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From Plate to Performance: The Impact of Diet on Exercise Performance and Recovery

1. Mikołaj Pograniczny [MP]
Andrzej Frycz Modrzewski Kraków University : Cracow, Gustawa Herlinga-Grudzińskiego 1 Street 30-705 Kraków, Małopolska, Poland, PL
https://orcid.org/0009-0009-8407-3605
E-mail: m.pograniczny@gmail.com

2. Adrianna Mielżyńska [AM]
Andrzej Frycz Modrzewski Kraków University : Cracow, Gustawa Herlinga-Grudzińskiego 1 Street 30-705 Kraków, Małopolska, Poland, PL
https://orcid.org/0009-0006-7359-4796
E-mail: adrianna.mielzynska.03@gmail.com

3. Natalia Jańczyk [NJ]
Stefan Zeromski Specialised Hospital (SP ZOZ) in Cracow: Cracow, os.
Na Skarpie 66 Street 31-913 Kraków, Małopolska, Poland, PL
https://orcid.org/0009-0000-1862-9681
E-mail: nataliajanczyk34@gmail.com

4. Adrianna Pacołta [AP]
Andrzej Frycz Modrzewski Kraków University : Cracow, Gustawa Herlinga-Grudzińskiego 1 Street 30-705 Kraków, Małopolska, Poland, PL
https://orcid.org/0009-0009-9258-8609
E-mail: apacolta@gmail.com

5. Marcelina Nalepka [MN]
Andrzej Frycz Modrzewski Kraków University : Cracow, Gustawa Herlinga-Grudzińskiego 1 Street 30-705 Kraków, Małopolska, Poland, PL
https://orcid.org/0009-0004-2950-9158
E-mail: marcelinanalepka@icloud.com

6. Jakub Pochopień [JP]
Andrzej Frycz Modrzewski Kraków University : Cracow, Gustawa Herlinga-Grudzińskiego 1 Street 30-705 Kraków, Małopolska, Poland, PL
https://orcid.org/0009-0007-4484-7069
E-mail : pochopien.jakub@interia.pl

7. Dawid Walkowicz [DW]
Jagiellonian University in Cracow: Cracow, Gołębia 24 Street 31-007 Kraków, Małopolska, Poland, PL
https://orcid.org/0009-0002-6205-5624
E-mail : dawid.walkowicz.kontakt@gmail.com

8. Marlena Jankowska [MJ]
Stefan Zeromski Specialised Hospital (SP ZOZ) in Cracow: Cracow, os. Na Skarpie 66 Street 31-913 Kraków, Małopolska, Poland, PL
https://orcid.org/0009-0005-2240-8853
E-mail: marlena.rosol@wp.pl

9. Michał Presak [MP]
5 Military Clinical Hospital SPZOZ in Cracow
Wrocławska 1-3 Street, 30-901 Krakow; Cracow, Malopolska, Poland, PL
https://orcid.org/0009-0006-0335-5917
E-mail: michal.presak@gmail.com

10. Karolina Baran [KB]
Independent Public Health Care Facility of the Ministry of Internal Affairs and Administration in Cracow, Kronikarza Galla 25 Street 30-053 Kraków, Małopolska, Poland, PL
https://orcid.org/0009-0004-1627-5065
E-mail: 99barankarolina@gmail.com

Abstract

Diet is a key and indispensable element in sports, influencing both physical performance and recovery processes. This paper analyzes the relationship between diet composition and its impact on athletic performance. Particular attention is given to the role of macronutrients (proteins, fats, and carbohydrates) as well as micronutrients and vitamins in optimizing the body's performance. The influence of diet and physical activity on hormonal regulation in athletes is also discussed. In addition to natural food components, the paper examines the role of performance-enhancing supplements such as creatine, caffeine, and beetroot juice, as well as substances with potentially negative effects, such as alcohol. The article also includes a brief mention of supplementation in e-sports, highlighting the effects of caffeine, L-theanine, and polyphenols on focus and reaction time. Furthermore, special attention is devoted to vegan athletes, analyzing their specific nutritional needs and the crucial role of supplementation in preventing deficiencies and supporting performance. The importance of personalized diet and supplementation, tailored to individual body needs and the specifics of a given sport discipline, is emphasized.

Keywords: Performance, diet, macronutrients, micronutrients, supplementations, metabolism, exercise, hormones, protein intake, carbohydrate loading, vegans, recovery, vitamins in sports, minerals in sports, dietary strategies

Background

Modern sports require not only intense training but also a well-balanced diet, which plays a crucial role in achieving optimal performance and supporting recovery. Proper nutrition influences physical endurance, metabolic adaptation, muscle repair processes, and hormonal balance in athletes. Macronutrients such as proteins, fats, and carbohydrates serve distinct functions, ranging from energy provision to muscle tissue regeneration. Meanwhile, micronutrients, including vitamins and minerals, are essential for enzymatic and hormonal functions, and their deficiencies can lead to decreased performance and an increased risk of injury.

In recent years, growing attention has been given to supplementation as a means of enhancing both performance and recovery. Substances such as creatine, caffeine, and beetroot juice have gained popularity due to their potential ergogenic effects. On the other hand, certain substances, such as alcohol, may negatively impact athletic performance and delay recovery.

Furthermore, the rise of e-sports has brought diet and supplementation into focus not only for physical sports but also for disciplines requiring high concentration and reflexes. Caffeine, L-theanine, and polyphenols have gained interest for their potential to support cognitive functions, which may be crucial for e-sports athletes.

An additional area of focus is the growing number of vegan athletes, whose dietary restrictions require careful planning to meet nutritional needs. Vegan diets, while rich in plant-based nutrients, may lack certain essential components such as vitamin B12, iron, and omega-3 fatty acids, which are critical for athletic performance and recovery. Supplementation with nutrients like EPA and DHA derived from algae, as well as fortified foods, plays a vital role in preventing deficiencies and supporting the unique demands of vegan athletes.

The individualization of nutritional and supplementation strategies has become a key factor in sports, allowing athletes to maximize performance and optimize recovery. This dissertation aims to analyze the impact of diet on exercise performance and recovery, considering both natural dietary components and supplementation in the context of various sports disciplines.

