Journal of Sports Sciences
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713721847

Dietary supplements for football

P. Hespel [a]; R. J. Maughan [b]; P. L. Greenhaff [c]
[a] Exercise and Health Laboratory, Faculty of Kinesiology and Rehabilitation Sciences, Katholieke Universiteit Leuven. Leuven. Belgium
[b] School of Sport and Exercise Sciences, Loughborough University. Loughborough. UK
[c] Centre for Integrated Systems Biology and Medicine, School of Biomedical Sciences, University of Nottingham Medical School, Queen's Medical Centre. Nottingham. UK

Online Publication Date: 01 July 2006
To cite this Article: Hespel, P., Maughan, R. J. and Greenhaff, P. L. , (2006) 'Dietary supplements for football', Journal of Sports Sciences, 24:7, 749 - 761
To link to this article: DOI: 10.1080/02640410500482974
URL: http://dx.doi.org/10.1080/02640410500482974

Journal of Sports Sciences, July 2006; 24(7): 749 – 761

Taylor & Francis
Taylor & Francis Group

Dietary supplements for football

P. HESPEL[1], R. J. MAUGHAN[2], & P. L. GREENHAFF[3]

[1]*Exercise and Health Laboratory, Faculty of Kinesiology and Rehabilitation Sciences, Katholieke Universiteit Leuven, Leuven, Belgium,* [2]*School of Sport and Exercise Sciences, Loughborough University, Loughborough, UK, and* [3]*Centre for Integrated Systems Biology and Medicine, School of Biomedical Sciences, University of Nottingham Medical School, Queen's Medical Centre, Nottingham, UK*

(Accepted 16 November 2005)

Abstract

Physical training and competition in football markedly increase the need for macro- and micronutrient intake. This requirement can generally be met by dietary management without the need for dietary supplemens. In fact, the efficacy of most supplements available on the market is unproven. In addition, players must be cautious of inadequate product labelling and supplement impurities that may cause a positive drug test. Nonetheless, a number of dietary supplements may beneficially affect football performance. A high endurance capacity is a prerequisite for optimal match performance, particularly if extra time is played. In this context, the potential of low-dose caffeine ingestion ($2 – 5\,mg \cdot kg$ body mass^{-1}) to enhance endurance performance is well established. However, in the case of football, care must be taken not to overdose because visual information processing might be impaired. Scoring and preventing goals as a rule requires production of high power output. Dietary creatine supplementation (loading dose: $15 – 20\,g \cdot day^{-1}$, 4 – 5 days; maintenance dose: $2 – 5\,g\,g \cdot day^{-1}$) has been found to increase muscle power output, especially during intermittent sprint exercises. Furthermore, creatine intake can augment muscle adaptations to resistance training. Team success and performance also depend on player availability, and thus injury prevention and health maintenance. Glucosamine or chondroitin may be useful in the treatment of joint pain and osteoarthritis, but there is no evidence to support the view that the administration of these supplements will be preventative. Ephedra-containing weight-loss cocktails should certainly be avoided due to reported adverse health effects and positive doping outcomes. Finally, the efficacy of antioxidant or vitamin C intake in excess of the normal recommended dietary dose is equivocal. Responses to dietary supplements can vary substantially between individuals, and therefore the ingestion of any supplement must be assessed in training before being used in competition. It is recommended that dietary supplements are only used based on the advice of a qualified sports nutrition professional.

Keywords: *Soccer, exercise, muscle, nutrition*

Introduction

The marketing pressure by the sports nutrition industry on athletic populations and sports nutrition professionals has engendered the widely held belief that the intake of dietary supplements is an essential part of participation in sports and physical activity. Many sports organizations and federations, as well as teams or individual athletes, also obtain substantial sponsorship from supplement companies. In the case of football, the administration of sports supplements has become a more or less standard procedure, often promoted by team physicians, coaches, and even the parents of young players. In this review, the relevance of supplement intake in football is discussed from a scientific perspective, together with some ethical concerns associated with supplement intake and sports education.

It is important to recognize that adequate intake of fluid and carbohydrate is crucial to endurance capacity and thus also to match performance in football, but these supplements are excluded from this review as they are covered elsewhere. In contrast to all supplements discussed in this review, the ingestion of supplements/drinks containing only water, electrolytes, and carbohydrates (so-called "fluid replenishers" and "energy drinks/gels/bars") can be seen as essential to adequate energy supply and rehydration during football at any level of competition (Burke, Loucks, & Broad, 2006; Shirreffs, Sawka, & Stone, 2006). Supplementation of water and carbohydrates in football not only serves

Correspondence: P. Hespel, Exercise and Health Laboratory, Faculty of Kinesiology and Rehabilitation Sciences, K.U. Leuven, Tervuursevest 101, B-3001 Leuven, Belgium. E-mail: peter.hespel@faber.kuleuven.be

ISSN 0264-0414 print/ISSN 1466-447X online
DOI: 10.1080/02640410500482974

ergogenic purposes but is also important for the prevention of adverse effects that could be associated with carbohydrate depletion and/or dehydration. Secondly, evidence is increasing to indicate that the ingestion of carbohydrate/protein-amino acid mixtures during the early phase of recovery from high-intensity exercise could facilitate post-exercise muscle glycogen storage as well as muscle protein synthesis, and thereby may enhance recovery and long-term adaptations to training (Hawley, Tipton, & Millard-Stafford, 2006).

Is there a need for supplements in football?

Training for and playing football can markedly increase the need for macro- and micronutrients. At a professional level, with often sustained periods of two matches per week, interspersed with training sessions, this increase can be substantial. However, this need can be covered adequately by dietary management, and establishing good eating practices to achieve the consistent intake of a well-balanced and healthy diet should be the primary nutritional strategy to support optimum performance in football (Burke *et al.*, 2006). Such practices include manipulation of the quantity and type of foods to meet fluctuating energy needs, the selection of food sources to provide adequate carbohydrate, protein, and micronutrients and, last but not least, the specific timing of intake of nutrients to facilitate recovery between exercise and promote adaptations to training (Hawley *et al.*, 2006; Williams & Serratosa, 2006). Therefore, coaches, physicians, parents, and others who are engaged in the training and education process of footballers must pay particular attention to developing adequate eating habits in players, rather than promoting the use of dietary supplements to compensate for presumed dietary shortcomings. This is particularly true for young players, who should be able to develop their football talent by the optimum combination of training and diet. It is most doubtful that the addition of dietary supplements could facilitate the expression of football talent.

Nevertheless, appropriate ingestion of some specific supplements in conjunction with appropriate training can contribute to enhanced performance in football. At its most basic, the most important measure of performance in football is the number of goals scored versus the number of goals conceded, but there are no research data to show that nutritional supplements can improve this balance. But there is sound scientific evidence that some supplements can affect factors that determine football performance. The so-called "ergogenic" effects of these supplements, however, are generally small, and thus probably relevant only in top-class footballers where extremely small differences in performance can make the difference between loss and victory, with potentially major financial and career implications. To counterbalance the strong marketing pressures generated by the supplement industry, it is important that players are well educated about effective procedures for supplement intake. It is also important to recognize that responses to supplements vary among players, and supplements that work for one player may not necessarily work for another. Furthermore, the use of supplements must always be tested in training before being applied in competition, to avoid unexpected side-effects. Each individual player must consider whether the small benefit obtained from supplement ingestion outweighs the associated risks (see below).

