International Journal of Nutrology
(Official Journal of the ABRAN - Brazilian Association of Nutrology)

REVIEW ARTICLE

DOI: 10.54448/ijn23226

Major nutrological approaches to macronutrients in the performance and body composition of highly trained athletes: a systematic review

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E-mail: rosangelapvhmed@gmail.com
DOI: https://doi.org/10.54448/ijn23226
Received: 02-24-2023; Revised: 06-13-2023; Accepted: 06-17-2023; Published: 06-19-2023; IJN-id: e23226

Abstract

Introduction: Findings around nutrient timing require appropriate context because factors such as age, gender, fitness level, previous fueling status, diet status, training volume, training intensity, program design, and time before upcoming training or competition can influence the extent to which timing can play a role in the adaptive response to exercise. Thus, nutrient timing is a feeding strategy that in almost all situations can be useful for promoting recovery and training adaptations. **Objective:** A systematic review was carried out to elucidate the importance of macronutrient consumption by highly trained athletes on performance and body composition. **Methods:** The present study followed a systematic review model (PRISMA). The search strategy was carried out in PubMed, Cochrane Library, Web of Science, Scopus, and Google Scholar databases, using scientific articles from 2009 to 2021. The low quality of evidence was attributed to case reports, editorials, and brief communications, according to the GRADE instrument. The risk of bias was analyzed according to the Cochrane instrument. **Results and Conclusion:** After the study eligibility process, a total of 42 scientifically favorable articles were found to compose the systematic review. Biases did not compromise the scientific basis of the studies. The amount depends on the mode and intensity of exercise, the quality of protein ingested, and the individual's energy and carbohydrate status. However, it should be noted that there is preliminary evidence that consuming much higher amounts of protein (>3 g/kg/d) may confer a benefit concerning body composition. Concerns that protein intake within this range is unhealthy are unfounded in healthy, exercising individuals. One should try to consume whole foods that contain high-quality protein sources. Timing of protein intake in the period spanning the exercise session can provide several benefits, including improved recovery and greater gains in lean body mass. Essential amino acids and leucine supplements are beneficial for the exercising individual by increasing muscle protein synthesis rates, decreasing muscle protein breakdown, and possibly aiding exercise recovery.

Keywords: Athletes. Nutrition. Macronutrients. Performance. Body composition.

Introduction

The International Society of Sports Nutrition (ISSN) reports objectively and critically on the importance of macronutrient consumption by healthy and exercising adults and, in particular, highly trained individuals in performance and body composition **[1,2]**. In this context, an acute stimulus to exercise, particularly resistance exercise and protein ingestion, stimulates muscle protein synthesis (MPS) and is synergistic when protein consumption occurs before or after resistance exercise. To maintain muscle mass through a positive muscle protein balance, a total daily protein intake in the range of 1.4-2.0 g protein/kg body weight/day (g/kg/d) is sufficient for most exercising individuals **[1]**.

Furthermore, all findings around nutrient timing require appropriate context because factors such as age, gender, fitness level, previous fueling status, diet status, training volume, training intensity, program design, and timing before the next training or competition can influence the extent to which timing can play a role in the adaptive response to exercise **[2]**. Nutrient timing is a feeding strategy that in almost any situation can be useful for promoting recovery and training adaptations.

ABRAN International Journal of Nutrology (Official Journal of the ABRAN - Brazilian Association of Nutrition)

It must be remembered that the general objective of any nutritional strategy is to improve the adaptive response to acute situations and/or chronic exercise. In almost all of these situations, this approach results in an athlete receiving a combination of nutrients at specific times that can be helpful rather than harmful **[2]**.

In this context, research studies typically employ a small number of study participants. In addition, in most cases, the studies primarily evaluated men. However, women oxidize more fat compared to men, and they also seem to utilize endogenous sources of fuel to different degrees **[3-5]**.