Research questions

The main research question of this dissertation is how diet affects athletic performance. In addition to this primary focus, the study will also examine the effects of various dietary supplements on sports performance and recovery, as well as the impact of physical activity on hormonal changes in athletes. By addressing these aspects, this dissertation aims to provide a comprehensive understanding of the relationship between nutrition, supplementation, and physiological adaptations in sports performance.

Purpose and scope

The purpose of this dissertation is to consolidate knowledge on sports nutrition, not only focusing on diet but also considering factors such as sleep and supplementation. Medical insights into individual nutrients, combined with perspectives from physiology, sports science, and dietetics, provide a holistic understanding of how these elements influence athletic performance.

The scope of this research encompasses the broad impact of diet and supplements on sports performance, exploring their role in optimizing endurance, strength, recovery, and overall physical condition. By integrating multiple disciplines, this study aims to offer a comprehensive perspective on the various factors that contribute to athletic success.

Structure of the essay

Taking all the above aspects into account, this article will first analyze how diet affects athletic performance (Section 1). Next, we will explore the impact of supplements on enhancing sports performance (Section 2). In the following section, we will focus on the necessity of supplementation for vegan athletes (Section 3). Finally, we will summarize all the discussed aspects in the conclusion (Section 4).

The Biochemistry of Essential Nutrients and Their Metabolic Functions

Nutritional Basis: The Role of Proteins, Fats, Carbohydrates, Vitamins, and Minerals.

It is impossible to discuss the impact of diet on athletic performance without a fundamental understanding of the biochemical changes and effects of essential macronutrients on the body. In this section, we will analyze the functions and influence of individual macronutrients, such as fats, carbohydrates, and proteins. We will then examine the role and effects of micronutrients and vitamins. This analysis will not only focus on the impact of specific nutrients on performance but also their metabolic effects, starting with basic concepts and progressing to more detailed explanations.

Macronutrients

Macronutrients are essential nutrients required by the human body in large amounts to sustain life, support physiological functions, and provide energy. They include proteins, fats and carbohydrates each playing a important role in metabolism, growth, and overall health. Unlike micronutrients, which are needed in smaller quantities, macronutrients serve as the primary source of energy and structural components of cells. For athletes, macronutrient balance is a key factor in optimizing performance, recovery, and endurance.

Proteins are biopolymeric structures composed of amino acids, of which 20 are commonly found in biological chemistry.[1] They play multiple roles in the body, regulating other tissues as hormones, influencing reaction activity as enzymes, and, most importantly, serving as the fundamental building blocks of muscles in athletes.[2] Studies of the response to resistance training show upregulation of muscle protein synthesis (MPS) for at least 24 hours in response to a single session of exercise, with increased sensitivity to the intake of dietary protein over this period. This highlights their essential and undeniable role in both sports and everyday life.[2] Laboratory based studies show that MPS is optimized in response to exercise by the consumption of high biological value protein, providing ~10 g essential amino acids in the early recovery phase (0–2 h after exercise). This translates to a recommended protein intake of 0.25–0.3 g/kg body weight. Animal proteins (meat, fish, eggs, dairy) are complete, containing all essential amino acids with high bioavailability, they enhance muscle growth and recovery due to their high leucine content. Plant proteins (legumes, soy, nuts, seeds, grains) are often incomplete but can be combined for a complete amino acid profile. While plant proteins have lower digestibility, they provide fiber and antioxidants, benefiting endurance athletes and reducing inflammation. Animal proteins are more efficiently absorbed, while plant-based options require higher intake but are more sustainable despite this, the latest scientific studies have found that animal protein tends to have a more favorable effect on lean mass compared to plant protein, and the benefit appears more pronounced in younger adults.[3]

Fats are a diverse group of organic compounds characterized by their insolubility in water. In dietary science, they primarily refer to triglycerides, which consist of glycerol and fatty acids. They play a vital role in the body as sustained energy, hormone production, cell function, and reducing inflammation. It helps preserve glycogen stores, supports testosterone and estrogen synthesis, and contributes to muscle recovery. Fat, in the form of plasma free fatty acids, intramuscular triglycerides and adipose tissue provides a fuel substrate that is both relatively plentiful and increased in availability to the muscle as a result of endurance training.[4] It is the most calorie-dense macronutrient, providing 9 kcal per gram of fat. Athletes should derive 20–35% of their total daily energy intake from fats, with endurance athletes benefiting from a slightly higher intake (25–35%) to support prolonged energy availability, while strength athletes typically maintain a moderate intake (20–30%) to prioritize protein and carbohydrates for muscle recovery. Too little fat (<15%) can lead to hormonal imbalances, reduced endurance, and impaired recovery, while excessive intake (>40%) may displace carbohydrates, reducing glycogen stores and high-intensity performance. Maintaining an optimal fat intake (20–35%) ensures balanced energy, proper recovery, and peak athletic performance. Although lipids are the least studied macronutrient in terms of their impact on athletic performance, increased consumption of polyunsaturated fatty acids (PUFAs) has been shown to promote muscle hypertrophy. The effect of a healthy diet rich in PUFA-n3s (>500 g/week of fish and seafood and a n-6:n-3 ratio of <2 for 24 weeks) in combination with resistance training was compared with the effect of resistance training alone.[5] The authors reported a significant increase in the hypertrophy of fast type IIA skeletal muscle fibres (+23%), an upregulation of mTOR in skeletal muscle and a downregulation of IL-1b, in comparison with the control group.[6] Further research is needed for a deeper analysis of the biochemical effects of lipids on athletic performance.