Risks associated with the use of dietary supplements

The market for nutritional supplements has become a multi-billion dollar business, spreading supplements worldwide. Unfortunately, in many cases, the labelling of products does not correspond with the actual content of the product. Some products contain less active ingredients than indicated on the label, or no active substance at all (Green, Catlin, & Starcevic, 2001). A typical example of such malpractice is the so-called "creatine-serum", which after several years of aggressive marketing and sales was recently demonstrated by several independent laboratories to contain no creatine (Harris, Almada, Harris, Dunnett, & Hespel, 2004). On the other hand, products have been found to contain substances not included on the label or much more active ingredients than indicated on the label (Gurley, Gardner, & Hubbard, 2000; Parasrampuria, Schwartz, & Petesch, 1998). Most alarming is the finding from recent field surveys that apparently innocent over-the-counter products that, according to the label, were supposed to contain only harmless compounds, contained pharmacological quantities of the anabolic steroid metadienone (De Cock *et al.*, 2001; Geyer *et al.*, 2004; Parr, Geyer, Reinhart, & Schanzer, 2004). This indicates that some companies will not hesitate to potentiate the purported actions of their sports supplements by the addition of dangerous prescription drugs, a practice that is criminal. Besides conceivable adverse health effects, the intake of such supplements could result in a positive doping test. For example, a substantial fraction (10–25%) of a variety of "off-the-shelf" supplements was found to be contaminated by androgenic prohormones, including compounds related to testosterone and nandrolone (Geyer *et al.*, 2004; www.dopinginfo.de). Ingestion of some androgenic prohormones (19-noradrostenedione and 19-norandrostenediol) can produce a positive doping test for nandrolone (Delbeke, Van Eenoo, Van Thuyne, & Desmet, 2002; Geyer *et al.*, 2004), as has occurred on many occasions in football and in other sports. Some supplements produced from plant extracts may contain substances that are on the banned substances list, primarily ephedrine (=ephedra) and morphine (Van Thuyne, Van Eenoo, & Delbeke, 2003). Typically, the product label would identify the plant of origin, such as "Ma Huang", but not the illegal compound, ephedra. It is important to emphasize that players at the higher levels of the game must expect to be tested for substance abuse, and must accept the consequences, irrespective of whether the doping regulations have been violated on purpose or by accident, for instance by the ingestion of a contaminated supplement. Furthermore, many dietary supplements have been found to contain micro- and macro-contaminants resulting from poor production and packaging practices in often unhygienic conditions. Last but not least, it is important to note that adequate long-term safety data are lacking for most sports supplements. The absence of reported side-effects in small-scale or short-term studies does not therefore prove that the supplement *is* safe. In addition, even if the active ingredient appears to be safe, the real risk may lie with the impurity of the product. Thus, consistent caution is warranted.

Selection of supplements that are relevant to football

Thousands of supplements, mostly pseudo-supplements, are available for purchase. To recognize supplements that are potentially effective and relevant to football, three requirements have been identified:

1. The supplement must work, which means that it must influence physical/physiological, mental, or health factors that determine performance in football.
2. The supplement must not cause any adverse health effects.
3. The supplement must be legal – that is, it must not contain any substance named in the banned substance list, or alternatively a substance that could result in a positive doping test.

It is reasonable to state that athletes should not ingest supplements that simply have no effect. Thus, supplements must have measurable effects on performance or on performance-related factors that go beyond the placebo effect that may result from the psychological effect of supplement intake. Still, football coaches and physicians should probably also appreciate that dietary supplements can serve as excellent placebos, provided they have no detrimental effects on either health or performance. If used as a placebo, it must be done for a small selection of important matches only.

It is probably correct to conclude that the acute ingestion of some dietary supplements could produce an ergogenic effect in football by directly enhancing match performance. Similarly, it is probably correct to state that some supplements could improve performance over the longer term by having a beneficial effect on health and injury prevention. Table I lists a number of supplements that work, and from a scientific perspective appear to be relevant to football. For most of these supplements, one or more physiological mechanisms have been elucidated to explain its purported performance or health effect. Table II, on the other hand, contains a number of supplements that *may* work. Scientific evidence to support these supplements is at present inconclusive, yet there are some valid data to suggest that these compounds might have some potential in aiding performance. However, further research is needed to justify any recommendation to use these products (see Table II). Scrutiny of Tables I and II will demonstrate that most commercially available supplements are not listed. This means that scientific support for an ergogenic or health effect is currently lacking, or more frequently that available research data indicate that these supplements do not work in healthy individuals and athletes. Some of the most popular sports supplements, such as L-carnitine, coenzyme Q10, ginseng and other so-called "adaptogens", glutamine, and ribose fall within this category of pseudo-sports supplements. Therefore, they will not be considered further.

Supplements for endurance

Aerobic endurance is a pivotal determinant of performance in football. Match duration in football is 90 min and can increase to 120 min when extra time is played. During this period, players on average perform between 9 and 12 km of intermittent running exercise, of which about 10% is sprinting (Reilly, 2005). There is no doubt that adequate pre-match and half-time carbohydrate intake can substantially improve endurance capacity as well as intermittent sprint power in the final stages of a match (Williams & Serratosa, 2006). Furthermore, bicarbonate and other alkalinizing agents like sodium citrate are also frequently considered as ergogenic supplements in all-out anaerobic exercise (Horswill, 1995; Matson & Tran, 1993). Bicarbonate intake ($200-300\,mg \cdot kg$ body $mass^{-1}$) increases buffer capacity, and can significantly enhance performance during short maximal exercise bouts lasting from about 20 s to about 5 min. However, gastrointestinal

Table I. Supplements that work in some exercise situations.

Supplement	Ergogenic or health effects	Physiological mechanisms linked to the observed effects
Amino acids/protein hydrolysate/protein[a]	Increases muscle volume/fat-free mass Stimulates recovery from exercise	Stimulates muscle amino acid uptake Stimulates muscle protein synthesis Stimulates insulin release Stimulates muscle glycogen resynthesis
Caffeine	Enhances endurance performance Stimulates reaction time, mental alertness, and visual information processing	Stimulates lipolysis and muscle fat oxidation rate Stimulates exogenous carbohydrate oxidation Increases heart rate Psychostimulatory action
Carbohydrates[b]	Enhance endurance performance Stimulates recovery from exercise	Stimulates and maintains muscle carbohydrate oxidation Prevents hypoglycaemia Stimulates muscle glycogen resynthesis Stimulates insulin release Increases endurance training workload Inhibits muscle protein degradation
Creatine	Stimulates muscle strength and power Increases muscle volume/fat-free mass Stimulates recovery from exercise	Increases muscle creatine content Facilitates muscle phosphocreatine resynthesis Shortens muscle relaxation time Increases resistance training workload Stimulates muscle glycogen resynthesis
Ephedra[c]	Facilitates short-term weight loss	Stimulates sympathetic nervous system Enhances resting energy expenditure

[a]For details on this category of supplements, see Hawley *et al.* (2006).
[b]For details on this category of supplements, see Burke *et al.* (2006), Shirreffs *et al.* (2006), and Williams and Serratosa (2006).
[c]This supplement is on the list of substances banned by WADA.

Table II. Supplements that may work in some exercise situations.*

Supplement	Ergogenic or health effects claimed	Proposed physiological mechanisms linked to the effects claimed
Antioxidants	Prevents muscle damage	Enhances defence against formation of reactive oxygen species in contracting muscles
Beta-hydroxy-β-methylbutyrate	Stimulates muscle strength and power Increases muscle volume/fat-free mass	Inhibits contraction-induced muscle cell degradation
Glucosamine	Alleviates joint pain Reduces symptoms of osteoarthritis	Stimulates the formation of bone cartilage
Vitamin C	Stimulates the immune system	Stimulates the activity of neutrophils, monocytes, and lymphocytes

*The available literature is inconclusive in supporting a possible "ergogenic" action in healthy individuals. Further studies are warranted.

distress, mostly cramping, diarrhoea or vomiting, associated with bicarbonate intake can be substantial. It is unlikely that the small beneficial effect possibly obtained from bicarbonate intake during the initial stage of a football match could outweigh the risk for gastrointestinal distress in a later stage, usually starting about 1 h after ingestion. Therefore, bicarbonate is not considered to be a sensible supplement in the context of football. Other supplements to be considered are caffeine and creatine.

Caffeine. Caffeine is a popular stimulant used by most individuals, including athletes. Caffeine is contained in coffee, tea, chocolate, and many other caffeinated food sources like cola. The physiological mechanisms of action of caffeine are only partially understood. Caffeine has been shown to stimulate fat utilization, leading to a reduced rate of muscle glycogen breakdown, but this does not appear to explain changes in performance. More likely, caffeine beneficially affects performance by reducing perception of fatigue, enhancing central drive, and/or improving muscle fibre recruitment (Graham, 2001; Magkos & Kavouras, 2004). The stimulatory action of caffeine on the brain is probably mediated by adenosine receptor blockade (Davis *et al.*, 2003).

