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Macronutrients and Ergogenic Aids in Adolescent Endurance and Recovery

Xiaoyu Huang

Kent School, Kent, USA
huangx27@kent-school.edu

Abstract. This paper investigates the functional importance of constant nutrients in the human body system and their promoting effect on exercise. Through different hypothetical real-life scenarios, the comprehensive contribution of dietary supplements in improving endurance exercise performance and promoting recovery is analyzed. The research results indicate that carbohydrates, as the main fuel for long-term high-intensity exercise, can maintain glycogen storage and delay fatigue through strategic and fixed intake after exercise. Protein can support muscle repair and adaptation by promoting protein synthesis to aid muscle growth. A standard recommendation suggests a daily consumption of 1.4-2.0 g/kg, which can be taken in a dispersed manner. Fat is a primary source for storing long-term energy and has dense and persistent characteristics, particularly associated with low-intensity endurance activities, playing a critical role in sustained endurance performance, but its function is often misunderstood. In addition to macronutrients, the study also explored the promoting effects of dietary supplements such as β - alanine and creatine on exercise performance. β-alanine can buffer muscle acidity, minimize fatigue, and creatine can store water in muscles, improving overall athletic performance. This paper integrates biochemical and performance-based findings through the exploration of each subsection of macronutrients by evaluating the mechanisms and practical implications of nutrition strategies in endurance sports.

Keywords: Endurance performance, macronutrients, dietary supplements, muscle recovery, sports nutrition

1. Introduction

When it comes to sports, most people think of the athlete in motion, the actions, and the power that are derived from watching television, games, or training. However, this perception, while compelling, is superficial and incomplete. What most people ignore is the fact that athletic performance is not solely a product of physical training or raw talent. Instead, it is a beautiful interplay between exercise, recovery, strength training, and most crucially, nutrition. The importance of proper nutrition, particularly the balance of macronutrients, lies in the groundwork for peak athletic performance and determines the locomotion for strength building, recovery enhancement, and body improvement.

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Macronutrients are essential nutrients that the human body needs in large quantities to provide energy, including carbohydrates, proteins, and fats. Each encompasses a specific role to fulfill, especially in the context of athletic performance. Under endurance activities, carbohydrates are the body's main fuel source and are composed of carbon, hydrogen, and oxygen. Glucose, a common monosaccharide, is not only ubiquitous in food sources but also vital for maintaining cellular function. It fuels key systems such as the brain, blood cells, and kidney medulla [1]. Fats, or lipids, share a similar elemental composition but contain proportionally less oxygen, and their hydrophobic structure is essential for energy storage and cell membrane integrity. Proteins, made of amino acids, support muscle repair, hormone production, and waste regulation [1]. Based on these definitions, it should be emphasized that for adolescent athletes whose bodies are still growing, proper macronutrient balance is crucial for their development. The needs and experiences of adolescence make nutrition planning not only important but also a necessary condition for maintaining physical performance and health.

During adolescence, both the body's fat-free mass (FFM) and fat mass (FM) undergo rapid changes, influenced by gender and obesity, which significantly alter metabolic demands [2]. A 1997 study on resting metabolic rate (RMR) in 371 adolescents found that lean body weight was the main determinant of RMR, accounting for 79.8% of its variation [2]. Even after controlling for body size and fat maintenance, males had higher RMRs than females, likely due to hormonal and muscular differences associated with puberty. Furthermore, the study also revealed a decrease in RMR between the ages of 10 and 16 ($P < 0.01$), indicating a marginally significant downward trend in metabolic rate as adolescents age. Consequently, despite overall growth, it underlines the vulnerability of adolescence and the nutritional needs that must not only support training but also accommodate their other factors of evolving metabolic changes.

Decades of sports nutrition research have consistently highlighted the importance of macronutrient intake for optimizing endurance and recovery in youth athletes. Surveys across multiple countries, apart from the United States, such as Switzerland and Australia, show that supplement use among adolescent athletes is widespread. In Switzerland, 84% of the 430 athletes consumed supplements weekly and 97% did so in the span of four weeks. Similarly, a pilot study in Australia showed that 60% of adolescent athletes reported using protein supplements in their diet, but had limited awareness of appropriate doses or potential risks, with highly significant results ($P<0.05\%$) [3]. The latest review and consensus report highlights a major research gap: most of the research evidence on the efficacy and safety of supplements comes from the adult population. Nowadays, research should focus on the norms of supplement use for adolescent athletes and improve related awareness. Despite global research indicating the value of macro nutrient strategies for exercise performance and recovery, specific data and knowledge for adolescents are still relatively scarce.

