supporting evidence	References
Common cold season	**Vitamin D_3**	Anti-inflammatory (tolerogenic[2]) effects. Essential fat-soluble vitamin known to influence several aspects of immunity e.g., AMP expression. Skin sunlight exposure accounts for 90% of the annual source of vitamin D and deficiency is evident in the winter in some athletes. Deficiency has been associated with increased risk of common cold and COVID-19 and poorer prognosis in hospitalised COVID-19 patients. RNI is 5–15 µg.day^{-1}. **FFNFO: 1,2,3,4,6**	Meta-analysis (n=10,933) shows some benefit of supplementation to decrease URI incidence. Wintertime supplementation by either simulated sunlight or oral D_3 to achieve sufficiency reduced URI severity and duration in military trainees. Recommend monitoring and 25 µg.day^{-1} D_3 fall-spring to maintain sufficiency where necessary. Increased risk of adverse outcomes supplementing >100 µg.day^{-1} D_3.	(Harrison et al., 2021; He et al., 2016; Martineau et al., 2017; Meltzer et al., 2020; Radujkovic et al., 2020)
	Vitamin C	Antioxidant (quenches ROS) that improves tolerance[2] by mitigating against excessive tissue damage. Increased ROS during heavy training. RNI is 40 mg.day^{-1} (United Kingdom). **FFNFO: 1,3,4,6**	Cochrane review of 5 studies in heavy exercisers (n=598) showed ~50% decrease in URI incidence when taking vitamin C (250–1000 mg.day^{-1}). No reported side effects. Unclear if antioxidants blunt adaptation in well-trained.	(Hemilä, 2017a; Hemilä and Chalker, 2013; Paulsen et al., 2014)
	Probiotics	Mutualistic benefits to gut health. Probiotics are live microorganisms. When administered orally for several weeks (e.g., daily dose of ~10^{10} live bacteria) can increase the numbers of beneficial gut	Supplementation during winter (common cold season) reduced URI incidence in athletes. Cochrane review of 12 studies (n=3,720) shows ~50% decrease in URI incidence, ~2 day shortening of URI and reduced antibiotic	(Gleeson, 2007; Hao et al., 2015; McFarland and Goh, 2019)

		bacteria. Exert anti-inflammatory tolerogenic[2] effects that maintain homeostasis. Beneficial interactions between commensal microbial community and host immunity via the common mucosal immune system. **FFNFO: 4**	prescription rates. Minor side effects reported.	
Suffering common cold	**Zinc Lozenges**	Antiviral effects of zinc lozenges. May decrease docking of common cold viruses with binding sites. Antioxidant and anti-inflammatory properties may improve tolerance[2]. **FFNFO: 4**	Meta-analysis (n=575, n=7 studies) shows benefit of zinc lozenges (75 mg.day^{-1} elemental zinc) to shorten common cold by ~33%; zinc must be taken < 24h after onset of URI. Many over-the-counter lozenges contain insufficient zinc and/or substances that bind zinc. Optimal lozenge composition and dosage to be determined. Side effects include bad taste and nausea.	(Hemilä, 2017b; Hemilä et al., 2017)
	Vitamin C	Antioxidant (quenches ROS). Improves tolerance[2] by mitigating against excessive inflammation and tissue damage during URI. Supplementation may compensate for lowered vitamin C in plasma and lymphocytes during infection. Preliminary evidence also shows low plasma vitamin C in COVID-19 patients. RNI is 40 mg.day^{-1} (United Kingdom). **FFNFO: 1,3,4,6**	Cochrane review showed no benefit of 'initiating' vitamin C supplementation (> 200 mg.day^{-1}) after onset of URI. However, high vitamin C doses (gram doses) likely required if initiating supplementation after onset of URI. High vitamin C doses (6-8 g.day^{-1}) during URI have been shown to reduce URI duration. Further research required.	(Anderson et al., 1974; Arvinte et al., 2020; Chiscano-Camón et al., 2020; Hemilä, 2017a; Hemilä, 1992; Hemilä and Chalker, 2013)
Foreign travel	**Probiotic**	Probiotics are live microorganisms. When administered orally for several weeks (e.g., daily dose of ~10^{10} live bacteria) can increase the numbers of beneficial gut	Probiotics can reduce risk of Travellers' Diarrhoea but do not decrease episode duration. Unclear whether beneficial for URI associated with foreign travel in elite athletes,	(Hao et al., 2015; Lomax and Calder, 2009; Patel, 2011; Svendsen et al., 2016)

