Sports Nutrition Needs
Before, During, and After Exercise

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KEYWORDS

• Sports nutrition • Protein • Hydration • Carbohydrates • Fat metabolism
• Nutrition and performance

KEY POINTS

- Maintaining proper hydration by drinking during exercise has the largest beneficial effect on performance of any single nutritional intervention.
- Sufficient hydration with water alone is fine for mild to moderate activity for less than 1 hour and does not lead to significant dehydration.
- Pre-exercise carbohydrate ingestion improves performance when carbohydrate ingestion is maintained throughout exercise and high plasma glucose concentrations maintained.
- Moderate to intense physical activity lasting longer than 1 hour may require carbohydrate or electrolyte supplementation drinks as an appropriate source of hydration.
- Replacing fluids lost through sweat is top priority for recovery. A total of 16 to 24 oz of fluid should be consumed for every 1 lb lost.

INTRODUCTION

Nutrition before, during, and after exercise can make the difference between exercise improvement and injury. It can determine if it will be the worst or best performance for an athlete. A major cause of poor performance during competition is improper nutrition.[1] The athlete's nutrition outside of these times certainly affects performance. However, even if an athlete aces their nutrition at those times, but fails to mind proper fueling needs before, during, and after exercise it can still undermine their performance. Any athlete that desires to maximize their exercise gains and competition performance must focus on proper fueling for their sport, which includes taking in the proper type and amount of nutrients before, during, and immediately after their practice or competition.

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FUELING BEFORE SPORT

Eating and then exercising can cause many athletes to experience stomach cramping and indigestion during sport exertion. This may lead some to think they should avoid eating before practice or very close to game time. Such a decision can inhibit stamina if their sport is long in duration and exhaustive exercise. Kirwin and colleagues[2] found that providing 75 g of moderate glycemic carbohydrate 45 minutes before exhaustive exercise lasting longer than 1 hour can improve endurance capacity by 10% to 16% compared with providing only water. It is important to begin a practice or competition with nutritional stores maximized, especially glycogen stores and hydration stores. It is well established that a lack of adequate fuel, specifically glycogen, or fluid before exercise can negatively impact performance.[3–5]

How much an athlete needs to eat and what food choices they should make when fueling before practice or a competition depend on how much time they have before commencing exercise, how much they weigh, and what type of sport they will be performing (**Table 1**). Eating or drinking too great of volume before exercise can have opposite the desired effect: gastrointestinal problems and performance impairment.[6] The less they weigh and the less time they have prior, the smaller the quantity of food and the more important that the food choice is something that digests quickly, such as juice, sport drink, fruit, or plain crackers. Choosing a liquid fuel choice especially shortens gastric emptying time and lowers the residual intestinal load, which may be beneficial for nervous athletes or athletes who need to "make weight" before completion. These food choices should be high in carbohydrate, but low in fat, fiber, and protein because the latter nutrients delay gastric emptying, increasing the chances of gastrointestinal upset and delaying availability of energy availability from carbohydrates.

Although studies conflict regarding the importance of choosing high- or low-glycemic carbohydrates before exercise, it seems that one does not provide any

Table 1
Pre-exercise fuel needs

Hours Before Exercise Start	Amount of Nutrient Required	Sample Fuel Choices (150-lb Athlete)
4	4 g CHO/kg body weight, 16–24 oz fluid	(273 g CHO) 3 oz grilled chicken, 1 C brown rice, 1 C mixed vegetables, 16 oz apple juice followed in 1.5 h with 1 large bagel with 1 Tbsp peanut butter, 1 Tbsp honey, 16 oz chocolate milk, and then 1 h later with 4 fig-filled cookies, 1 large banana, and 16 oz water
3	3 g CHO/kg body weight, 16–24 oz fluid	(205 g CHO) 6-in turkey sub sandwich, low-fat condiments, 1 oz baked chips, 1 C mixed fruit, 16 oz grape juice, 2 fig cookies
2	2 g CHO/kg body weight, 16–24 oz fluid	(136 g CHO) 1 peanut butter and jelly sandwich, 1.5 C cherries with pits, 16 oz vanilla almond milk
1	1 g CHO/kg body weight, 16–24 oz fluid	(68 g CHO) 1 large banana, 12 oz chocolate soy milk, 12 oz water
<1	30 g CHO, 8–12 oz fluid	1.5 C grapes, 12 oz water

Abbreviation: CHO, carbohydrate.

performance enhancement over the other. Febbraio and colleagues[7] studied the effect of varied glycemic pre-exercise meals on eight trained cyclists. Each of the male athletes either received a high-glycemic index meal (mashed potatoes), low-glycemic index meal (muesli), or placebo meal (diet gelatin) 30 minutes before a 120-minute cycling bout at 70% V_{O_2} max. This was followed by a 30-minute performance ride where total work was recorded. This test was repeated on each cyclist on three different occasions, at least a week apart, to allow for every subject to be tested with each of the varied glycemic pre-exercise meals. Although glucose and insulin levels varied in each test group before, during, and after exercise, no differences in work output was measured during the 30-minute performance cycle. Choosing low-glycemic over high-glycemic foods before exercise may affect substrate use, but neither seems to offer a clear performance benefit over the other.