Therefore, the present study aimed to carry out a systematic review to elucidate the importance of macronutrient consumption by highly trained athletes on performance and body composition.

Methods

Study Design

The present study followed a concise systematic review model, following the rules of systematic review - PRISMA (Transparent reporting of systematic review and meta-analysis-HTTP://www.prisma-statement.org/).

Search Strategy and Search Sources

The search strategy was carried out in PubMed, Cochrane Library, Web of Science and Scopus, and Google Scholar databases using scientific articles from 2009 to 2021, using the descriptors (MeSH Terms): *Athletes; Nutrition; Macronutrients; Performance; Body composition*, and using the Booleans "and" between the MeSH terms and "or" between the historical findings.

Study Quality and Risk of Bias

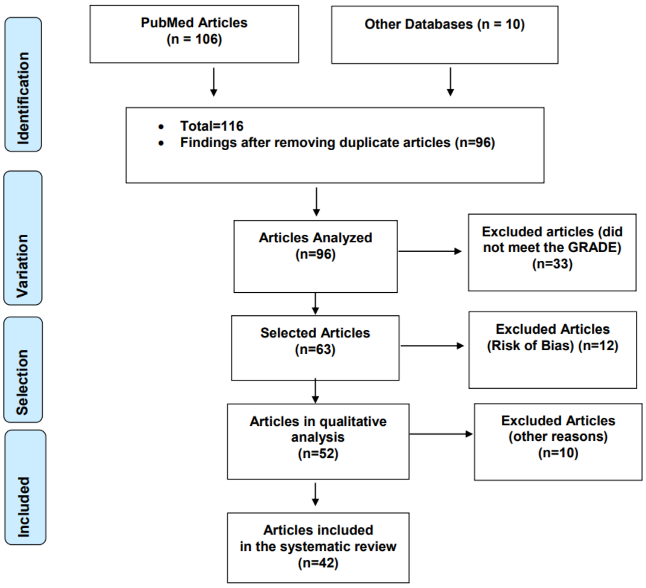
Quality was rated as high, moderate, low, or very low for risk of bias, clarity of comparisons, precision, and consistency of analyses. The most evident highlight was for systematic review articles or meta-analysis of randomized clinical trials, followed by randomized clinical trials. The low quality of evidence was attributed to case reports, editorials, and brief communications, according to the GRADE instrument. The risk of bias was analyzed according to the Cochrane instrument.

Results

Summary of Findings

As a corollary of the literary search system, 116 studies were analyzed that were submitted to eligibility analysis, and, then, 42 studies of high to medium quality were selected (Figure 1), considering in the first instance the level of scientific evidence of studies in study type such as metaanalysis, consensus, randomized clinical trial, prospective and observational. The biases did not compromise the scientific basis of the studies.

Figure 1. Flowchart showing the article selection process.



Body Composition and Sports Performance

The International Society of Sports Nutrition (ISSN) has determined the importance of macronutrient consumption by healthy, exercising adults. Table 1 below summarizes the ISSN position **[1,2]**.

Table 1. Summary of the ISSN positioning of macronutrient consumption by athletes.

✓ The timing of energy intake and the proportion of certain macronutrients ingested can improve tissue recovery and repair, increase muscle protein synthesis, and improve mood states after intense or high-volume exercise.
✓ Endogenous glycogen stores are maximized by following a high carbohydrate diet (8 to 12 g carbohydrate/kg/day [g/kg/day]); in addition, these stores are mostly sold out by high-volume workouts.
✓ If rapid glycogen replacement (<4 h recovery time) is required, strategies should be followed: carbohydrate refeeding (1.2 g/kg/h), with a preference for carbohydrate sources with a high glycemic index (> 70); the addition of caffeine ✓ (3-8 mg/kg).
✓ Combination of carbohydrates (0.8 g/kg/h) with protein (0.2-0.4 g/kg/h)
✓ Prolonged (>60 min) bouts of high intensity (>70% VO_2 max) challenge fuel supply and fluid regulation, therefore carbohydrates should be consumed at a rate of ~30 to 60 g carb/h (carbohydrate 6 to 8%), electrolyte solution (6 to 12 fluid ounces) every 10 to 15 minutes throughout an exercise session lasting more than 70 minutes.