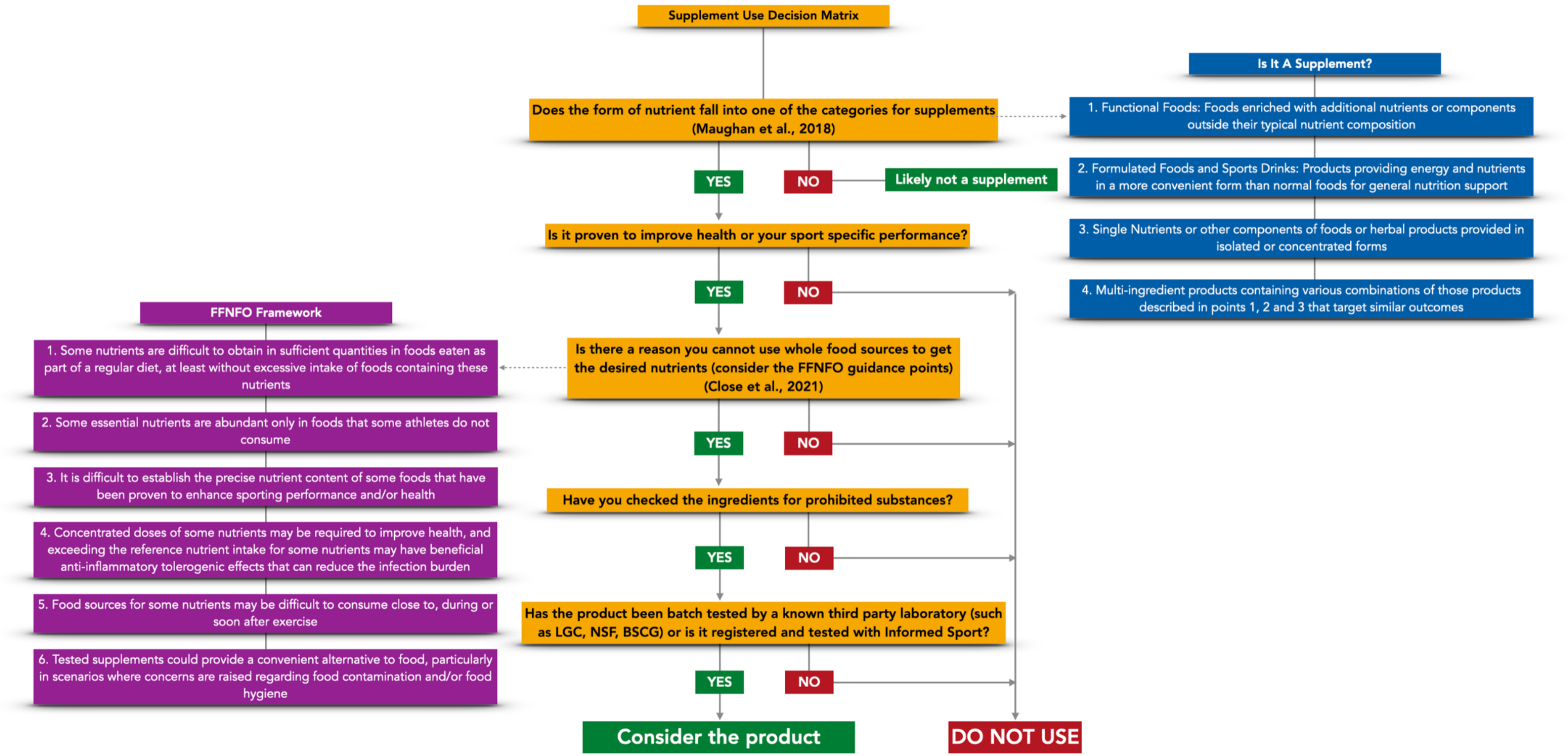
	bacteria. Diarrhoea and URI are commonly reported in occupational travellers. International air travel increased GI and URI symptoms 5-fold in elite athletes, likely due to increased pathogen exposure and/or multi-stressor effects on immunity. Probiotics can reinforce the gastrointestinal barrier, compete with pathogens for attachment, inhibit pathogen growth and improve tolerance[2] to harmless foreign substances in the gut. Benefits extend beyond the gut via the common mucosal immune system. **FFNFO: 4**	although Cochrane review reports reduced URI in wider community studies. Minor side effects reported. Supplementation required in the weeks before and during travel; further studies required.	
Vitamin C	Antioxidant (quenches ROS) with known tolerogenic effects[2] by mitigating against excessive inflammation and tissue damage during URI. Foreign travel is associated with increased URI in elite athletes, likely due to increased pathogen exposure and/or multi-stressor effects on immunity. RNI is 40 $mg.day^{-1}$ (United Kingdom). **FFNFO: 1,3,4,6**	No direct supporting evidence in travelling athletes, although Cochrane review shows reduced URI in heavy exercisers taking vitamin C (250–1000 $mg.day^{-1}$). Unclear if antioxidants blunt adaptation in well-trained. No reported side effects.	(Hemilä and Chalker, 2013; Schwellnus et al., 2012; Svendsen et al., 2016)

AMP = antimicrobial protein; COVID-19 = coronavirus disease 2019; RNI = reference nutrient intake; URI = upper respiratory infection; ROS = reactive oxygen species; GI = gastrointestinal infection. [1]Supplement must come from a reliable source and be tested by established quality assurance programme (Maughan et al., 2018b). [2]Tolerance dampens defence activity yet controls infection at a non-damaging level (Walsh, 2019).