The ergogenic effect of caffeine in endurance exercise performance is well established (for recent reviews, see Doherty & Smith, 2005; Graham, 2001; Magkos & Kavouras, 2004), which explains its extensive use by endurance athletes. Early studies demonstrated that the ingestion of caffeine doses of between 5 and 13 mg · kg body mass^{-1} caused a substantial improvement in endurance exercise capacity (Graham & Spriet, 1991; Pasman, Van Baak, Jeukendrup, & de Haan, 1995). However, more recent studies have shown that caffeine can be equally as effective at lower doses in the range of 2 – 6 mg · kg body mass^{-1} (Graham & Spriet, 1995; Kovacs, Stegen, & Brouns, 1998). In a study that used a sensitive exercise performance model and that employed well-trained cyclists as participants, it was shown that the ingestion of as little as about 90 mg of caffeine during a 2 h exercise test could result in significant performance improvements in a subsequent time-trial (Cox *et al.*, 2002b). Caffeine is rapidly absorbed and if ingested during the pre-match warm-up, the performance effects will be maintained for the entire match, even if extra time is played (Bell & McLellan, 2002). For example, when ingested on an empty stomach, peak plasma levels are usually reached within 1 h. However, the ergogenic effect is maintained for at least 3 h after ingestion. Intake of a caffeine in the form of coffee yields smaller effects than intake of a similar dose of pure caffeine (Graham, Hibbert, & Sathasivam, 1998), and there may be some gastrointestinal distress associated with drinking strong coffee (Tarnopolsky, 1994).

Responses to caffeine intake and withdrawal can vary greatly among individuals depending on the degree of habituation (Bangsbo, Jacobsen, Nordberg, Christensen, & Graham, 1992; Bell & McLellan, 2002; Fisher, McMurray, Berry, Mar, & Forsythe, 1986; Graham, 2001; Hetzler, Warhaftig-Glynn, Thompson, Dowling, & Weltman, 1994; Magkos & Kavouras, 2004; Van Soeren & Graham, 1998; Van Soeren, Sathasivam, Spriet, & Graham, 1993). Therefore, individual tuning of the dosage in the context of training is very important. Frequent high-dose caffeine intake results in rapid desensitization. This in turn establishes the need to use even higher doses. Hence a rational use of caffeine in football probably ideally includes moderate daily caffeine use, with acute caffeine spikes on match days (3 – 6 mg · kg body mass^{-1} during warming up). It is sometimes suggested that habitual caffeine users should consider withdrawing from caffeine for about 4 days to enhance the beneficial effects of an acute pre-match caffeine dose, but the evidence for performance benefits when this is done is not entirely convincing. In addition, the participants in the study of Cox *et al.* (2002b) were habitual caffeine users and yet a positive effect on performance was seen with only 90 mg of caffeine. Besides its effect on endurance, small doses of caffeine (1 – 2 mg · kg body mass^{-1}) can also beneficially influence reaction time, alertness, and visual information processing, which are crucial to success in goalkeeping and outfield play (Haskell, Kennedy, Wesnes, & Scholey, 2005). However, overdosing will negatively affect reaction time and alertness, which might counterbalance the stimulatory effect of caffeine on endurance performance (Figure 1). Similarly, it could be argued that the metabolic effects of high-dose caffeine intake could induce insulin resistance

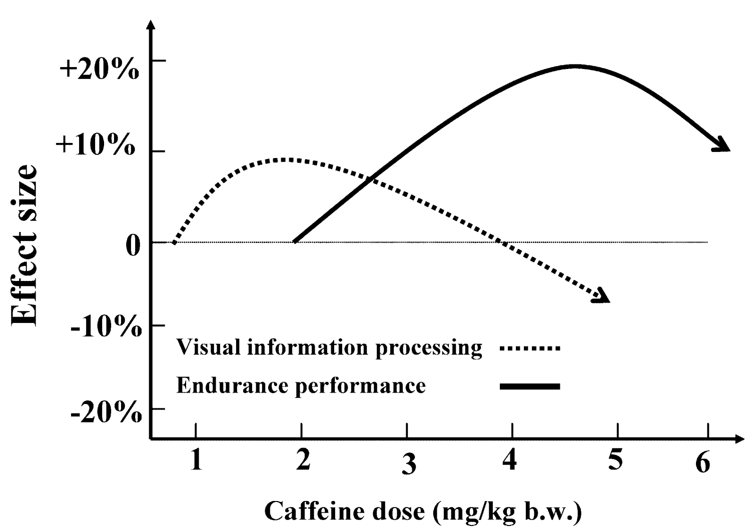

Figure 1. Caffeine affects both visual information processing and endurance capacity. However, the dose needed to yield an optimal effect on visual information processing is substantially lower than that required to yield an optimal effect on endurance capacity. If too high a dose of caffeine is ingested, caffeine can impair visual information processing. Therefore, outfield players should seek a dose to enhance endurance capacity, without negatively affecting visual information processing, whereas goalkeepers should stick to the lower dose. Depending on the degree of habituation, responses to a given caffeine dose can vary greatly between individuals, with habitual caffeine users needing higher doses. Therefore, the doses indicated on the x-axis, as well as the effect-size on the y-axis, are indicative.

in skeletal muscle and tachycardia. For the goal-keeper the lower dose ($1-2\,mg \cdot kg$ body mass^{-1}) is obvious, while the outfield players should rather seek a dosage to enhance endurance without causing mental over-arousal and gross metabolic and heart rate perturbations.

The common use of caffeine as a social stimulant in society probably proves that low-dose caffeine intake can be considered safe. However, high-dose caffeine intake is widely thought to be associated with adverse health effects, in particular at the level of the cardiovascular system (Tarnopolsky, 1994). The diuretic effect of caffeine at the doses recommended here is negligible, which means that there is no reason to avoid caffeine intake or withdraw from caffeine-containing beverages in the approach to matches to be played in hot environmental conditions (Armstrong *et al.*, 2005; Maughan & Griffin, 2003).

Caffeine use in competition was formerly considered as doping by the International Olympic Committee in cases where the intake produced urinary caffeine concentrations higher than $12\,\mu g \cdot ml^{-1}$. However, in early 2004 the World Anti-Doping Agency (WADA) removed caffeine from the list of banned substances, although its use is being monitored. Still, the discussion does not seem to be closed and the regulations might change again.

Creatine. Dietary creatine supplementation is popular in athletic populations, and it has been reported on numerous occasions to increase muscle strength and power (see next section for further details on this topic). However, co-ingestion of creatine with a carbohydrate-rich diet can enhance post-exercise glycogen repletion in humans (Robinson, Sewell, Hultman, Greenhaff, 1999; van Loon *et al.*, 2004). There is no direct evidence for a beneficial effect on endurance performance (Terjung *et al.*, 2000), but this latter effect might facilitate the restoration of muscle glycogen stores following exercise, especially when recovery time between matches is limited.

Supplements for strength and power

In addition to the requirement for a high endurance capacity to maintain running ability throughout a match, footballers must also be able to produce high power outputs. It is unquestionable that the ability to suddenly accelerate, perform short maximal intermittent sprints, jump higher than the opponent, or generate high kicking and tackling forces is a pre-requisite of high-level football performance (Reilly, 2005). Muscle strength is an important determinant of maximal power output in all athletes. Therefore, supplements that have the potential to enhance muscle strength and power are important to football. Issues pertaining to the stimulation of resistance training adaptations as a result of the ingestion of amino acid-protein-carbohydrate supplements are addressed in detail elsewhere (Hawley *et al.*, 2006). In the context of this review, however, two additional supplements need to be considered, creatine and to a lesser extent 3-hydroxymethylbutyrate.

Creatine. Creatine is a natural guanidine compound occurring in meat and fish in concentrations of between 3 and $7\,g \cdot kg^{-1}$ (Walker, 1979). Synthetic creatine supplements exist as creatine monohydrate or various creatine salts, such as creatine citrate or creatine pyruvate. There is no evidence that so-called "special" creatine formulations are better than simple (and cheaper!) creatine monohydrate powder. However, creatine salts, in contrast with creatine monohydrate, are easily soluble and stable in solution and thus could be included in sports drinks or gels. On the other hand, creatine monohydrate must be consumed soon after it is brought in to solution. It is well established that creatine supplementation can enhance power output during short maximal sprints (Terjung *et al.*, 2000), in particular during intermittent exercise modes (Casey, Constantin-Teodosiu, Howell, Hultman, & Greenhaff, 1996; Greenhaff, Casey, Short, Harris, & Söderlund, 1993; Hespel *et al.*, 2001; Van Leemputte, Vandenberghe, & Hespel, 1999; Vandenberghe *et al.*, 1996, 1997), even when contained in an endurance exercise event like football (Cox, Mujika, Tumilty, & Burke, 2002a; Mujika, Padilla, Ibañez, Izquierdo, & Gorostiaga, 2000; Vandebuerie, Vanden Eynde, Vandenberghe, & Hespel, 1998). Furthermore, several studies have shown that creatine supplementation can potentiate the gains in fat-free mass and muscle force and power output that accompany resistance training (Hespel *et al.*, 2001; Kreider *et al.*, 1998; Maganaris & Maughan, 1998; Volek *et al.*, 1999).