Carbohydrates are the primary energy source for the human body. They are composed of carbon, hydrogen, and oxygen and can be classified into three main types: sugars, starches, and fibers. In sports and physical activity, carbohydrates play a crucial role in fueling muscles, maintaining endurance, and supporting recovery. They are stored as glycogen in muscles and the liver, providing readily available energy during exercise. Sugars are simple carbohydrates, such as glucose, fructose, and sucrose, that provide a quick and immediate energy source, especially beneficial before and during exercise as they rapidly replenish blood glucose levels and help delay fatigue. Sports drinks and energy gels are commonly used by athletes to sustain high-intensity performance. Starches are complex carbohydrates found in foods like whole grains, rice, pasta, and potatoes, providing a slow and sustained release of energy as they take longer to digest and gradually increase blood glucose levels. Consuming starches before exercise helps maintain endurance and prolonged performance, while post-exercise intake aids in glycogen replenishment and recovery. Fibers, although not a direct energy source, support digestive health and blood sugar regulation. Athletes should consume fiber in moderate amounts, especially before competition, to prevent gastrointestinal discomfort. Even when working at the highest intensities that can be supported by oxidative phosphorylation, carbohydrate offers advantages over fat as a substrate since it provides a greater yield of adenosine triphosphate per volume of oxygen that can be delivered to the mitochondria, thus improving gross exercise efficiency.[7] Figure 1 indicates that daily carbohydrate needs range from 3–5 g/kg/day for low-intensity activity to 8–12 g/kg/day for extreme endurance training. Higher carbohydrate availability enhances performance, endurance, and recovery, while low-carb strategies may support metabolic adaptation. **Figure 1** indicates that daily carbohydrate needs range from 3–5 g/kg/day for low-intensity activity to 8–12 g/kg/day for extreme endurance training. Higher carbohydrate availability

Figure 1. Summary of guidelines for carbohydrate intake by athletes - Thomas DT, Erdman KA, Burke LM. American College of Sports Medicine Joint Position Statement. Nutrition and Athletic Performance. Med Sci Sports Exerc. 2016 Mar;48(3):543-68. doi: 10.1249/MSS.0000000000000852. Erratum in: Med Sci Sports Exerc. 2017 Jan;49(1):222. doi: 10.1249/MSS.0000000000001162. PMID: 26891166, p 550.

	Situation	Carbohydrate Targets	Comments on Type and Timing of Carbohydrate Intake
DAILY NEEDS FOR FUEL AND RECOVERY			
1. The following targets are intended to provide high carbohydrate availability (ie, to meet the carbohydrate needs of the muscle and central nervous system) for different exercise loads for scenarios where it is important to exercise with high quality and/or at high intensity. These general recommendations should be fine-tuned with individual consideration of total energy needs, specific training needs and feedback from training performance.			
2. On other occasions, when exercise quality or intensity is less important, it may be less important to achieve these carbohydrate targets or to arrange carbohydrate intake over the day to optimise availability for specific sessions. In these cases, carbohydrate intake may be chosen to suit energy goals, food preferences, or food availability.			
3. In some scenarios, when the focus is on enhancing the training stimulus or adaptive response, low carbohydrate availability may be deliberately achieved by reducing total carbohydrate intake, or by manipulating carbohydrate intake related to training sessions (eg, training in a fasted state, undertaking a second session of exercise without adequate opportunity for refuelling after the first session).			
Light	• Low intensity or skill-based activities	3–5 g/kg of athlete's body weight/d	• Timing of intake of carbohydrate over the day may be manipulated to promote high carbohydrate availability for a specific session by consuming carbohydrate before or during the session, or in recovery from a previous session.
Moderate	• Moderate exercise program (eg, ~1 h per day)	5–7 g/kg/d	
High	• Endurance program (eg, 1–3 h/d mod-high-intensity exercise)	6–10 g/kg/d	• Otherwise, as long as total fuel needs are provided, the pattern of intake may simply be guided by convenience and individual choice.
Very High	• Extreme commitment (eg, >4–5 h/d mod-high intensity exercise	8–12 g/kg/d	• Athletes should choose nutrient-rich carbohydrate sources to allow overall nutrient needs to be met.
ACUTE FUELLING STRATEGIES – these guidelines promote high carbohydrate availability to promote optimal performance in competition or key training sessions			
General fuelling up	• Preparation for events < 90 min exercise	7–12 g/kg per 24 h as for daily fuel needs	• Athletes may choose carbohydrate-rich sources that are low in fiber/residue and easily consumed to ensure that fuel targets are met, and to meet goals for gut comfort or lighter 'racing weight'.
Carbohydrate loading	• Preparation for events > 90 min of sustained/intermittent exercise	36–48 h of 10–12 g/kg body weight per 24 h	
Speedy refuelling	• <8 h recovery between 2 fuel demanding sessions	1–1.2 g/kg/h for first 4 h then resume daily fuel needs	• There may be benefits in consuming small regular snacks • Carbohydrate rich foods and drink may help to ensure that fuel targets are met.
Pre-event fuelling	• Before exercise > 60 min	1–4 g/kg consumed 1–4 h before exercise	• Timing, amount and type of carbohydrate foods and drinks should be chosen to suit the practical needs of the event and individual preferences/experiences. • Choices high in fat/protein/fiber may need to be avoided to reduce risk of gastrointestinal issues during the event. • Low glycemic index choices may provide a more sustained source of fuel for situations where carbohydrate cannot be consumed during exercise.
During brief exercise	• <45 min	Not needed	
During sustained high intensity exercise	• 45–75 min	Small amounts including mouth rinse	• A range of drinks and sports products can provide easily consumed carbohydrate. • The frequent contact of carbohydrate with the mouth and oral cavity can stimulate parts of the brain and central nervous system to enhance perceptions of well-being and increase self-chosen work outputs.
During endurance exercise including 'stop and start' sports	• 1–2.5 h	30–60 g/h	• Carbohydrate intake provides a source of fuel for the muscle to supplement endogenous stores. • Opportunities to consume foods and drinks vary according to the rules and nature of each sport. • A range of everyday dietary choices and specialised sports products ranging in form from liquid to solid may be useful • The athlete should practice to find a refuelling plan that suits their individual goals including hydration needs and gut comfort.
During ultra-endurance exercise	• >2.5–3 h	Up to 90 g/h	• As above. • Higher intakes of carbohydrate are associated with better performance. • Products providing multiple transportable carbohydrates (Glucose:fructose mixtures) achieve high rates of oxidation of carbohydrate consumed during exercise.

For acute fueling, athletes should consume 7–12 g/kg/day before events <90 min and 10–12 g/kg/day for >90 min events (carbohydrate loading). Post-exercise refueling requires 1–1.2 g/kg/h for the first 4 hours, while pre-event meals (1–4 h before competition) should provide 1–4 g/kg.