Understanding how macronutrients affect endurance and adolescent athletes' long-term health and athletic success depend both on their ability to recuperate. This article explores how macro nutrient intake affects the endurance and recovery of adolescent athletes, analyzes the physiological functions of each nutrient, the role of supplements, and the potential risks that may arise from imbalanced nutrient intake during this critical growth stage. This article aims to fill the gap in research on the physiological needs of adolescent athletes by analyzing the unique roles of each macronutrient in athletic performance.

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2. In-depth rationale

2.1. Carbohydrates and endurance performance in adolescents

A 15-year-old cross-country runner deliberately avoids carbohydrates to maintain his figure, which are the most vital energy component for endurance sports. Insufficient carbohydrate intake during prolonged physical activity can result in glycogen depletion, causing extreme deprivation of energy and hindering recovery [4]. This is esbpecially prevalent among adolescent athletes, and research by the ISSN has shown that glycogen synthesis is slower during this stage, making carbohydrates more critical.

Glycogen, essentially a polysaccharide composed of excess glucose, is a major obstacle for athletes as its main function is to store glucose in muscles and the liver to ensure athletic performance. Several people know that glucose provides energy for the body - it is broken down by the oxygen produced by respiration and enters the cellular respiratory cycle. Yet, without carbohydrates, it is insufficient to replenish the glycogen needed for our body, as the intake and timing of carbs can influence the rate of glycogen storage after exercising [4]. For instance, during resistance training, a leg extension exercise with the intensity of six sets and at a rep of 12 can significantly reduce glycogen stores by almost 40% [4]. This intensity, nevertheless, is incomparable with endurance sports that require long periods of aerobic movement. Research shows that the recommended daily infusion to maximize optimal glycogen storage is reported to be 5-12g/kg a day, and for high-intensity training such as endurance sports, it can range up to 8-10g/kg/day. With this notion in mind, adolescent athletes should prioritize carbohydrate intake and erase their false insight into the function of this essential macronutrient based on training load. A wide variety of foods, both natural and commercial, can serve as viable carbohydrate sources for athletes across different training phases (See Table 1).

Table 1. CHO-Rich food sources [5]

CHO Source	Food Type	CHO/100 g	Athletic Benefit/Notes
Oats	Grain	~68g	Slow-digesting; sustained energy for long workouts
Wheat	Grain	~54g	Good complex carb; often found in breads and pastas
Corn cereal	Grain	~55g	Often fortified; quick energy pre-workout
Banana	Fruit	~54g	High in glucose + potassium; ideal pre-run snack
Raisins	Fruit	~65g	Fast-digesting sugars; good intra-workout fuel
Potato	Vegetable	~20g	Easily digested; can replenish glycogen quickly
White rice	Grain	~28g	Fast absorption; good post-workout recovery carb
Brown rice	Grain	~26g	High fiber; slower energy release
Spaghetti	Grain	~26g	Versatile carb for carb-loading before events
Honey	Natural sweetener	~80-85g	High-CHO natural food; made of fructose and glucose → supports higher CHO absorption

2.2. Protein intake for recovery and growth

Protein supports muscle repair and synthesis - during movements that require a lot of muscle strength, muscle tissue can produce tiny tears. A meta-analysis conducted by Cermak and colleagues

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in 2012 reviewed 22 randomized controlled trials (involving 680 participants) and found that supplementing protein during long-term resistance training significantly increased muscle mass and strength in various body components [6,7]. Nonetheless, the quality, timing, and dosage of protein consumption are equally important as the quantity. As stated by the International Society of Sports Nutrition (ISSN), recommendations for the optimal amount of consumption for athletes suggest a portion of 0.25 g/kg of body weight, translating to a simple ingestion range of 20-40g, ideally taken over separate intervals throughout the day [6]. Consuming excessive amounts all at once, such as in two large protein shakes back to back, may not be efficiently utilized by the body in building muscle and can lead to gastrointestinal discomfort, such as bloating.

Additionally, real-world research supports the idea that simply consuming commercial protein beverages does not guarantee improved athletic performance or recovery. In a field-based study of 103 high school athletes undergoing a 5-week strength training program, researchers compared the effects of chocolate milk (CM, a protein-rich beverage) versus a carbohydrate-only drink on recovery and performance. The CM group showed a 12.3% improvement in composite strength scores (bench press + squat), while the CHO group only saw a 2.7% increase [8]. These findings indicate that protein may aid in strength enhancement, but context, timing, and consistent training are key. The people under this experimental study had their workouts carefully planned, with a strictly fixed structure of strength and conditioning for 4 days a week of pre- and post-testing [8,9]. Simply adding protein shakes without aligning intake to the body's needs won't yield the desired performance results and may even hinder recovery.