A classical creatine loading regimen consists of an initial loading phase ($15-20\,g \cdot day^{-1}$ for 4–7 days) followed by a maintenance dose ($2-5\,g \cdot day^{-1}$) (Terjung *et al.*, 2000). However, there are some data to indicate that the effects of creatine supplementation may fade after 2 months (Derave, Eijnde, & Hespel, 2003). Although research data in this regard are still lacking, it is probably sensible to interrupt periods of creatine supplementation (8–10 weeks) with wash-out periods of at least 4 weeks. Individuals with a low initial muscle creatine content, like vegetarians (Burke *et al.*, 2003; Delanghe *et al.*, 1989; Watt, Garnham, & Snow, 2004), respond better to creatine supplementation than others with a high natural muscle creatine content. Ingesting creatine in conjunction with training sessions can stimulate muscle creatine uptake, as exercise is known to facilitate the disposal of ingested creatine into musculature (Harris, Söderlund, & Hultman, 1992; Robinson *et al.*, 1999). Ingesting creatine supplements in combination with post-exercise carbohydrate-amino acid-protein supplements can enhance muscle creatine retention by virtue of elevated circulating insulin concentrations (Green, Hultman, Macdonald, Sewell, & Greenhaff, 1996; Steenge, Simpson, & Greenhaff, 2000).

Creatine is not on the doping list and creatine intake in healthy adults, following the aforementioned guidelines, has been found to be generally safe (Terjung *et al.*, 2000). Initial concern with regard to the potential adverse effects of creatine on renal function has been dampenedd by studies showing intact renal function after acute and prolonged dietary creatine intake (Poortmans *et al.*, 1997; Poortmans & Francaux, 1999). Creatine loading is often accompanied by a rapid increase in body mass (1 – 3 kg within 3 – 4 days is not uncommon), which probably results mainly from intracellular water and/or glycogen accumulation driven by muscle creatine uptake. This increase in muscle water content may increase intramuscular pressure, which in some few individuals may predispose to development of a compartment syndrome (Schroeder *et al.*, 2001).

The physiological mechanisms underlying the effects of creatine supplementation are only partly understood. There are data to indicate that the increased muscle creatine content due to creatine intake can facilitate flux through the creatine kinase reaction and thereby prevent net ATP degradation during high-intensity muscle contractions (Casey *et al.*, 1996). This could also explain the shortening of muscle relaxation time seen after creatine loading (Van Leemputte *et al.*, 1999). Furthermore, stimulation of muscle phosphocreatine resynthesis probably contributes to enhanced recovery between intermittent bouts of short maximal exercise (Greenhaff, Bodin, Söderlund, & Hultman, 1994). The mechanisms underlying the potential of creatine to stimulate muscle anabolism during resistance training are unclear. One study has found creatine intake to stimulate satellite cell proliferation (Dangott, Schultz, & Mozdziak, 1999). Others have observed creatine to impinge on intracellular signalling pathways involved in regulation of muscle protein metabolism (Deldicque *et al.*, 2005; Louis, Van Beneden, Dehoux, Theisen, & Francaux, 2004). However, direct evidence that creatine can stimulate net protein synthesis in human muscle is missing (Louis *et al.*, 2003a, 2003b). Alternatively, changes in muscle protein accretion can occur as a consequence of individuals performing more work during high-intensity training programmes while consuming creatine (Kreider *et al.*, 1998). At least part of the increase in body mass due to creatine intake does not reflect protein accretion but intracellular water accumulation (Ziegenfuss, Lowery, & Lemon, 1998).

Beta-hydroxy-β-methylbutyrate (HMB). HMB is a naturally occurring metabolite of the branched-chain amino acid leucine. Based on observations in animals (Chua, Siehl, & Morgan, 1979; Tischler, Desautels, & Goldberg, 1982), it was hypothesized that this compound could contribute to muscle anabolism by mediating the action of leucine to inhibit muscle protein breakdown (Gallagher, Carrithers, Godard, Schulze, & Trappe, 2000a; Nissen *et al.*, 1996). Over the past 10 years, a small number of studies have looked at the potential of oral HMB to stimulate muscle hypertrophy (for a recent review, see Nissen & Sharp, 2003). Published results are equivocal, yet a recent meta-analysis of available data suggested that HMB intake at a rate of $1.5 - 3.0\,g \cdot day^{-1}$ could result in larger gains in fat-free mass and muscle power output associated with resistance training. This effect may be due to inhibition of contraction-induced proteolysis (Nissen *et al.*, 1996). Short-term HMB intake (1 – 8 weeks) does not appear to induce any detrimental side-effects (Gallagher, Carrithers, Godard, Schulze, & Trappe, 2000b; Nissen *et al.*, 1996; Nissen & Sharp, 2003), but there are no data on its long-term (> 8 weeks) effects and side-effects. HMB is not on the doping list. In summary, overall evidence in favour of an ergogenic action of HMB is weak and more data from independent laboratories are needed.

Supplements for health

Long-term team performance in football depends to a large extent on the degree of match participation by the better players. In this respect, some supplements might contribute to injury prevention or rehabilitation from injury, health maintenance, or prevention of fatigue and overtraining.

Antioxidants. Oxygen utilization in contracting muscles results in the formation of reactive oxygen species (ROS), which, if produced in excess of the muscle antioxidant defence system, may result in muscle cell damage (Sen, 2001). However, one should also consider that the formation of ROS probably also contributes to promoting training adaptations by impinging on intracellular signalling pathways during exercise (Sen, 2001). Still, using only the former argument, a number of antioxidant nutritional supplements are marketed to prevent muscle tissue damage in athletes. This primarily includes beta carotene, vitamins C and E, selenium, ubiquinone, and several phytochemicals (Clarkson & Thompson, 2000; Ji & Peterson, 2004; Sen, 2001; Urso & Clarkson, 2003). Available research on the potential ergogenic effects of antioxidant supplements is equivocal, and there is no consensus as to whether strenuous exercise training increases the need for antioxidants in the diet. Numerous studies have looked at the potential of single or combined antioxidant supplements on indices of exercise-induced muscle damage. Some studies have found small beneficial effects, but others have found no effect, while one study even reported antioxidant intake to exaggerate tissue damage (Barr & Rideout, 2004; Clarkson & Thompson, 2000; Sen, 2001; Urso & Clarkson, 2003). Against this background, and awaiting further scientific evidence, there is probably no sound scientific rationale to recommend antioxidant supplementation in footballers. It definitely is a better option to include a selection of foods with a high content of antioxidants in the daily diet (Kris-Etherton, Lichtenstein, Howard, Steinberg, & Witztum, 2004; and see www.americanheart.org).

Creatine. Creatine can enhance the gain of fat-free mass produced by a given amount of resistance training. It also has been demonstrated that creatine supplementation can facilitate the recovery of muscle volume and muscular functional capacity during rehabilitation training following an episode of muscle atrophy due to leg immobilization (Hespel *et al.*, 2001). Given the high incidence of leg injuries and concomitant muscle disuse atrophy in football, creatine supplementation may be a worthwhile option to enhance post-injury rehabilitation and thereby speed up return to training and competition.

Glucosamine. The incidence of knee- and ankle-joint injuries is conceivably higher in football than in any other sport and frequently prevents players from participating in training and competition. Glucosamine and chondroitin are two popular substances being promoted for maintenance of joint health (Gorsline & Kaeding, 2005). In Europe these substances are sold only in the form of prescription drugs, while in the USA they are available as over-the-counter dietary supplements. It is believed that both glucosamine and chondroitin can help to enhance the structural integrity and resilience of bone cartilage. Discordant findings with regard to the effects of glucosamine and chondroitin have been reported (McAlindon, LaValley, Gulin, & Felson, 2000). However, it is probably correct to conclude from some well-controlled studies that glucosamine can retard the progression of osteoarthritis, at least in older people (Pavelka *et al.*, 2002; Reginster *et al.*, 2001). Furthermore, observations in older individuals with chronic knee pain indicate that glucosamine can yield an analgesic effect and serve as an alternative or adjuvant treatment to non-steroid anti-inflammatory drugs (Braham, Dawson, & Goodman, 2003). A recent safety review of glucosamine concluded that glucosamine supplementation in accordance with current indications and dosage regimens ($20-25\,\text{mg}\cdot\text{kg body mass}^{-1}$) is probably safe. Bloating or diarrhoea may occur, and individuals with shellfish allergies should refrain from glucosamine intake (Anderson, Nicolosi, & Borzelleca, 2005).