During exercise, carbohydrate intake depends on duration: brief efforts (<45 min) require none, high-intensity sessions (45–75 min) benefit from small amounts or a mouth rinse, endurance events (1–2.5 h) require 30–60 g/h, and ultra-endurance (>2.5–3 h) may require up to 90 g/h using multiple transportable carbohydrates. Maintaining proper carbohydrate intake sustains energy levels, delays fatigue, and optimizes performance.

Micronutreints

Micronutrients are essential vitamins and minerals required in small amounts to support physiological functions. Unlike macronutrients, they do not provide energy but play a key role in metabolism, immune function, muscle contraction, bone health, and oxygen transport. They are classified into vitamins, which regulate metabolism and support health (water-soluble: vitamin C, fat-soluble: vitamins A, D, E, K), and minerals, which are essential for cellular function (major minerals: calcium, magnesium, potassium; trace elements: iron, zinc,)

Iron is an essential mineral which is vital for DNA synthesis, electron transport within the cell, and oxygen transportation to tissues via hemoglobin, as roughly 70% of the body's iron is bound to hemoglobin in red blood cells.[8] Female are the most at risk for iron deficiency, primarily due to iron loss through menstrual bleeding, which, when combined with losses from physical exertion, can lead to significant deficiencies. Iron requirements for all female athletes may be increased by up to 70% of the estimated average requirement.[9] Athletes following diets low in iron, such as vegetarians or regular blood donors, are at higher risk of deficiency. In such cases, regular monitoring of blood iron levels is crucial to prevent anemia. When discussing iron, it is essential to address ferritin and hepcidin. Ferritin is the primary iron-storage protein in the body, and its blood levels serve as an indicator of iron reserves. Low ferritin levels (<30 ng/mL in women, <40 ng/mL in men) may indicate iron deficiency, leading to reduced performance and impaired oxygen transport, while excessively high ferritin may signal inflammation or excessive iron storage, which can be harmful. Hepcidin is a hormone that regulates iron absorption and distribution, its elevated levels inhibit iron uptake from the intestines and release from ferritin stores, potentially causing deficiencies even with adequate dietary intake. The intake of iron supplements in the period immediately after strenuous exercise is contra-indicated since there is the potential for elevated hepcidin levels to interfere with iron absorption.[10] Although there is some evidence that iron supplements can achieve performance improvements in athletes with iron depletion who are not anemic, athletes should be educated that routine, unmonitored supplementation is not recommended, not considered ergogenic without clinical evidence of iron depletion, and may cause unwanted gastrointestinal distress.[9]

Zinc supplementation plays a crucial role in enhancing athletic performance, as demonstrated in the study "Effects of a Novel Zinc-Magnesium Formulation on Hormones and Strength" by L.R. Brilla and Victor Conte (2000), conducted on American football players.[11] Over an eight-week period, the athletes were given ZMA, a supplement containing 30 mg of zinc monomethionine aspartate, 450 mg of magnesium aspartate, and 10.5 mg of vitamin B6. The study showed that zinc levels significantly increased in the supplemented group (from 0.80 to 1.04 µg/ml), whereas they slightly declined in the placebo group (from 0.84 to 0.80 µg/ml).[12] A similar pattern was observed for magnesium, where concentrations rose among ZMA users while decreasing in the control group. These findings indicate that supplementation effectively counteracts the depletion of these minerals, which may occur due to intense physical training. One of the key effects of supplementation was an improvement in anabolic hormone levels.[13] Free testosterone increased in the ZMA group (132.1 to 176.3 pg/mL), whereas in the placebo group, it showed a slight decline. Additionally, insulin-like growth factor-1 (IGF-1), which plays a crucial role in muscle growth, increased among athletes using ZMA, while it decreased in those receiving a placebo. Since both testosterone and IGF-1 are linked to muscle adaptation and recovery, these results suggest that zinc supplementation may support hormonal balance during periods of intense exercise. The impact of ZMA was also evident in muscle performance. Strength assessments using the Biodex dynamometer showed notable gains among supplemented athletes, with torque at 180°/s increasing from 189.9 Nm to 211 Nm.[14] In contrast, the placebo group exhibited only minimal changes. Furthermore, the power output of ZMA users improved more significantly than that of the control group, suggesting that proper mineral intake may contribute to enhanced muscle function and overall physical performance. There is substantial evidence that zinc influences IGF-1 production, which is vital for muscle hypertrophy and recovery. Studies have indicated that a deficiency of this mineral can impair strength, endurance, and overall exercise adaptation. Research on animals has shown that zinc deprivation can reduce IGF-1 levels by nearly 69%, whereas supplementation can increase them by 194%.[15] This highlights the potential consequences of inadequate zinc intake among athletes and underscores the importance of ensuring sufficient dietary levels. In summary, ensuring sufficient zinc intake, especially in combination with magnesium and vitamin B6, may help regulate hormone levels, supporting testosterone and IGF-1 production. This can contribute to muscle growth, increased strength, and faster recovery. Athletes engaged in high-intensity training should prioritize proper zinc intake to enhance performance and prevent potential deficiencies.

Calcium is especially important for growth, maintenance, and repair of bone tissue; regulation of muscle contraction; nerve conduction; and normal blood clotting.[16] Its role in regulating muscle contractions, nerve conduction, and maintaining bone health makes it an essential component of an athlete's diet. Adequate calcium intake can support physical performance, enhance muscle strength, and improve recovery after intense training. The recommended daily calcium intake for adults is around 1000-1300 mg, but athletes may have increased requirements due to greater calcium loss through sweat and the intense strain placed on the musculoskeletal system. In cases of insufficient calcium intake from the diet, supplementation should be considered. However, athletes should not take supplements on their own, instead, they should consult a nutritionist or doctor to avoid excessive intake, which can lead to calcium-phosphorus imbalance and kidney problems.