✓ When carbohydrate delivery is inadequate, the addition of protein can help increase performance, improve muscle damage, promote euglycemia, and facilitate glycogen resynthesis.
✓ Carbohydrate intake during resistance exercise (eg, 3-6 sets of 8-12 repetitions max using various exercises has been shown to promote euglycemia and higher glycogen stores.
✓ Consumption of carbohydrates alone or in combination with protein during resistance exercise increases muscle glycogen stores, improves muscle damage, and facilitates acute and chronic adaptations to training.
✓ Meeting total daily protein intake, preferably with evenly spaced protein meals (approximately every 3 hours during the day), should be seen as a primary area of emphasis for individuals to exercise.
✓ Ingestion of essential amino acids (EAA; approximately 10 g), either in free form or as part of a protein bolus of approximately 20 to 40 g, has been shown to maximally stimulate muscle protein synthesis (MPS).
✓ Pre- and/or post-exercise nutritional interventions (carbohydrate + protein or protein alone) can work as an effective strategy to support strength increases and improvements in body composition. However, the size and timing of a pre-exercise meal can affect the degree to which post-exercise protein feeding is needed.
✓ Post-exercise intake (immediately after 2 h) of high-quality protein sources stimulates robust increases in MPS.

Various body attributes (body size, shape, and composition) are considered to contribute to success in various sports. Of these, body mass and body composition are often focal points for athletes because they are more capable of being manipulated. While it is clear that assessing and manipulating body composition can aid in the progression of an athletic career, athletes, coaches, and coaches should be reminded that athletic performance cannot be accurately predicted based on BW and composition alone. A single, rigid ideal body composition should not be recommended for any event or group of athletes **[6]**. However, there are relationships between body composition and sports performance that are important to consider when preparing an athlete **[6]**.

In sports that involve strength, athletes strive to gain muscle mass through a muscle hypertrophy program at specific times in the annual macrocycle. While some athletes aim to gain absolute size and strength per se, in other sports where the athlete must move their body mass or compete in weight divisions, it is important to optimize the power/weight ratio rather than absolute power **[7]**.

Thus, some strength athletes also want to achieve low levels of body fat. In sports that involve weight divisions (e.g. combat sports, light rowing, and weightlifting), competitors generally target the lowest possible bodyweight category while maximizing their lean mass within that goal.

Other athletes strive to maintain a low body mass and/or body fat level for distinct advantages **[8]**. Distance runners and cyclists benefit from a low energy cost of movement and a favorable weightto-surface area ratio for heat dissipation. Team athletes can increase their speed and agility by being lean, while athletes in acrobatic sports (eg, diving, gymnastics, and dance) gain biomechanical advantages from being able to move their bodies in a smaller space. In some of these sports and others (eg, bodybuilding), there is an aesthetic element in determining performance outcomes **[8]**.

While there are demonstrated advantages in achieving a certain body composition, athletes may feel pressure to strive to achieve derisively low weight/body fat goals or to achieve them in an unrealistic time frame **[6]**. These athletes may be susceptible to practicing extreme weight management behaviors or continuous dieting with low levels of nutrients to repeat previous success with a lower weight or leaner body composition **[6,9]**. Extreme methods of weight control can be harmful to health. Disordered performance and eating patterns have also been observed in these sports settings **[6,9]**.

However, there are scenarios where an athlete improves their health and performance by reducing body weight or body fat as part of a periodized strategy. Ideally, this occurs within a program that gradually achieves an individualized ideal body composition over the athlete's athletic career and allows weight and body fat to be tracked within an adequate range within the annual training cycle **[9]**.