6. Guidance on how best to deliver a ‘food first, but not always a food only’ sport nutrition strategy in a safe and evidence-based manner

The present narrative review has highlighted that sports supplements can offer an advantage over a food only approach to performance nutrition in some specific situations. However, given the risks outlined in section 2, it is crucial that athletes considering using sports supplements can do so safely. The SENr has developed a decision flow chart to help guide athletes on the use of supplements and we believe this remains an excellent point of reference to help to guide decision making today. We have adapted this flow chart (Figure 1) to include the key questions raised in this manuscript with reference to the FFNFO approach along with support on what classifies as a supplement (Maughan et al., 2018a; Maughan et al., 2018b). Central to the SENr flow chart is the requirement that all supplements must be independently batch tested for contaminants by a reputable laboratory, and without this process we strongly advise against the use of any supplement, even if there is a logical rationale for its use using the FFNFO criteria. Several companies offer a batch testing service including, but not limited to, Informed Sport, NSF, Banned Substance Control Group (BSCG) and The Cologne List, with thousands of supplements now batch tested annually. Indeed, all the supplements discussed in this manuscript can be sourced from a batch tested range. It must be stressed, however, that even if a supplement is batch tested, this does not guarantee that it is free from prohibited substances, or that the dosage provided on the label is accurate, and therefore batch testing is best described as ‘risk minimisation’, rather than ‘risk free’. Despite having access to sports nutritionists and dietitians, some athletes may still choose to use uncertified supplements (Vento and Wardenaar, 2020; Wardenaar et al., 2021). Ultimately, the athlete should make the final decision after receiving the best available advice from suitably qualified support staff, but, if athletes do choose to use supplements, practitioners should continue to encourage these athletes to use batch-tested products.

Figure 1. Supplement use decision flow chart including guidance as to what is a supplement and the FFNFO criteria.



7. Conclusions

A food first approach to sport nutrition is correctly advocated by a number of expert consensus statements and position stands, although to date there has been some confusion as to what 'food first' actually means. We have therefore proposed a working definition of the food first approach which is crucial to help guide nutritional practice. Given the well-defined benefits of a small number of dietary supplements on an athlete's health and performance, it is important that food first is not interpreted as a strictly food only approach. Indeed, we propose six 'FFNFO scenarios whereby a food only approach may not be the preferred *modus operandi*. In these specific situations, it is acceptable for the athlete, in collaboration with their sport dietitian/nutritionist to consider the strategic use of sports supplements providing that a comprehensive risk management strategy is implemented as defined in the FFNFO Framework. As a consequence, it is important to stress that the correct terminology should be 'food-first but not food only'.

Conflict of Interest

GLC has previously received payment for nutrition consultancy at Everton, Nottingham Forest, West Bromwich Albion, Aston Villa Football club, Munster Rugby, England Rugby, The Lawn Tennis Association, The Football Association, The English Institute of Sport, The Saudi Arabian Olympic Association and The European Tour Golf. He has previously provided consultancy to HealthSpan Elite and Get Buzzing Bars and currently provides consultancy to NutritionX for which he has received an honorarium. GC has spoken on several occasions for GSSI and produced articles for their exchange series for which he has received an honorarium. GC currently or has previously received research grants from the MRC, BSSRC, GSK, Sirtris, Research into Ageing, Aliment Nutrition, Naturecan, HH Sheikh Mansour Bin Zayad Al Nahyan Global Arabian Horse Flat Racing Festival, The Racing Foundation, The British Horse Racing Association, The Rugby Football Union, The Lawn Tennis Association, Newport Gwent Dragons, Gloucester Rugby, Everton FC and Aston Villa FC. He did not receive any form of financial support directly related to this manuscript. **AMK** has received payment for consultancy work within professional sports teams and with individual athletes: Blackburn Rovers, Everton and Fulham Football Clubs; Catalans Dragons Rugby League, England Rugby League, England Rugby Union, London Irish Rugby Union, Sale Sharks Rugby Union; Toronto Wolfpack Rugby League, and Wasps Rugby Union; and The English Institute of Sport and Intra Performance Group. He did not receive any form of financial support directly related to the manuscript. **NPW** has received research funding from the UK Ministry of Defence and Danone Waters and served on the Gatorade Sport Science Institute expert panel in 2019. He did not receive any form of financial support directly related to the manuscript. **RJM** contributed a scientific review to a meeting of the Gatorade Sports Science Institute in Texas in March 2019: travel and accommodation were paid and an honorarium was received for participation in the meeting and for preparation of a summary paper for publication in the SSI Sports Science Exchange. He did not receive any other form of financial support directly related to this manuscript.

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