Magnesium, an essential mineral, plays a profound role in over 300 enzymatic processes, energy production, and muscle contraction, making it critical for athletic performance. It is involved in pathways generating adenosine triphosphate (ATP), the primary energy currency of the cell, and ensures proper muscle and nerve function. Magnesium's impact on performance, recovery, and overall health has been the subject of various studies, particularly in the context of intense physical activity. Magnesium is involved in the pathways generating adenosine triphosphate (ATP) and energy in mitochondria.[17] Its role in the electron transport chain and transmembrane transport processes has direct implications for muscle function and endurance. During physical exertion, stress increases magnesium demands due to substantial losses through sweat and urine. The mineral's importance spans muscle contraction, growth, and athletic performance. Observational studies highlight magnesium's ability to reduce fatigue and improve recovery metrics. Magnesium administration elicited the reductions in heart rate, ventilation, oxygen uptake, and carbon dioxide production during submaximal work.[18] These outcomes were complemented by improved endurance and peak oxygen uptake in supplementation trials. For instance, 25 days of magnesium administration, at 390 mg daily, increased peak oxygen uptake and total work output during work capacity tests.[18] These findings point to magnesium's efficacy in supporting endurance activities and mitigating exertion-related fatigue. Athletes are at a greater risk of magnesium depletion due to rigorous training and increased losses through perspiration. Magnesium deficiency is associated with symptoms like muscle spasms, reduced endurance, and impaired recovery. It is worth noting that dietary magnesium deprivation is associated with increased oxygen requirements to complete submaximal exercise and reduced endurance performance.[18] Given these risks, maintaining adequate magnesium intake is essential for peak performance. The recommended dietary allowance for magnesium is approximately 420 mg/day for men and 320 mg/day for women. However, athletes may require higher levels due to increased physical demands and sweat losses. Magnesium-rich sources include green leafy vegetables, nuts, seeds, and whole grains. Supplementation may be advised for individuals with measurable deficiencies or those undergoing intensive training regimens. Emerging research links magnesium to anabolic hormonal balance, particularly testosterone, which plays a pivotal role in muscle growth and repair. Regular testing for magnesium status, particularly serum and intracellular levels, can help identify deficiencies that might impair performance. Targeted dietary interventions or supplementation strategies should be personalized based on the individual's needs, rigorousness of training, and specific activity demands. In conclusion, magnesium's vital functions in energy production, muscle function, and recovery position it as an indispensable nutrient for athletes. Employing a tailored approach to nutrition that incorporates adequate magnesium intake, along with monitoring and supplementation when necessary, can significantly enhance athletic performance and reduce recovery times.

Potassium is essential for the proper functioning of skeletal muscles, particularly during intense exercise, as it plays a key role in muscle contraction and fatigue development. When muscles undergo repeated contractions, potassium ions exit the muscle cells, leading to a disturbed balance of potassium across the cell membrane. This imbalance causes depolarization of the membrane, reduced action potential strength, and diminished release of calcium ions from the sarcoplasmic reticulum, ultimately decreasing the force of muscle contractions. Cairns and Lindinger observed that a diminished transsarcolemmal K(+) gradient per se can reduce maximal force in non-fatigued muscle, suggesting that K(+) causes fatigue.[19]

Moderate increases in extracellular potassium levels (7–10 mM) during light to moderate activity can paradoxically enhance muscle efficiency by improving calcium release, promoting blood circulation, and facilitating neuromuscular signaling. However, during prolonged or high-intensity efforts, potassium levels may become dangerously imbalanced due to an energy deficit that hinders the work of the sodium-potassium pump. This deficit not only worsens membrane depolarization but also disrupts the muscle's ability to sustain electrical activity over time. The gold standard for fatigue is the intact perfused muscle under central control.[20] To counteract these imbalances, mechanisms such as the activation of sodium-potassium pumps and adjustments in chloride channel activity come into play. However, these safeguards can be overwhelmed during extreme physical stress, leading to a combination of ionic disturbances and energy depletion. This dual effect underscores potassium's significant but complex role in supporting muscle performance during moderate exercise while contributing to fatigue under heavier workloads.

Vitamin D3 (cholecalciferol) plays a crucial role in athletic performance and recovery due to its involvement in skeletal muscle function, immune system modulation, and injury prevention. Vitamin D3 is synthesized in the skin upon exposure to ultraviolet B (UVB) light and is also available through dietary sources such as fatty fish, eggs, and fortified products. During biochemical processes, vitamin D is converted into 25-hydroxyvitamin D

(25(OH)D) in the liver and then to 1,25-dihydroxyvitamin D (1,25(OH)2D) in the kidneys.[21] The pleiotropic effect of vitamin D is related to the fact that vitamin D receptors (VDRs) have been found in almost all human cells, including those in bones and muscles.[22] Despite the recognition of its significance, a large percentage of athletes suffer from deficiency, which can hinder performance and delay recovery from injuries. Vitamin D acts through two pathways: the genetic pathway, in which it influences muscle growth and differentiation by activating the expression of genes, particularly in fast-twitch fibers (type II), and the non-transcriptional signaling pathway associated with the membrane (rapid, non-genomic or membrane), where the receptor for 1.25-OHVITD is located.[23,24,25] This mechanism has been shown to enhance the interaction between myosin and actin in the sarcomere, increasing the strength of muscle contraction. A study on ballet dancers by Wyon et al. from 2014 revealed that vitamin D supplementation improved vertical jump height by 7.1% and isometric strength by 18.7%, emphasizing its role in neuromuscular performance. Also vitamin D appears to improve aerobic capacity by influencing oxygen transport mechanisms. The study by Brzeziański et al. (2022) demonstrated a significant improvement in VO2max in young soccer players who received 20,000 IU of vitamin D twice weekly. The improvement in VO2max was attributed to vitamin D's role in boosting mitochondrial efficiency and optimizing oxygen usage, especially by influencing hemoglobin synthesis. While supplementation benefits those with deficiencies, further research is needed to standardize dosing guidelines and understand the long-term implications of supplementation. Addressing vitamin D deficiency should be prioritized, particularly through tailored nutrition plans and monitored supplementation regimens during seasons of limited sun exposure. This proactive approach could optimize performance and reduce injury risks among athletes worldwide.

Vitamin C is a water-soluble antioxidant, has shown potential in reducing markers of muscle damage when combined with other antioxidants like vitamin E or quercetin. However, high doses often provide no benefits and, in some cases, may hinder performance metrics, impair muscle strength and hypertrophy gains, and disrupt mitochondrial biogenesis. Based on a lack of consistent data and potential for blunted physiologic adaptations to training, long-term high-dosage supplementation with vitamin C is not recommended.[26,27] Athletes should obtain antioxidants through a nutrient-rich diet instead of through supplement use.