2.3. Fat and long-term storage of energy

There is a common misconception about one of the core macronutrients - fat (i.e. lipids), and many people are misled by its name. There are various types of lipids, among which triglycerides (neutral fats) are fatty acids attached to glycerol, storing energy for higher animals; Phospholipids are another type of lipid in animal and plant nerve tissues, which secrete glycerol and phosphate when broken down; Sphingomyelin is composed of fatty acids, phosphate, choline, and a nitrogen-containing base called sphingosine [10]. Based on this, the diet of athletes is crucial for maintaining the duration of energy reserves. The previous text has elaborated on the importance of carbohydrates and their ability to provide short-term energy. Research has shown that if carbohydrate intake is insufficient, glycogen levels in muscles will significantly decrease, leading to fatigue. Athletes under intensive endurance training typically have higher far oxidative capacity level, meaning that they have the ability to spare more glycogen during the endurance sport [10]. Data shows that these athletes who are fed iso-caloric high-fats in their nutritional diet displayed an increase in endurance in both genders than those who took a low-fat diet [10]. Suggestions for a proper, basic, and healthy diet that boosts glycogen performance in long endurance exercises can include all three of the macronutrients: CHO, protein, and fat, comprised of 30%, 20% and 30%, while the remainder of percentages are strategically allocated between carbohydrate and fat domains, depending on the sport's extent of rigor and focus, aiming to determine the optimal energy-storage method for our body [10].

2.4. The benefits and risks of supplements

Supplements are additional supplements to the daily diet, many of which are already present in the human body and in daily food. Their main purpose is to optimize specific physiological processes during high-intensity training. Therefore, it cannot be generalized that certain dietary supplements

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are harmful to the body; the key lies in daily intake. For example, beta-alanine is an amino acid that is non-essential and boosts carnosine levels in muscle tissues by buffering acid build-up in order to delay fatigue in endurance sports (from a stunning 30% to 65%) [11]. It is also reported to bring beneficial effects such as protein protection against glycation, antioxidant activity, and anti-aging activity [11]. However, its impact on aerobic capacity appears to be limited. Some studies have shown no significant improvement in VO2peak after beta-alanine supplementation during graded exercise tests [11]. Notwithstanding, other findings suggest it can raise the anaerobic threshold, allowing athletes to sustain higher workloads before the onset of fatigue. For example, Zoeller et al. reported an increase in power output "at the lactate threshold after 28 days of beta-alanine supplementation," while Stout et al. found a 13% increase in ventilatory threshold in female athletes. These improvements are attributed to enhanced intracellular buffering capacity, which helps delay lactic acid accumulation and improve short bursts of high-intensity performance. Nonetheless, this does not guarantee or determine that beta-analine supplementation is by all means effective in raising the anaerobic threshold for less lactic acid buildup.

Similarly, another common dietary supplement is creatine. Creatine is among the most well-researched nutritional supplements for athletes, with its uses ranging from dietary to even therapeutic [12]. Short-term supplementation—usually around 20g daily for 5-7 days—has been demonstrated to raise muscle creatine and phosphocreatine levels by 10-40%, resulting in improvements in strength and muscle endurance [12]. There are no reported health risks that creatine itself brings, yet it is recommended that for a safe and well-structured diet of an athlete, a balanced diet of food should be eaten, including a limitation for supplement intake between 1.2g and 1.7g/kg body mass [13]. While these supplements can enhance performance or aid recovery, they should be used with caution and only to complement a well-rounded diet instead of replacing it. Not all supplements are appropriate for adolescent athletes, and risks may be posed if taken inappropriately. Understanding the benefits, purpose, and what the appendage does for the body is crucial before incorporating it into a training routine.

3. Conclusion

Macronutrients play essential and distinct roles in supporting energy production, muscle adaptation and growth, and overall performance in endurance sports. While general awareness of these nutrients is important, a deeper understanding of their specific functions makes it just as crucial. It is one thing to acquire exposure and another to achieve the ability to balance them with nuanced perception, evading common misconceptions and making strategic inferences. From maintaining glycogen storage and delaying fatigue, synthesizing adequate protein for the muscles to grow and repair, providing sustained energy as a source of long-term storage, and by intaking ergogenic and dietary supplements for further enhancements of body coordination, macronutrient balance operates altogether as one whole picture, providing all means of benefits for the body to function at its most optimal level. Together, evidence-based nutrition strategies and research of targeted supplementation form an integrated approach to maximizing athletic performance and recovery in endurance contexts while ruling out plausible pitfalls that could undermine the body's capacity to perform at its peak.

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