The program should also include avoiding situations where athletes inadvertently gain excessive amounts of body fat as a result of a sudden lack of energy when energy expenditure is abruptly reduced (eg, off-season or injury). Additionally, athletes are cautioned against sudden or excessive body fat gain which is part of the culture of some sports where a high body mass is considered helpful for performance. Although body mass index is not appropriate as a substitute for body composition in athletes, a chronic interest in weight gain can put some athletes at risk for an obese body mass index, which can increase their risk of meeting the criteria for obesity metabolic syndrome **[10]**. Sports dietitians should be aware of sports that promote achieving a large body mass and screen for metabolic risk factors **[10]**.

Functional Nutrition

Higher protein intake (2.3-3.1 g/kg/d) is sometimes required to maximize the retention of lean body mass in resistance-trained individuals during exercise. There is new evidence to suggest that higher protein intake (>3.0 g/kg/d) may have positive effects on body composition in resistancetrained individuals. General recommendations are 0.25 g of a high-quality protein per kg of body weight, or an absolute dose of 20-40 g **[1]** (Table 2).

Table 2. Main effects of protein consumption **[28]**.

✓ Protein supplementation can promote increases in skeletal muscle crosssectional area and lean body mass, along with a hyper-energetic diet and a heavy resistance training program.
✓ When combined with a resistance training program and a hypo energetic diet, a high daily protein intake (2 - 3 × the RDI) can promote greater fat mass losses and greater overall improvements in body composition.
✓ Several protein sources are available, with their advantages and disadvantages.
✓ Protein sources are evaluated based on amino acid content, particularly EAAs.
✓ The content of fat, calories, and micronutrients and the presence of various bioactive peptides contribute to the quality of a protein.
✓ Leucine content and digestion rate have also been shown in several scientific studies to play an important role in an athlete's ability to train, compete and recover.
✓ Blends of protein sources can provide a favorable combination of key nutrients such as leucine, EAAs, bioactive peptides, and antioxidants.

Protein servings should contain 700-3000 mg of leucine and/or a higher relative leucine content, plus a balanced dose of EAAs. These protein doses should be evenly distributed every 3-4 hours throughout the day. The optimal period for protein intake is likely a matter of individual tolerance, as benefits are derived from pre- or post-workout intake. However, the anabolic effect of exercise is long-lasting (at least 24 hours) but likely decreases with increasing post-exercise time **[1]**.

While physically active individuals can obtain their daily protein requirements through the consumption of whole foods, supplementation is a practical way to ensure adequate quality and quantity of protein intake while minimizing caloric intake, particularly for athletes who normally perform high training volumes **[11]**. Rapidly digested proteins that contain high proportions of EAAs and leucine are most effective in stimulating MPS. Endurance athletes should focus on getting adequate carbohydrate intake to promote optimal performance. Adding protein can help offset muscle damage and promote recovery. Furthermore, ingestion of casein proteins before sleep (30-40 g) provides increases in overnight MPS and metabolic rate without influencing lipolysis **[12]**.

In this context, several studies report that protein supplementation results in significant improvements in lean body weight in cross-sectional areas compared to placebo treatments **[13-23]**. Andersen et al. **[13]** examined 22 healthy men who completed a 14-week resistance training program (3 days/week, consisting of 3 to 4 sets of lower body exercises) while supplementing 25 g of a highquality protein blend or 25 g of carbohydrates. When the milk protein blend was fed, significantly greater increases in fat-free mass occurred in muscle cross-sectional areas in Type I and Type II muscle fibers when compared to the changes seen in carbohydrate consumption.

Besides, a meta-analysis by Cermak and colleagues **[21]** reported a mean increase in fat-free mass of 0.69 kg (95% confidence interval: 0.47-0.91 kg) when supplementing with protein was provided versus placebo during a resistance training program. Other analyzes by Tipton, Phillips, and Pasiakos **[22,24,25]**, respectively, provide further support that protein supplementation (15–25 g for 4 to 14 weeks) increases lean mass gain when combined with the conclusion of a resistance training program.