The Role of Supplements in Sports Training

Performance-enhancing supplements

Performance-enhancing supplements such as caffeine, beetroot juice, and creatine have gained immense popularity among athletes striving to push their limits. These supplements, backed by solid scientific research, offer targeted benefits. In this section, we will focus not only on supplements with positive effects but also on those with negative impacts. Nowadays, more and more people, not just professional athletes, are turning to stimulants, so I will aim to present all aspects and consequences of their use.

Caffeine is the most common stimulant, not only among athletes but also among regular individuals who do not engage in sports. It is found in many products, although it is most commonly associated with coffee. However, it can also be present in tea, cocoa, guarana, and increasingly popular energy drinks. Caffeine has global effects on the central nervous system (CNS) and on hormonal, metabolic, muscular, cardiovascular, pulmonary, and renal functions during rest and exercise.[28] It affects the body through multiple pathways, including acting as an adenosine receptor antagonist, and its analgesic effects on CNS, which contributes to increased alertness and reduced fatigue during exercise. Caffeine also stimulates bronchodilation of alveoli, vasodilation of blood vessels, neural activation of muscle contraction, blood filtration in the kidneys, catecholamine secretion, and lypolysis.[28] Caffeine supplementation in doses between 3 and 6 mg/kg of body mass may improve jump height and sprint ability, particularly in female players, but individual response to caffeine must be considered.[29] Also this stimulant can increase the total running distance, and the distance covered at high intensity and sprint velocity during a simulated match.[29] This indicates that caffeine can be a useful tool for athletes in both endurance and high-intensity intermittent efforts when used responsibly. However, the dosage should be individually adjusted, as it may vary depending on age, lifestyle, and genetic factors. Despite many benefits, it's important to consume it in moderation. Overconsumption can result in adverse effects like dizziness, headaches, restlessness, anxiety, trouble sleeping, and stomach discomfort, particularly when intake surpasses 9 mg/kg of body weight.

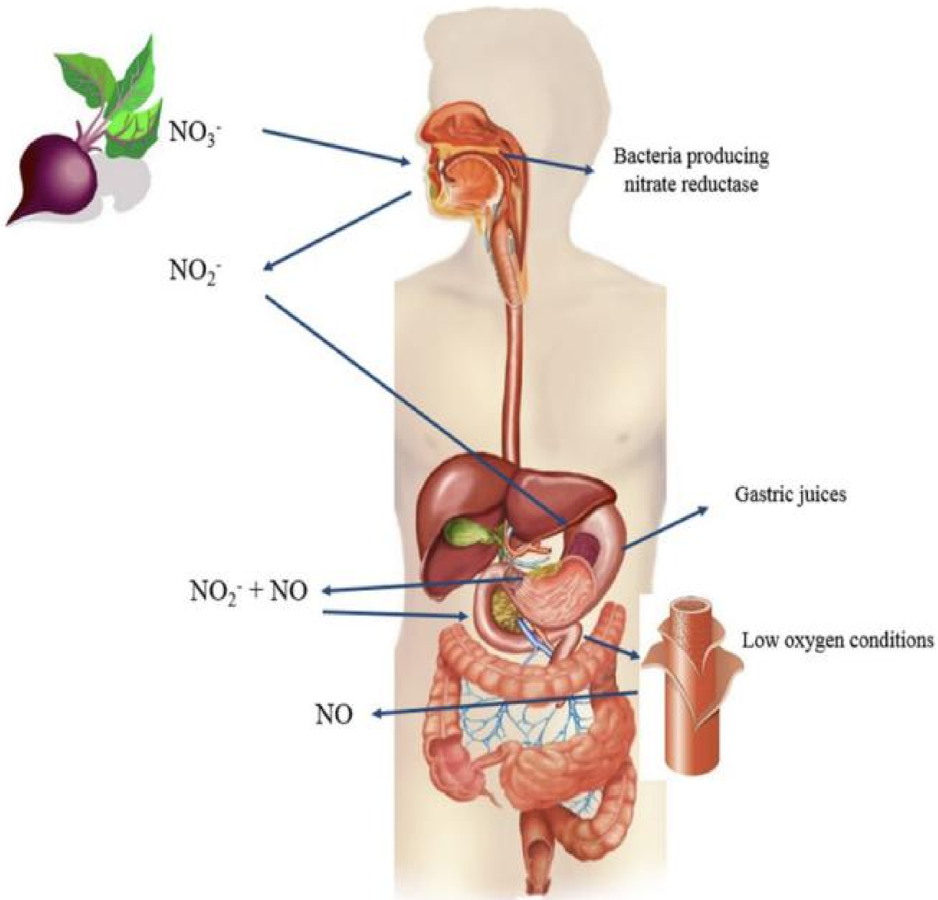
Beetroot supplementation has gained significant attention in sports nutrition due to its high nitrate (NO_3^-) content, which serves as a precursor for nitric oxide (NO) production in the body. As shown in Figure 2 The process begins with dietary intake of nitrate-rich foods, such as beetroot juice. In the mouth, specific bacteria on the tongue reduce nitrate (NO_3^-) to nitrite (NO_2^-) through enzymatic activity. This nitrite is subsequently swallowed and absorbed in the stomach and intestines. Under low oxygen conditions, nitrite is further reduced to nitric oxide (NO) in the bloodstream and tissues. Beetroot juice supplementation can improve performance in intermittent high-intensity efforts. For example, it has been observed to enhance phosphocreatine resynthesis, which delays its depletion during repetitive exercise bouts.

Additionally, beetroot juice improves cardiorespiratory endurance in athletes, with benefits such as reduced O_2 cost during exercise.[30] Moreover, beetroot's effects extend to metabolic and neuroendocrine mechanisms. It has been noted that nitrate-rich beetroot supplementation can improve mitochondrial efficiency,[31] which is particularly beneficial for endurance athletes. The antioxidant properties of beetroot, attributed to its betalains and polyphenols, also contribute to reducing oxidative stress and inflammation, further supporting recovery and performance. In conclusion, beetroot supplementation offers a multifaceted approach to enhancing athletic performance, combining physiological, metabolic, and antioxidant benefits.