Footballers could also consider using glucosamine or chondroitin supplementation as a strategy to prevent knee pain or osteoarthritis. However, this practice is certainly premature because there is currently no evidence to indicate that glucosamine or chondroitin could serve to prevent osteoarthritis and/or joint pain in healthy athletes. It is also important to note that most data with regard to the effects of glucosamine and chondroitin have been obtained from studies involving older individuals, and thus it is unclear whether these findings can be readily extrapolated to young footballers afflicted by knee pain or osteoarthritis.

Vitamin C. It is well established that strenuous exercise training, including the repetition of football games, can have an immunosuppressive effect (Gleeson & Bishop, 2000; Gleeson, Lancaster, & Bishop, 2001; Gleeson, Nieman, & Pedersen, 2004; Gleeson & Pyne, 2000; Hiscock & Pedersen, 2002; Lakier, 2003; Malm, Ekblom, Ekblom, 2004; Nieman, 2001, Nieman *et al.*, 2003; Nieman *et al.*, 2002; Pedersen & Toft, 2000). Because vitamin C has been suggested to be implicated in immunoregulation (Bhaskaram, 2002), it could play a role in reducing the incidence of infectious disease, which is important for keeping players fit and available to play. Research findings on the effect of vitamin C on infectious disease or on markers of immune function are equivocal. Recent reviews of available studies concluded that vitamin C supplementation does not beneficially affect the risk of developing a cold, yet could slightly ($\sim 8\%$) reduce the duration of a cold (Douglas, Hemila, D'Souza, Chalker, & Treacy, 2004; Hemila, 1996, 2004). However, such an effect requires a vitamin C dose of only about $200\,\text{mg}\cdot\text{day}^{-1}$, which is very easy to obtain from a well-balanced diet (see Table III).

Supplements for weight reduction

Body weight gains can be a problem for some athletes, including footballers. Excess body fat can impair endurance capacity and power output during football. The logical strategy to reduce body weight is to shift the balance of dietary energy intake relative to energy expenditure towards a net deficit, primarily by reducing energy intake. However, not all players can achieve the expected body fat goal in this way.

Table III. Some foods with a very high content ($>50\,mg \cdot 100\,g^{-1}$) of vitamin C.

Food product*	Typical amount of food product needed to obtain a vitamin C intake of ~200 mg
Blackberries	130 g
Breakfast cereals	300 g
Broccoli	180 g
Cauliflower	250 g
Cress	400 g
Guava	75 g
Fennel (root)	220 g
Kiwi	280 g
Mango	400 g
Orange	400 g
Papaya	250 g
Pepper (green or red)	130 g
Parsley	130 g
Red cabbage	330 g
Sprouts	130 g
Strawberries	330 g

*Vitamin C content refers to fresh products. Similar canned or deep-frozen food products contain substantially less vitamin C.

Therefore, players often seek the assistance of "fat-burning supplements" to facilitate body weight reduction. Ephedra is a popular supplement in this regard. As mentioned earlier, L-carnitine is not an effective dietary supplement. Although carnitine plays an essential role in fat oxidation in skeletal muscle, dietary supplementation with L-carnitine does not increase the muscle store of carnitine and therefore it cannot serve to reduce body weight by increasing fat oxidation rates.

Ephedra. Ephedra is a herbal equivalent of ephedrine and is contained in Ma Huang (Pittler & Ernst, 2005; Saper, Eisenberg, & Phillips, 2004). Ephedra can act as a beta-adrenoceptor agonist, which means it can increase resting energy expenditure by virtue of activation of the sympathetic nervous system, which also results in increased heart rate. Research data indicate that dietary intake of ephedra can be effective in facilitating short-term weight loss (Dwyer, Allison, & Coates, 2005; Shekelle *et al.*, 2003a, 2003b). Furthermore, the effects of ephedra on body weight reduction can be exaggerated by the simultaneous ingestion of caffeine and aspirin (Daly, Krieger, Dulloo, Young, & Landsberg, 1993; Dulloo, 2002; Dwyer *et al.*, 2005). The herbals guarana and white willow bark may be valid alternatives for caffeine and aspirin, respectively (Daly *et al.*, 1993). Other supplements that are believed to enhance the effects of ephedra are green tea and yohimbine. However, there is also substantial evidence that the adverse effects to health associated with the intake of these "weight-loss cocktails" are substantial (Andraws, Chawla, & Brown, 2005; Haller, Benowitz, & Jacob, 2005; Pittler, Schmidt, & Ernst, 2005; Shekelle *et al.*, 2003a). Adverse events documented include nausea, vomiting, psychiatric symptoms, autonomic hyperactivity, and cardiac arrhythmias. Moreover, cases of myocardial infarction, cerebrovascular accident, serious psychiatric pathology, and even death have been reported. In addition, ephedrine and ephedra are included on the list of banned substances issued by WADA. Intake of ephedra can result in a positive doping test, and from a health perspective the use of ephedra and ephedra-containing mixtures is dangerous, so its use must be strongly discouraged at any level of competition.

Combination of supplements and timing of supplement intake

A prevailing view of athletes is "if a little is good, then more is better", and therefore it is not uncommon for them to ingest excessive amounts of various supplements. This is an expensive practice and is unlikely to facilitate the ergogenic effects of the respective supplements. In addition, such practice raises a safety concern because on the one hand the side effects of supplement overdosing are unknown, and on the other hand overdosing also increases the intake rate of contaminants possibly contained in the supplements. Furthermore, athletes as a rule use multiple supplements. From a theoretical point of view, supplements acting via different physiological mechanisms could act additively or even in a synergistic way. However, the physiological mechanisms of action of the various supplements discussed in this section are incompletely understood. Moreover, very few studies have looked at combinations of supplements, which render it difficult to make specific recommendations. However, available data and field experience taken together indicate that there is no significant interaction between the supplements discussed in this review. There is one exception: caffeine has been found to negate at least the short-term effects of creatine supplementation, which suggests that co-ingestion of these substances should probably be avoided (Hespel, Op't, & Van Leemputte, 2002; Van Leemputte *et al.*, 1999). It is well established that exercise can enhance the responses of muscle to creatine and protein/amino acid intake (Harris *et al.*, 1992; Robinson *et al.*, 1999; Tipton & Wolfe, 2004; Wolfe, 2000). Furthermore, co-ingestion of an insulinogenic carbohydrate/amino acid mixture and creatine could conceivably facilitate muscle creatine retention, when the mixture is consumed in sufficient quantities to stimulate marked insulin release (Green *et al.*, 1996; Steenge, Lambourne, Casey, Macdonald, & Greenhaff, 1998; Steenge *et al.*, 2000). Also, from a practical point of view it is probably a sensible idea to time the intake of the above-mentioned supplements to coincide with strength and power exercise sessions, including early recovery (1 – 3 h). There are no specific recommendations with regard to the timing of intake of the other supplements addressed here.

References

Anderson, J. W., Nicolosi, R. J., & Borzelleca, J. F. (2005). Glucosamine effects in humans: A review of effects on glucose metabolism, side effects, safety considerations and efficacy. *Food and Chemical Toxicology*, *43*, 187 – 201.

Andraws, R., Chawla, P., & Brown, D. L. (2005). Cardiovascular effects of ephedra alkaloids: A comprehensive review. *Progress in Cardiovascular Diseases*, *47*, 217 – 225.

Armstrong, L. E., Pumerantz, A. C., Roti, M. W., Judelson, D. A., Watson, G., Dias, J. C. *et al.* (2005). Fluid, electrolyte, and renal indices of hydration during 11 days of controlled caffeine consumption. *International Journal of Sports Nutrition and Exercise Metabolism*, *15*, 252 – 265.

Bangsbo, J., Jacobsen, K., Nordberg, N., Christensen, N. J., & Graham, T. (1992). Acute and habitual caffeine ingestion and metabolic responses to steady-state exercise. *Journal of Applied Physiology*, *72*, 1297 – 1303.

Barr, S. I., & Rideout, C. A. (2004). Nutritional considerations for vegetarian athletes. *Nutrition*, *20*, 696 – 703.

Bell, D. G., & McLellan, T. M. (2002). Exercise endurance 1, 3, and 6 h after caffeine ingestion in caffeine users and nonusers. *Journal of Applied Physiology*, *93*, 1227 – 1234.

Bhaskaram, P. (2002). Micronutrient malnutrition, infection, and immunity: An overview. *Nutrition Reviews*, *60*, S40 – S45.