In addition to fat-free mass accumulation, increasing daily protein intake through a combination of foods and supplementation to levels above the recommended daily intake (RDI) (0.8 g/kg/day, increasing to 1.2– 2.4 g/kg/day for endurance and strength athletes), by restricting energy intake (30 to 40% reduction in energy intake), has been shown to maximize adipose tissue loss and promote the maintenance of free mass of fat **[26-31]**. Most of this work was done with overweight and obese individuals who were given an energy-restricted diet that provided a higher ratio of protein to carbohydrate.

As a classic example, Layman and investigators **[26]** randomized obese women to consume one of two energy-restricted diets (1600–1700 kcal/day) that were higher in carbohydrate (> 3.5: carbohydrate/protein ratio) or protein (<1.5: ratio of carbohydrates to proteins). The groups were divided into groups that followed a five-day-a-week exercise program (walking +

resistance training, 20–50 min/workout) and a control group that performed light walking for less than 100 min a week. Still, greater amounts of fat were lost when greater amounts of protein were ingested, but even greater amounts of fat loss occurred when the exercise program was added to the high-protein diet group, resulting in significant reductions in body fat.

Using an active population ranging from normal weight to overweight (BMI: 22-29 kg/m2), Pasiakos and colleagues **[28]** examined the impact of progressively increasing dietary protein over a 21-day study period. A more intense model of energy reduction was employed, resulting in each participant reducing their caloric intake by 30% and increasing their energy expenditure by 10%. Each person was randomly assigned to consume a diet that contained 1 × (0.8 g/kg), 2 × (1.6 g/kg), or 3 × (2.4 g/kg) of the RDI for protein. Participants were measured for changes in body weight and body composition. While the greatest body weight loss occurred in the 1×RDI group, this group also lost the highest percentage of fat-free mass and the lowest percentage of fat mass. The 2× and 3× RDI groups lost significant amounts of body weight that consisted of 70% and 64% fat mass, respectively.

These results indicate that increasing dietary protein can promote favorable adaptations in body composition by promoting the accumulation of fat-free mass when combined with a hyperenergetic diet and a heavy resistance training program and can also promote mass loss. fat when higher daily protein intakes (2-3 × RDI) are combined with an exercise program and a low-energy diet **[28]**.

Protein Intake And Meal Timing

Table 3 below presents the main relationships between protein intake and meal times.

Table 3. Key considerations for protein intake and timing of meals **[1]**.

✓ In the absence of food and response to resistance exercise, muscle protein balance remains negative.
✓ Skeletal muscle is sensitized to the effects of proteins and amino acids for up to 24 hours after the completion of an endurance exercise.
✓ A protein dose of 20 to 40 g of protein (10 to 12 g of EAAs, 1 to 3 g of leucine) stimulates MPS, which can help promote a positive nitrogen balance.
✓ EAAs are critically needed to achieve maximum MPS rates, making high-quality protein sources rich in EAAs and leucine the preferred protein sources.
✓ Studies have suggested that pre-exercise feeding of amino acids in combination with carbohydrates can achieve maximal MPS rates, but the feeding of protein and amino acids during this period is not documented to increase exercise performance.
✓ Ingestion of carbohydrates + proteins or EAAs during endurance and endurance exercise can help maintain a favorable anabolic hormone profile, minimize increases in muscle damage, promote increases in muscle cross-sectional area, and increase time to exhaustion during running and cycling prolonged.
✓ The administration of protein after exercise, when combined with a suboptimal intake of carbohydrates (<1.2 g/kg/day), may enhance muscle glycogen recovery and help mitigate changes in markers of muscle damage.
✓ Total protein and calorie intake appear to be the most important consideration when it comes to promoting positive adaptations to resistance training, and the impact of timing strategies (immediately before or immediately after) to increase these adaptations in non-athletic populations appears to be Minimum.