Creatine is one of the most widely used dietary supplements in sports, and its popularity stems from numerous ergogenic benefits. Its primary mechanism of action involves increasing phosphocreatine levels in muscles, which enhances the rapid resynthesis of ATP—the fundamental energy source for working muscles. Supplementation increases lean body mass as well as strength, power, and efficacy in short-duration, high-intensity exercises.[32] Creatine supplementation allows for an increase in phosphocreatine stores in muscles, delaying fatigue and improving performance in short, intense efforts. In the study "The Use of Varying Creatine Regimens on Sprint Cycling," it was demonstrated that creatine supplementation produced an average improvement of 0.7%, 11.8% and 11.1% for the 40g, 100g and 135g ACRL respectively.[33] These results indicate that an appropriate creatine dosage can significantly enhance performance in repeated cycling sprints. ACRL stands for Acute Creatine Loading Regimen. It refers to a specific protocol for creatine supplementation, typically involving high doses of creatine over a short period (e.g., 4–7 days) to rapidly saturate muscle creatine stores. It is important to note that creatine does not appear to have significant side effects with short-term use, though the long-term effects of supplementation require further research. There is still limited evidence on how creatine supplementation translates into real-world competitive performance. Nevertheless, creatine remains one of the most well-researched and effective supplements for enhancing high-intensity exercise capacity.

As shown in **Figure 2** The process begins with dietary intake of nitrate-rich foods, such as beetroot juice. In the mouth, specific bacteria on the tongue reduce nitrate (NO3-) to nitrite (NO2-) through enzymatic activity. This nitrite is subsequently swallowed and absorbed in the stomach and intestines. Under low oxygen conditions, nitrite is further reduced to nitric oxide (NO) in the bloodstream and tissues. Beetroot juice supplementation can improve performance in intermittent high-intensity efforts. For example, it has been observed to enhance phosphocreatine resynthesis, which delays its depletion during repetitive exercise bouts.

Figure 2. Conversion of NO3− in beetroot juice to NO - Domínguez R, Maté-Muñoz JL, Cuenca E, García-Fernández P, Mata-Ordoñez F, Lozano-Estevan MC, Veiga-Herreros P, da Silva SF, Garnacho-Castaño MV. Effects of beetroot juice supplementation on intermittent high-intensity exercise efforts. J Int Soc Sports Nutr. 2018 Jan 5;15:2. doi: 10.1186/s12970-017-0204-9. PMID: 29311764; PMCID: PMC5756374, p 2.



Alcohol consumption is common in many societies and often intertwined with social and cultural practices. Athletes, like the general population, are not exempt from its use. However, the unique demands placed on athletes bodies make the effects of alcohol particularly consequential for their performance and recovery. Alcohol adversely affects several physiological systems critical to athletic performance. It impairs metabolism, neural function, cardiovascular physiology, and thermoregulation. Alcohol inhibits Ca2+ transients into the myocyte by inhibiting sarcolemmal Ca2+ channel actions.[34] It leads to a reduction in muscle strength by disrupting excitation-contraction coupling, which could greatly affect sports that demand high muscular power and coordination. Furthermore, alcohol acts as a diuretic, exacerbating dehydration by reducing the release of anti-diuretic hormone (ADH) and increasing fluid loss. Beyond its harmful impact on muscles, alcohol also affects the central nervous system by lowering brain activity and disrupting balance, reaction time, and coordination. These impairments can linger for hours after drinking, making it harder for athletes to perform precise and complex movements. The post-exercise period is critical for recovery and adaptation. Alcohol consumption during this phase can interfere with several recovery mechanisms. Acute alcohol consumption, at the levels often consumed by athletes, may negatively alter normal immunoendocrine function, blood flow, and protein synthesis so that recovery from skeletal muscle injury may be impaired.[35] This is particularly problematic in team sports, where alcohol is often part of post-game celebrations. One well-documented effect is alcohol's impact on muscle protein synthesis (MPS), a key process in muscle repair and adaptation. Research shows that alcohol suppresses the activation of pathways vital for MPS, such as mTOR, while simultaneously increasing muscle-specific ligases associated with atrophy. This dual effect hinders recovery by reducing the rate at which muscles repair and rebuild after exercise. A study comparing binge drinking patterns among college students revealed that athletes are more likely to report binge drinking than are students who are not involved in athletics.[36] This highlights the normalization of alcohol consumption in team environments, where it is sometimes used for bonding or stress relief, despite its potential to undermine athletic goals. The detrimental effects of alcohol on athletic performance and recovery are well-supported by scientific evidence. From metabolic disruptions and impaired recovery processes to its prevalence among athletes, the habit of drinking alcohol poses challenges to achieving peak performance. By understanding these impacts, athletes can make informed choices that prioritize their health and success in sports.

The Role of Supplementation in Enhancing Psychophysical Performance in Esports Athletes

Esports has seen a meteoric rise in popularity over recent years, transforming from casual gaming into a global phenomenon. What was once considered a niche hobby is now recognized as a legitimate sport, with professional tournaments, dedicated athletes, and millions of fans watching worldwide. This shift highlights the unique demands of esports athletes, who rely on sharp mental and physical performance to excel. That's why in my article, I've included a brief discussion about the role of supplementation and its potential to optimize cognitive abilities. Stimulants like caffeine, L-theanine, and polyphenols are particularly relevant, offering promising ways to enhance focus, reaction times, and overall mental resilience for players competing at the highest level.

Caffeine, a widely used stimulant in the gaming world, doses of 1–4 mg/kg body weight improve alertness, concentration, and reaction time alertness, reaction speed, and energy levels.[37] Low to moderate doses, typically 3–6 mg per kilogram of body weight, have positive effects without harmful side effects. This makes it an ideal supplement for esports players in competitions that demand high levels of focus.

L-theanine, an amino acid found naturally in tea, is notable for its ability to promote relaxation while simultaneously enhancing focus and cognitive flexibility. When combined with caffeine, L-theanine can improve reaction time, working memory, and the accuracy of task verification.[38]

Polyphenols, present in foods like cocoa and berries, offer antioxidant benefits that protect brain cells and support cognitive health. They have been shown to improve speed in rapid visual information processing task, a higher order task with elements of vigilance, working memory, and executive function, in young participants.[39]

Incorporating these bioactive compounds into their diet can provide esports players with sustained mental sharpness and resilience. These three components form a potent trio for upgrading cognitive function, essential in high-pressure gaming scenarios.Incorporating these bioactive compounds into their diet can provide esports players with sustained mental sharpness and resilience. These three components form a potent trio for upgrading cognitive function, essential in high-pressure gaming scenarios.