Braham, R., Dawson, B., & Goodman, C. (2003). The effect of glucosamine supplementation on people experiencing regular knee pain. *British Journal of Sports Medicine*, *37*, 45 – 49.

Burke, D. G., Chilibeck, P. D., Parise, G., Candow, D. G., Mahoney, D., & Tarnopolsky, M. (2003). Effect of creatine and weight training on muscle creatine and performance in vegetarians. *Medicine and Science in Sports and Exercise*, *35*, 1946 – 1955.

Burke, L. M., Loucks, A., & Broad, N. (2006). Energy and carbohydrate for training and recovery. *Journal of Sports Sciences*, *24*, 675 – 685.

Casey, A., Constantin-Teodosiu, D., Howell, S., Hultman, E., & Greenhaff, P. L. (1996). Creatine ingestion favorably affects performance and muscle metabolism during maximal exercise in humans. *American Journal of Physiology: Endocrinology and Metabolism*, *271*, E31 – E37.

Chua, B., Siehl, D. L., & Morgan, H. E. (1979). Effect of leucine and metabolites of branched chain amino acids on protein turnover in heart. *Journal of Biological Chemistry*, *254*, 8358 – 8362.

Clarkson, P. M., & Thompson, H. S. (2000). Antioxidants: What role do they play in physical activity and health? *American Journal of Clinical Nutrition*, *72*, 637S – 646S.

Cox, G. R., Desbrow, B., Montgomery, P. G., Anderson, M. E., Bruce, C. R., Macrides, T. A. *et al.* (2002b). Effect of different protocols of caffeine intake on metabolism and endurance performance. *Journal of Applied Physiology*, *93*, 990 – 999.

Cox, G., Mujika, I., Tumilty, D., & Burke, L. (2002a). Acute creatine supplementation and performance during a field test simulating match play in elite female football players. *International Journal of Sports Nutrition and Exercise Metabolism*, *12*, 33 – 46.

Daly, P. A., Krieger, D. R., Dulloo, A. G., Young, J. B., & Landsberg, L. (1993). Ephedrine, caffeine and aspirin: Safety and efficacy for treatment of human obesity. *International Journal of Obesity and Related Metabolic Disorders*, *17* (suppl. 1), S73 – S78.

Dangott, B., Schultz, E., & Mozdziak, P. E. (1999). Dietary creatine monohydrate supplementation increases satellite cell mitotic activity during compensatory hypertrophy. *International Journal of Sports Medicine*, *20*, 13 – 16.

Davis, J. M., Zhao, Z., Stock, H. S., Mehl, K. A., Buggy, J., & Hand, G. A. (2003). Central nervous system effects of caffeine and adenosine on fatigue. *American Journal of Physiology: Regulatory and Integrative Comparative Physiology*, *284*, R399 – R404.

De Cock, K. J., Delbeke, F. T., Van Eenoo, P., Desmet, N., Roels, K., & De Backer, P. (2001). Detection and determination of anabolic steroids in nutritional supplements. *Journal of Pharmaceutical and Biomedical Analysis*, *25*, 843 – 852.

Delanghe, J., De Slypere, J. P., De Buyzere, M., Robbrecht, J., Wieme, R., & Vermeulen, A. (1989). Normal reference values for creatine, creatinine, and carnitine are lower in vegetarians. *Clinical Chemistry*, *35*, 1802 – 1803.

Delbeke, F. T., Van Eenoo, P., Van Thuyne, W., & Desmet, N. (2002). Prohormones and sport. *Journal of Steroid Biochemistry and Molecular Biology*, *83*, 245 – 251.

Deldicque, L., Louis, M., Theisen, D., Nielens, H., Dehoux, M., Thissen, J. P. *et al.* (2005). Increased IGF mRNA in human skeletal muscle after creatine supplementation. *Medicine and Science in Sports and Exercise*, *37*, 731 – 736.

Derave, W., Eijnde, B. O., & Hespel, P. (2003). Creatine supplementation in health and disease: What is the evidence for long-term efficacy? *Molecular and Cellular Biochemistry*, *244*, 49 – 55.

Doherty, M., & Smith, P. M. (2005). Effects of caffeine ingestion on rating of perceived exertion during and after exercise: A meta-analysis. *Scandinavian Journal of Medicine and Science in Sports*, *15*, 69 – 78.

Douglas, R. M., Hemila, H., D'Souza, R., Chalker, E. B., & Treacy, B. (2004). Vitamin C for preventing and treating the common cold. *Cochrane Database of Systemic Review*, CD000980.

Dulloo, A. G. (2002). Herbal simulation of ephedrine and caffeine in treatment of obesity. *International Journal of Obesity and Related Metabolic Disorders*, *26*, 590 – 592.

Dwyer, J. T., Allison, D. B., & Coates, P. M. (2005). Dietary supplements in weight reduction. *Journal of the American Dietetic Association*, *105*, S80 – S86.

Fisher, S. M., McMurray, R. G., Berry, M., Mar, M. H., & Forsythe, W. A. (1986). Influence of caffeine on exercise performance in habitual caffeine users. *International Journal of Sports Medicine*, *7*, 276 – 280.

Gallagher, P. M., Carrithers, J. A., Godard, M. P., Schulze, K. E., & Trappe, S. W. (2000a). β-Hydroxy- β-methylbutyrate ingestion. Part I: Effects on strength and fat free mass. *Medicine and Science in Sports and Exercise*, *32*, 2109 – 2115.

Gallagher, P. M., Carrithers, J. A., Godard, M. P., Schulze, K. E., & Trappe, S. W. (2000b). β-Hydroxy- β-methylbutyrate ingestion. Part II: Effects on hematology, hepatic and renal function. *Medicine and Science in Sports and Exercise*, *32*, 2116 – 2119.

Geyer, H., Parr, M. K., Mareck, U., Reinhart, U., Schrader, Y., & Schanzer, W. (2004). Analysis of non-hormonal nutritional supplements for anabolic-androgenic steroids – results of an international study. *International Journal of Sports Medicine*, *25*, 124 – 129.

Gleeson, M., & Bishop, N. C. (2000). Special feature for the Olympics. Effects of exercise on the immune system: Modification of immune responses to exercise by carbohydrate, glutamine and anti-oxidant supplements. *Immunology and Cell Biology*, *78*, 554 – 561.

Gleeson, M., Lancaster, G. I., & Bishop, N. C. (2001). Nutritional strategies to minimise exercise-induced immunosuppression in athletes. *Canadian Journal of Applied Physiology*, *26* (suppl.), S23 – S35.

Gleeson, M., Nieman, D. C., & Pedersen, B. K. (2004). Exercise, nutrition and immune function. *Journal of Sports Sciences*, *22*, 115 – 125.

Gleeson, M., & Pyne, D. B. (2000). Special feature for the Olympics. Effects of exercise on the immune system: Exercise effects on mucosal immunity. *Immunology and Cell Biology*, *78*, 536 – 544.

Gorsline, R. T., & Kaeding, C. C. (2005). The use of NSAIDs and nutritional supplements in athletes with osteoarthritis: Prevalence, benefits, and consequences. *Clinical Sports Medicine*, *24*, 71 – 82.

Graham, T. E. (2001). Caffeine and exercise: Metabolism, endurance and performance. *Sports Medicine*, *31*, 785 – 807.

Graham, T. E., Hibbert, E., & Sathasivam, P. (1998). Metabolic and exercise endurance effects of coffee and caffeine ingestion. *Journal of Applied Physiology*, *85*, 883 – 889.

Graham, T. E., & Spriet, L. L. (1991). Performance and metabolic responses to a high caffeine dose during prolonged exercise. *Journal of Applied Physiology*, *71*, 2292 – 2298.

Graham, T. E., & Spriet, L. L. (1995). Metabolic, catecholamine, and exercise performance responses to various doses of caffeine. *Journal of Applied Physiology*, *78*, 867 – 874.

Green, A. L., Hultman, E., Macdonald, I. A., Sewell, D. A., & Greenhaff, P. L. (1996). Carbohydrate ingestion augments skeletal muscle creatine accumulation during creatine supplementation in humans. *American Journal of Physiology: Endocrinology and Metabolism*, *271*, E821 – E826.

Green, G. A., Catlin, D. H., & Starcevic, B. (2001). Analysis of over-the-counter dietary supplements. *Clinical Journal of Sport Medicine*, *11*, 254 – 259.

Greenhaff, P. L., Bodin, K., Söderlund, K., & Hultman, E. (1994). Effect of oral creatine supplementation on skeletal muscle phosphocreatine resynthesis. *American Journal of Physiology: Endocrinology and Metabolism*, *266*, E725 – E730.