Regarding the recommended intake, the current RDI for protein is 0.8 g/kg/day with several lines of evidence indicating that this value is not an appropriate amount for an athlete in training to meet their daily needs. While previous recommendations have suggested that a daily intake of 1.21.3 g/kg/day is an adequate amount, most of this work has been completed using the nitrogen balance technique, which is known to systematically underestimate the protein requirements **[1]**.

Daily and per-dose requirements are combinations of several factors, including exercise volume, age, body composition, total energy intake, and the athlete's training status. A daily intake of 1.4 to 2.0 g/kg/day operates as a minimum recommended amount, while larger amounts may be necessary for people trying to restrict energy intake while maintaining fat-free mass.

Recommendations on optimal protein intake per serving for athletes to maximize MPS are varied and depend on age and recent resistance exercise stimuli. General recommendations are 0.25 g of a high-quality protein per kg of body weight, or an absolute dose of 20-40 g. Higher doses (~40g) are likely needed to maximize MPS responses in elderly subjects. Even larger amounts (~70g) appear to be necessary to promote attenuation of muscle protein breakdown **[1]**.

The stimulation or spread of these feeding episodes approximately three hours apart has been consistently reported to promote sustained and increased levels of

MPS and performance benefits. Protein sources containing higher levels of EAAs are considered higher quality protein sources. The body uses 20 amino acids to produce proteins, seven of which are essential (nine conditionally), requiring their intake to meet daily needs **[1]**.

EAAs seem to be solely responsible for the increase in MPS with doses ranging from 6 to 15 g, all exerting stimulatory effects. Furthermore, doses of approximately one to three g of leucine per meal appear to be necessary to stimulate the protein translation mechanism **[1]**.

BCAAs (ie isoleucine, leucine, and valine) appear to exhibit individual and collective abilities to stimulate protein translation. However, the extent to which these changes align with the changes in SPM remains to be fully explored. Although higher doses of leucine have been shown to independently stimulate increases in protein synthesis, a balanced intake of EAAs promotes the greatest increases. Prioritizing protein feeding with adequate levels of leucine/BCAAs will best promote the increase in MPS **[1]**.

Timing of nutrient intake is an area of research that continues to attract interest from researchers, trainers, and consumers. First, all nutrient timing-related findings require appropriate context, as factors such as age, gender, fitness level, previous fueling status, diet status, training volume, training intensity, program design, and time before the next workout or competition may influence the extent to which it may play a role in the adaptive response to exercise. Second, almost all research on this topic requires further investigation.

In this sense, the timing of nutrient intake is a feeding strategy that, in almost all situations, can be useful to promote recovery and adaptations to training. This context is important because many nutrient synchronization studies demonstrate favorable changes that do not meet the statistically significant thresholds, thus leaving the reader to interpret the level of practical significance that exists from the results **[1]**.

According to the ISSN, when a strategy can help or have a neutral effect and fits into the daily schedule and ability to deliver, then from a purely practical perspective it is worth employing **[1,2]**. It's worth noting that differences in real-world athletic performance can be so small that it's still worth following strategies that offer minimal benefit. It must be remembered that the general objective of any nutritional strategy is to improve the adaptive response to acute and/or chronic exercise.

In almost all of these situations, this approach results in an athlete receiving a combination of nutrients at specific times that may be helpful and have not yet been shown to be harmful. This perspective also has the advantage of offering more flexibility in the supply considerations that a coach or athlete may employ. Using this approach, when both situations (timed or untimed nutrient intake) provide positive results, our perspective is to advise an athlete to follow whichever strategy offers more convenience or compliance, if for another reason it does not provide vital nutrients in amounts in a moment that will support the physiological response to exercise **[2]**.

Endurance Training - Carbohydrates and Proteins

Combining carbohydrates and protein is a strategy employed by endurance and strength athletes to increase exercise performance, promote glycogen replacement, minimize muscle damage, and promote positive nitrogen balance.