Nutrition and Supplementation for Vegan Athletes

Adopting a vegan diet has grown increasingly popular among athletes in recent years. Ethical considerations, environmental concerns, and perceived health benefits have driven individuals to eliminate all animal-derived products from their diets. While this dietary shift can support a healthy lifestyle, it also presents unique nutritional challenges for athletes who have higher energy and nutrient demands. Addressing these challenges requires careful diet planning and, in most cases, strategic supplementation to meet performance goals. A vegan diet, by nature, excludes many nutrient-dense foods traditionally consumed by athletes, such as meat, dairy, and eggs. Vegans are exposed to many deficiencies. This includes the sufficiency of energy and protein; the adequacy of vitamin B12, iron, zinc, calcium, iodine and vitamin D; and the lack of the long-chain n-3 fatty acids EPA and DHA in most plant-based sources.[40] One of the most significant concerns is protein intake. While many plant-based sources, such as legumes, nuts, and tofu, provide protein, they are often lower in essential amino acids required for muscle repair and growth. Furthermore, vegan athletes are at risk of deficiencies in critical micronutrients, including vitamin B12, calcium, iodine, and zinc. Energy intake can also pose challenges. Vegan diets are typically high in fiber, which can create a feeling of fullness and reduce overall calorie consumption.

Specific supplementation recommendations for vegan athletes include:

• Vitamin B12 - this vitamin is absent from plant-based foods. Deficiency can lead to neurological and hematological impairments if not addressed.

• Vitamin D3 - for vegans, the need for vitamin D is even greater due to the elimination of animal-based foods that naturally contain it. Additionally, vegan athletes who train indoors with limited exposure to sunlight should monitor their vitamin D levels more frequently to prevent deficiencies.

• Omega-3 Fatty Acids (EPA and DHA) - plant-based sources like flaxseed and walnuts provide alpha-linolenic acid (ALA), a precursor to EPA and DHA, but the conversion rate is low. When it comes to taking vegan supplements, the most effective options are EPA and DHA derived from algae.
• Iron - while plant-based diets often contain adequate iron, its non-heme form has lower bioavailability. Combining iron-rich foods with vitamin C can enhance absorption, but supplementation may be needed for individuals with increased iron demands, such as endurance athletes.
• Calcium and Zinc - deficiencies in calcium and zinc are common due to the exclusion of dairy and potential bioavailability issues with plant-based sources. Fortified plant milks and calcium supplements are often recommended.

A vegan diet offers numerous health benefits, including a high intake of antioxidants and dietary fiber, but it requires careful planning to meet the nutritional demands of athletic performance. Supplementation with key nutrients like vitamin B12, iron, and omega-3s is vital to avoid deficiencies and optimize physical performance. By incorporating fortified foods, strategically managing their diet, and seeking professional nutritional guidance, vegan athletes can thrive in their respective sports. With veganism continuing to rise in popularity, further research is crucial to ensure evidence-based recommendations that promote both health and athletic excellence.

Summary

This paper highlights the critical role of diet and supplementation in optimizing athletic performance and supporting recovery. The analysis underscores the importance of macronutrients (proteins, fats, and carbohydrates) in providing energy, facilitating metabolic adaptation, and promoting muscle repair. Micronutrients and vitamins, crucial for enzymatic and hormonal functions, are shown to play an equally vital role, with their deficiencies posing significant risks to performance and recovery. The impact of diet on hormonal balance further emphasizes its complexity and individualized nature. Supplementation emerges as a valuable tool for enhancing athletic performance, with ergogenic substances like creatine, caffeine, and beetroot juice offering tangible benefits. However, the adverse effects of substances such as alcohol highlight the need for informed consumption choices by athletes. The paper also recognizes the unique challenges faced by vegan athletes in meeting their nutritional needs, emphasizing the necessity of targeted supplementation—such as vitamin B12, iron, and omega-3 fatty acids—to avoid deficiencies and maintain performance levels.

Conclusion

A key conclusion of this work is the importance of individualized nutritional and supplementation strategies. Athletes dietary plans should be personalized, taking into account their individual physiological needs, sport-specific demands, and lifestyle choices, such as veganism. This tailored approach allows for the optimization of performance, recovery, and overall health. Future research should aim to explore the long-term effects of personalized diets and supplementation strategies, especially among diverse athletic populations. There is also a growing need to investigate the dietary requirements for emerging fields such as e-sports, where cognitive demands are paramount. By continuing to refine our understanding of these interactions, sports science can provide increasingly effective tools to help athletes achieve their full potential.

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Authors' Contributions Statement:
Conceptualization: [MP] [AM] [NJ] [AP] [MN] [JP] [DW] [MJ] [MP] [KB]
Formal Analysis: [MP] [AM] [NJ] [AP] [MN] [JP] [DW] [MJ] [MP] [KB]
Investigation: [MP] [AM] [NJ] [AP] [MN] [JP] [DW] [MJ] [MP] [KB]
Methodology: [MP] [AM] [NJ] [AP] [MN] [JP] [DW] [MJ] [MP] [KB]
Project Administration: [MP] [AM] [NJ] [AP] [MN] [JP] [DW] [MJ] [MP] [KB]
Resources: [MP] [AM] [NJ] [AP] [MN] [JP] [DW] [MJ] [MP] [KB]
Software: [MP] [AM] [NJ] [AP] [MN] [JP] [DW] [MJ] [MP] [KB]
Supervision: [MP] [AM] [NJ] [AP] [MN] [JP] [DW] [MJ] [MP] [KB]
Validation: [MP] [AM] [NJ] [AP] [MN] [JP] [DW] [MJ] [MP] [KB]
Visualization: [MP] [AM] [NJ] [AP] [MN] [JP] [DW] [MJ] [MP] [KB]
Writing original Draft: [MP] [AM] [NJ] [AP] [MN] [JP] [DW] [MJ] [MP] [KB]
Writing - Review and Editing: [MP] [AM] [NJ] [AP] [MN] [JP] [DW] [MJ] [MP] [KB]

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