Greenhaff, P. L., Casey, A., Short, A. H., Harris, R., & Söderlund, K. (1993). Influence of oral creatine supplementation on muscle torque during repeated bouts of maximal voluntary exercise in man. *Clinical Science*, *84*, 565 – 571.

Gurley, B. J., Gardner, S. F., & Hubbard, M. A. (2000). Content versus label claims in ephedra-containing dietary supplements. *American Journal of Health: System Pharmacy*, *57*, 963 – 969.

Haller, C. A., Benowitz, N. L., & Jacob, P., III (2005). Hemodynamic effects of ephedra-free weight-loss supplements in humans. *American Journal of Medicine*, *118*, 998 – 1003.

Harris, R. C., Almada, A. L., Harris, D. B., Dunnett, M., & Hespel, P. (2004). The creatine content of creatine serum and the change in the plasma concentration with ingestion of a single dose. *Journal of Sports Sciences*, *22*, 851 – 857.

Harris, R. C., Söderlund, K., & Hultman, E. (1992). Elevation of creatine in resting and exercised muscle of normal subjects by creatine supplementation. *Clinical Science*, *83*, 367 – 374.

Haskell, C. F., Kennedy, D. O., Wesnes, K. A., & Scholey, A. B. (2005). Cognitive and mood improvements of caffeine in habitual consumers and habitual non-consumers of caffeine. *Psychopharmacology (Berlin)*, *179*, 813 – 825.

Hawley, J. A., Tipton, K. D., & Millard-Stafford, M. L. (2006). Promoting training adaptations through nutritional interventions. *Journal of Sports Sciences*, *24*, 709 – 721.

Hemila, H. (1996). Vitamin C and common cold incidence: A review of studies with subjects under heavy physical stress. *International Journal of Sports Medicine*, *17*, 379 – 383.

Hemila, H. (2004). Vitamin C supplementation and respiratory infections: A systematic review. *Military Medicine*, *169*, 920 – 925.

Hespel, P., Op't, E. B., & Van Leemputte, M. (2002). Opposite actions of caffeine and creatine on muscle relaxation time in humans. *Journal of Applied Physiology*, *92*, 513 – 518.

Hespel, P., Op't Eijnde, B., Van Leemputte, M., Ursø, B., Greenhaff, P., Labarque, V. *et al.* (2001). Oral creatine supplementation facilitates the rehabilitation of disuse atrophy and alters the expression of muscle myogenic factors in humans. *Journal of Physiology*, *536*, 625 – 633.

Hetzler, R. K., Warhaftig-Glynn, N., Thompson, D. L., Dowling, E., & Weltman, A. (1994). Effects of acute caffeine withdrawal on habituated male runners. *Journal of Applied Physiology*, *76*, 1043 – 1048.

Hiscock, N., & Pedersen, B. K. (2002). Exercise-induced immunodepression – plasma glutamine is not the link. *Journal of Applied Physiology*, *93*, 813 – 822.

Horswill, C. A. (1995). Effects of bicarbonate, citrate, and phosphate loading on performance. *International Journal of Sport Nutrition*, *5* (suppl.), S111 – S119.

Ji, L. L., & Peterson, D. M. (2004). Aging, exercise, and phytochemicals: Promises and pitfalls. *Annals of the New York Academy of Sciences*, *1019*, 453 – 461.

Kovacs, E. M. R., Stegen, J. H. C. H., & Brouns, F. (1998). Effect of caffeinated drinks on substrate metabolism, caffeine excretion, and performance. *Journal of Applied Physiology*, *85*, 709 – 715.

Kreider, R. B., Ferreira, M., Wilson, M., Grinstaff, P., Plisk, S., Reinardy, J. *et al.* (1998). Effects of creatine supplementation on body composition, strength, and sprint performance. *Medicine and Science in Sports and Exercise*, *30*, 73 – 82.

Kris-Etherton, P. M., Lichtenstein, A. H., Howard, B. V., Steinberg, D., & Witztum, J. L. (2004). Antioxidant vitamin supplements and cardiovascular disease. *Circulation*, *110*, 637 – 641.

Lakier, S. L. (2003). Overtraining, excessive exercise, and altered immunity: Is this a T helper-1 versus T helper-2 lymphocyte response? *Sports Medicine*, *33*, 347 – 364.

Louis, M., Poortmans, J. R., Francaux, M., Berre, J., Boisseau, N., Brassine, E. *et al.* (2003a). No effect of creatine supplementation on human myofibrillar and sarcoplasmic protein synthesis after resistance exercise. *American Journal of Physiology: Endocrinology and Metabolism*, *285*, E1089 – E1094.

Louis, M., Poortmans, J. R., Francaux, M., Hultman, E., Berre, J., Boisseau, N. *et al.* (2003b). Creatine supplementation has no effect on human muscle protein turnover at rest in the postabsorptive or fed states. *American Journal of Physiology: Endocrinology and Metabolism*, *284*, E764 – E770.

Louis, M., Van Beneden, R., Dehoux, M., Thissen, J. P., & Francaux, M. (2004). Creatine increases IGF-I and myogenic regulatory factor mRNA in C(2)C(12) cells. *FEBS Letters*, *557*, 243 – 247.

Maganaris, C. N., & Maughan, R. J. (1998). Creatine supplementation enhances maximum voluntary isometric force and endurance capacity in resistance trained men. *Acta Physiologica Scandinavica*, *163*, 279 – 287.

Magkos, F., & Kavouras, S. A. (2004). Caffeine and ephedrine: Physiological, metabolic and performance-enhancing effects. *Sports Medicine*, *34*, 871 – 889.

Malm, C., Ekblom, O., & Ekblom, B. (2004). Immune system alteration in response to two consecutive football games. *Acta Physiologica Scandinavica*, *180*, 143 – 155.

Matson, L. G., & Tran, Z. V. (1993). Effects of sodium bicarbonate ingestion on anaerobic performance: A meta-analytic review. *International Journal of Sports Nutrition*, *3*, 2 – 28.

Maughan, R. J., & Griffin, J. (2003). Caffeine ingestion and fluid balance: A review. *Journal of Human Nutrition and Dietetics*, *16*, 411 – 420.

McAlindon, T. E., LaValley, M. P., Gulin, J. P., & Felson, D. T. (2000). Glucosamine and chondroitin for treatment of osteoarthritis: A systematic quality assessment and meta-analysis. *Journal of the American Medical Association*, *283*, 1469 – 1475.

Mujika, I., Padilla, S., Ibañez, J., Izquierdo, M., & Gorostiaga, E. (2000). Creatine supplementation and sprint performance in football players. *Medicine and Science in Sports and Exercise*, *32*, 518 – 525.

Nieman, D. C. (2001). Exercise immunology: Nutritional countermeasures. *Canadian Journal of Applied Physiology*, *26* (suppl.), S45 – S55.

Nieman, D. C., Dumke, C. L., Henson, D. A., McAnulty, S. R., McAnulty, L. S., Lind, R. H., & Morrow, J. D. (2003). Immune and oxidative changes during and following the Western States Endurance Run. *International Journal of Sports Medicine*, *24*, 541 – 547.

Nieman, D. C., Henson, D. A., McAnulty, S. R., McAnulty, L., Swick, N. S., Utter, A. C., Vinci, D. M., Opiela, S. J., & Morrow, J. D. (2002). Influence of vitamin C supplementation on oxidative and immune changes following an ultramarathon. *Journal of Applied Physiology*, *92*, 1970 – 1977.

Nissen, S. L., & Sharp, R. L. (2003). Effect of dietary supplements on lean mass and strength gains with resistance exercise: A meta-analysis. *Journal of Applied Physiology*, *94*, 651 – 659.

Nissen, S., Sharp, R., Ray, M., Rathmacher, J. A., Rice, D., Fuller, J. C., Jr. *et al.* (1996). Effect of leucine metabolite beta-hydroxy-beta-methylbutyrate on muscle metabolism during resistance-exercise training. *Journal of Applied Physiology*, *81*, 2095 – 2104.

Parasrampuria, J., Schwartz, K., & Petesch, R. (1998). Quality control of dehydroepiandrosterone dietary supplement products. *Journal of the American Medical Association*, *280*, 1565.

Parr, M. K., Geyer, H., Reinhart, U., & Schanzer, W. (2004). Analytical strategies for the detection of non-labelled anabolic androgenic steroids in nutritional supplements. *Food Additives and Contaminants*, *21*, 632 – 640.