In this vein, studies have examined pre-endurance exercise intake of carbohydrates and protein on performance as well as metabolic, but very few have directly investigated the impact of altering the timing of nutrients being administered. Thus, Ivy and colleagues **[32]** recruited trained cyclists to complete three hours of cycling exercise at an intensity of 45-75% of VO_2 max before exercising to exhaustion at 85% of VO_2 max. Participants ate 7.75% carbs or a solution of 7.75% carbs + 1.94% protein. When protein was added to carbohydrates, endurance was significantly improved.

Similarly, Saunders and colleagues **[33]** had participants cycle to exhaustion on two separate occasions (75 to 85% of VO_2 max) within 24 hours of ingesting a carbohydrate or carbohydrate and protein solution throughout the exercise session (1 .8 mL/kg every 15 min) followed by a single bolus dose (10 mL/kg) immediately after exhaustion. The combination of carbohydrates and protein resulted in significantly improved performance as well as a reduction in muscle damage.

Thus, post-exercise nutrient timing strategies are of great interest. Ivy et al. **[34]** analyzed a 2.5-hour cycling session (65–75% VO2max) before consuming a combination of carbohydrate and protein (80 g carbohydrate + 28 g protein + 6 g fat) or two different doses (high: 108 g carbohydrate + 6 g fat or low: 80 g carbohydrate + 6 g fat) carbohydrate immediately after and 2 h after completing the exercise session. While the timing was not specifically investigated, the combination of carbohydrate and protein allowed for greater glycogen recovery during the four-hour investigation window employed by the research team.

These findings replicated previous findings by this research group and led them to conclude that the addition of protein favorably promoted glycogen recovery phases **[35]**. Berardi et al. later published two similar studies **[36,37]** that also showed that providing a combination of carbohydrates and protein facilitated the greater recovery of muscle glycogen when ingested shortly after the completion of a workout and before subsequent resistance exercise.

Main Clinical Results

Research studies typically employ a small number of study participants. In addition, most studies primarily evaluated men. This last point is particularly important as researchers have documented that women oxidize more fat compared to men and also appear to utilize endogenous fuel sources to different degrees **[38-40]**.

Furthermore, the size of potential effects tends to be small, and when small potential effects are combined with a small number of study participants, the ability to determine statistical significance remains low. However, this consideration remains relevant as it underscores the need for more research to better understand the possibility of a group and individual changes that can be expected when nutrient timing is manipulated **[41]**.

In many situations, the effectiveness of nutrient timing is inherently linked to the concept of optimal supply. Therefore, the importance of adequate intake of energy, carbohydrates, and proteins must be emphasized to ensure that athletes are adequately supplied for optimal performance and maximize possible adaptations to physical training **[42]**.

Prolonged (> 60 - 90 min) exercise of moderate to high intensity (65–80% VO_2 max) relies heavily on endogenous carbohydrate stores, and timing strategies to maximize these stores (carbohydrate loading strategies or glycogen supercompensation) have been shown to facilitate recovery and compensate for these changes **[43]**.

In addition, high-intensity exercise (particularly in hot, humid conditions) requires aggressive replacement of carbohydrates and fluids. Consumption of 1.5 to 2 cups of a 6 to 8% carbohydrate solution (6 to 8 g of carbohydrate per 100 mL of liquid) is an effective strategy to replace fluid, maintain glucose levels in the blood and promote performance. The need for carbohydrate replacement increases in importance as training and competition extends beyond 70 min of activity and the need for carbohydrates during shorter periods is less well established **[44]**.

Rapid ingestion of high amounts of carbohydrates (≥ 1.2 g/kg/h) for 4 to 6 h after exhaustive exercise can rapidly stimulate muscle glycogen replacement **[42]**. The addition of protein (0.2-0.5 g/kg/h) to carbohydrates increases the rate of glycogen resynthesis when ingesting <1.2 g/kg/h carbohydrate. Additionally, the additional protein can minimize muscle damage, promote favorable hormone balance, and speed recovery from intense exercise.