Pasman, W. J., Van Baak, M. A., Jeukendrup, A. E., & de Haan, A. (1995). The effect of different dosages of caffeine on endurance performance time. *International Journal of Sports Medicine*, *16*, 225 – 230.

Pavelka, K., Gatterova, J., Olejarova, M., Machacek, S., Giacovelli, G., & Rovati, L. C. (2002). Glucosamine sulfate use and delay of progression of knee osteoarthritis: A 3-year, randomized, placebo-controlled, double-blind study. *Archives of Internal Medicine*, *162*, 2113 – 2123.

Pedersen, B. K., & Toft, A. D. (2000). Effects of exercise on lymphocytes and cytokines. *British Journal of Sports Medicine*, *34*, 246 – 251.

Pittler, M. H., & Ernst, E. (2005). Complementary therapies for reducing body weight: A systematic review. *International Journal of Obesity and Related Metabolic Disorders*, *29*, 1030 – 1038.

Pittler, M. H., Schmidt, K., & Ernst, E. (2005). Adverse events of herbal food supplements for body weight reduction: Systematic review. *Obesity Reviews*, *6*, 93 – 111.

Poortmans, J. R., Auquier, H., Renaut, V., Durussel, A., Saugy, M., & Brisson, G. R. (1997). Effect of short-term creatine supplementation on renal responses in men. *European Journal of Applied Physiology*, *76*, 566 – 567.

Poortmans, J. R., & Francaux, M. (1999). Long-term oral creatine supplementation does not impair renal function in healthy athletes. *Medicine and Science in Sports and Exercise*, *31*, 1108 – 1110.

Reginster, J. Y., Deroisy, R., Rovati, L. C., Lee, R. L., Lejeune, E., Bruyere, O. *et al.* (2001). Long-term effects of glucosamine sulphate on osteoarthritis progression: A randomised, placebo-controlled clinical trial. *Lancet*, *357*, 251 – 256.

Reilly, T. (2005). An ergonomics model of the football training process. *Journal of Sports Sciences*, *23*, 561 – 572.

Robinson, T. M., Sewell, D. A., Hultman, E., & Greenhaff, P. L. (1999). Role of submaximal exercise in promoting creatine and glycogen accumulation in human skeletal muscle. *Journal of Applied Physiology*, *87*, 598 – 604.

Saper, R. B., Eisenberg, D. M., & Phillips, R. S. (2004). Common dietary supplements for weight loss. *American Family Physician*, *70*, 1731 – 1738.

Schroeder, C., Potteiger, J., Randall, J., Jacobsen, D., Magee, L., Benedict, S. *et al.* (2001). The effects of creatine dietary supplementation on anterior compartment pressure in the lower leg during rest and following exercise. *Clinical Journal of Sports Medicine*, *11*, 87 – 95.

Sen, C. K. (2001). Antioxidants in exercise nutrition. *Sports Medicine*, *31*, 891 – 908.

Shekelle, P., Hardy, M. L., Morton, S. C., Maglione, M., Suttorp, M., Roth, E. *et al.* (2003a). Ephedra and ephedrine for weight loss and athletic performance enhancement: Clinical efficacy and side effects. *Evidence Report Technological Assessment*, (Summ.), 1 – 4.

Shekelle, P. G., Hardy, M. L., Morton, S. C., Maglione, M., Mojica, W. A., Suttorp, M. J. *et al.* (2003b). Efficacy and safety of ephedra and ephedrine for weight loss and athletic performance: A meta-analysis. *Journal of the American Medical Association*, *289*, 1537 – 1545.

Shirreffs, S. M., Sawka, M. N., & Stone, M. (2006). Water and electrolyte needs for soccer training and match-play. *Journal of Sports Sciences*, *24*, 699 – 707.

Steenge, G. R., Lambourne, J., Casey, A., Macdonald, I. A., & Greenhaff, P. L. (1998). Stimulatory effect of insulin on creatine accumulation in human skeletal muscle. *American Journal of Physiology: Endocrinology and Metabolism*, *275*, E974 – E979.

Steenge, G. R., Simpson, E. J., & Greenhaff, P. L. (2000). Protein- and carbohydrate-induced augmentation of whole body creatine retention in humans. *Journal of Applied Physiology*, *89*, 1165 – 1171.

Tarnopolsky, M. (1994). Caffeine and endurance performance. *Sports Medicine*, *18*, 109 – 125.

Terjung, R. L., Clarkson, P. M., Eichner, E. R., Greenhaff, P. L., Hespel, P., Israel, R. G. *et al.* (2000). The physiological and health effects of oral creatine supplementation. *Medicine and Science in Sports and Exercise*, *32*, 706 – 717.

Tipton, K. D., & Wolfe, R. R. (2004). Protein and amino acids for athletes. *Journal of Sports Sciences*, *22*, 65 – 79.

Tischler, M. E., Desautels, M., & Goldberg, A. L. (1982). Does leucine, leucyl-tRNA, or some metabolite of leucine regulate protein synthesis and degradation in skeletal and cardiac muscle? *Journal of Biological Chemistry*, *257*, 1613 – 1621.

Urso, M. L., & Clarkson, P. M. (2003). Oxidative stress, exercise, and antioxidant supplementation. *Toxicology*, *189*, 41 – 54.

Vandebuerie, F., Vanden Eynde, B., Vandenberghe, K., & Hespel, P. (1998). Effect of creatine loading on endurance capacity and sprint power in cyclists. *International Journal of Sports Medicine*, *83*, 2055 – 2063.

Vandenberghe, K., Gillis, N., Van Leemputte, M., Van Hecke, P., Vanstapel, F., & Hespel, P. (1996). Caffeine counteracts the ergogenic action of muscle creatine loading. *Journal of Applied Physiology*, *80*, 452 – 457.

Vandenberghe, K., Goris, M., Van Hecke, P., Van Leemputte, M., Vangerven, L., & Hespel, P. (1997). Long-term creatine intake is beneficial to muscle performance during resistance training. *Journal of Applied Physiology*, *83*, 2055 – 2063.

Van Leemputte, M., Vandenberghe, K., & Hespel, P. (1999). Shortening of muscle relaxation time after creatine loading. *Journal of Applied Physiology*, *86*, 840 – 844.

van Loon, L. J., Murphy, R., Oosterlaar, A. M., Cameron-Smith, D., Hargreaves, M., Wagenmakers, A. J. *et al.* (2004). Creatine supplementation increases glycogen storage but not GLUT-4 expression in human skeletal muscle. *Clinical Science (London)*, *106*, 99 – 106.

Van Soeren, M. H., & Graham, T. E. (1998). Effect of caffeine on metabolism, exercise endurance and catecholamine responses after withdrawal. *Journal of Applied Physiology*, *85*, 1493 – 1501.

Van Soeren, M. H., Sathasivam, P., Spriet, L. L., & Graham, T. E. (1993). Caffeine metabolism and epinephrine responses during exercise in users and nonusers. *Journal of Applied Physiology*, *75*, 805 – 812.

Van Thuyne, W., Van Eenoo, P., & Delbeke, F. T. (2003). Urinary concentrations of morphine after the administration of herbal teas containing *Papaveris fructus* in relation to doping analysis. *Journal of Chromatography B: Analytical Technologies in the Biomedical and Life Sciences*, *785*, 245 – 251.

Volek, J. S., Duncan, N. D., Mazzetti, S. A., Staron, R. S., Putukian, M., Gómez, A. L. *et al*. (1999). Performance and muscle fiber adaptations to creatine supplementation and heavy resistance training. *Medicine and Science in Sports and Exercise*, *31*, 1147 – 1156.

Walker, J. B. (1979). Creatine: biosynthesis, regulation, and function. *Advances in Enzymology*, *50*, 177 – 242.

Watt, K. K., Garnham, A. P., & Snow, R. J. (2004). Skeletal muscle total creatine content and creatine transporter gene expression in vegetarians prior to and following creatine supplementation. *International Journal of Sports Nutrition and Exercise Metabolism*, *14*, 517 – 531.

Williams, C., & Serratosa, L. (2006). Nutrition on match day. *Journal of Sports Sciences*, *24*, 687 – 697.

Wolfe, R. R. (2000). Protein supplements and exercise. *American Journal of Clinical Nutrition*, *72*, 551S – 557S.

Ziegenfuss, T. M., Lowery, L. M., & Lemon, P. W. R. (1998). Acute fluid volume changes in men during three days of creatine supplementation. *Journal of Exercise Physiology*, *1*, 1 – 9.