For athletes who perform high volumes (i.e.,≥8h) of exercise per week and subsequently require the need to continually and rapidly replenish endogenous glycogen stores, the most effective strategy for maximizing endogenous glycogen stores is to consume a daily diet rich in carbohydrates (8-12 g/kg/day) **[2]**.

Using a 20 to 40 g serving of a high-quality protein source that contains approximately 10 to 12 g of the EAAs maximizes MPS rates that remain elevated for three to four hours after exercise. Protein consumption during the peri-workout period is a pragmatic and sensible strategy for athletes, especially those who perform high volumes of exercise. Not consuming protein after training (eg, waiting several hours after exercise) offers no benefit **[2]**.

The impact of administering a dose of protein (with or without carbohydrates) during the periworkout period over several weeks may work as a strategy to increase adaptations to exercise. Key factors that can influence overall results include total daily protein intake, an individual's training status, and when the last dose of protein was consumed **[2]**. As with carbohydrates, timing considerations for protein appear to be of lower priority than ingesting optimal amounts of daily protein (1.4-2.0 g/kg/day).

Given the restriction of caloric intake for weight loss, changing the frequency of meals showed limited effects on body composition. However, more frequent meals may be more beneficial when accompanied by an exercise program. The impact of changing meal frequency in combination with an exercise program in non-athlete or athlete populations deserves further investigation. It is established that changing the frequency of meals (outside of an exercise program) can help control hunger, appetite, and satiety **[2]**.

Nutrient synchronization strategies that involve changing the distribution of intermediatesized protein doses (20 to 40 g or 0.25 to 0.40 g/kg/dose) every three to four hours improve the increase in rates of MPS throughout the day and favorably improve body composition and physical performance results. It should also be considered that other factors, such as the type of exercise stimulus, training status, and consumption of mixed macronutrient meals versus single protein intake, can affect how protein is metabolized throughout the day **[2]**.

When consumed 30 minutes before sleep, 30 to 40 g of casein can increase MPS rates and improve muscle strength and hypertrophy. Furthermore, protein intake before sleep can increase the morning metabolic rate while exerting a minimal influence on lipolysis rates. In addition, protein intake before sleep can work as an effective way to meet daily protein needs, as well as provide a metabolic stimulus for muscle adaptation **[2]**.

Changing the timing of energy intake (i.e., total calories over a day) can improve weight loss, changes in body composition, and health-related markers, particularly when a greater proportion of calories are consumed during breakfast and to a greater extent when this meal provides higher amounts of dietary protein **[2]**.

In line with the position of the International Society of Sports Nutrition that most exercising individuals should consume a minimum of approximately 1.4 to 2.0 g of protein per kg of body weight per day to optimize training-induced adaptations. Importantly, this recommendation also falls within the Institute of Medicine's Acceptable Macronutrient Distribution Range (AMDR) of 10 to 35% protein **[44]**.

Conclusion

The amount depends on the mode and intensity of exercise, the quality of protein ingested, and the individual's energy and carbohydrate status. However, it should be noted that there is preliminary evidence that consuming much higher amounts of protein (>3 g/kg/d) may confer a benefit concerning body composition. Concerns that protein intake within this range is unhealthy are unfounded in healthy, exercising individuals. One should try to consume whole foods that contain high-quality protein sources. Timing of protein intake in the period spanning the exercise session can provide several benefits, including improved recovery and greater gains in lean body mass. EAAs and leucine supplements are beneficial for the exercising individual by increasing MPS rates, decreasing muscle protein breakdown, and possibly aiding exercise recovery.

Acknowledgement

Not applicable.

Ethical Approval

Not applicable.

Informed consent

Not applicable.

Funding

Not applicable.

Data sharing statement

No additional data are available.

Conflict of interest

The authors declare no conflict of interest.

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