Exceptions to these guidelines include the importance of ingesting protein before strength-building exercise. Before weight lifting, a strength athlete is likely to choose more protein and less carbohydrates, but still low fiber and fat, and ample fluids. Consuming amino acids before strength training may have an anticatabolic effect.[8] However, strength athletes need very little protein to achieve this effect. As little as 6 g of amino acids, combined with 35 g carbohydrate, just before resistance exercise improves protein muscle accretion.[9,10]

A full-size meal 3 to 4 hours before exercise start is ideal, and enhances endurance capacity.[11,12] Such amount of time safely allows for full digestion and absorption of nutrients. Food choices should be high in carbohydrate, low in fiber, and low in fat. A moderate amount of lean protein is encouraged. Ample fluids should also be included (5–7 mL/kg) to promote optimal hydration.[13] The goal of the precompetition meal is not to load up with large portions and multiple plates of food. The body more easily digest small amounts of food that are ingested at various intervals over time: one plate full of food for a meal and a small snack each of the hours leading up to exercise time (eg, banana an hour after, mini sport bar 1 h before, and sport drink just before beginning). Small amounts of fluid (6–12 oz) should be included along with all snacks or meals.

FUELING DURING SPORT

Hydration

Maintaining proper hydration by drinking during exercise has the largest beneficial effect on performance of any single nutritional intervention. Dehydration compromises cardiovascular function by decreasing blood flow to muscles and cardiac output.[14] The resulting increase in heart rate causes a decrease in stroke volume. Hypovolemia hampers an athlete's thermoregulation. The more hyperthermic an athlete is, the greater their work capacity decreases.[15] Low blood volume, from dehydration, also thwarts oxygen and glucose transport to muscle cells. At just a 2% loss in body fluids, an athlete's performance is impaired.[16,17] Fatigue and performance impairment caused by dehydration can cause athletes to compromise their physical mechanics. Therefore, not only does dehydration impair performance, it indirectly raises an athlete's risk of injury and directly raises their risk for heat-related illnesses.[18] Equally important to performance and hydration is ensuring an athlete does not drink in excess of their fluid and electrolyte losses. When serum sodium levels are diluted less than 130 mEq/L, intracellular swelling occurs and alters central nervous system function. This is labeled symptomatic hyponatremia and can occur when athletes drink in excess of their fluid losses, deplete their extracellular fluid sodium by heavy sweat loss, or a combination of high fluid intake and excessive sweating. Hyperhydration has no beneficial exercise performance effects.[19] Symptomatic hyponatremia and dehydration are negatively associated with exercise performance.

To optimize sport performance and minimize risk of injury, the hydration goal for every athlete should be to match their rate of losses, specifically fluid and electrolytes.[20] When an athlete does not have access to a formal sweat test to calculate their loss of fluids and electrolytes, they can attempt to calculate their own. By weighing before and immediately after exercise, subtracting any fluids lost by urination, and by adding any fluids consumed, an athlete can guesstimate the amount of individualized sweat rate (see **Table 2** for an example of a sweat rate tracking form). Electrolyte losses cannot be as easily measured, but sodium needs still can be estimated based on these same results. Average human sweat contains 920 to 1150 mg sodium per liter.[21] Because some athletes cannot always drink as much fluid as they are losing, it is necessary to increase the amount of sodium intake, along with maximal fluid intake, until the rate of sweat loss is kept at least less than a 2% loss. If sweat loss is high, including electrolytes in fluids consumed encourages greater fluid intake, aids in maintaining plasma volume, and reduces urine production.[21] When an athlete cannot tolerate greater fluid intake, increasing the amount of sodium ingested may help encourage hydration.[22] The American Dietetic Association and the American College of Sports Medicine and Dietitians of Canada recommend the individualized approach of matching fluid intake with sweat losses, but also generally advise athletes to drink 6 to 12 oz of fluid every 15 to 20 minutes as tolerated and to include sodium.[13] In general, the greater the loss of sweat, the more fluid and electrolytes are required to achieve euhydration.

It seems that minimizing dehydration may be part of the solution to aiding athletes in avoiding gastrointestinal issues while staying fueled during exercise.[23] The gut has become known as an important athletic organ, particularly in the case of endurance athletes who must consume the most fluid and fuel while exercising. Certain adaptations occur in the stomach and intestines of well-trained athlete's that allow them to better tolerate larger volumes of fluid or fuel. The average stomach volume is 50 to 100 mL, but it can expand up to 1000 mL with no increase in abdominal pressure. If some athletes are to match their fluid intake equal to their amount of sweat lost, their ingested fluid volume may exceed the comfort of the stomach's approximately 1000 mL expansion.[24] However, the higher the fluid volume, the higher is the gastric emptying rate. The addition of glucose greatly slows the gastric emptying rate, but can increase the rate of absorption by the intestines. The gastric emptying rate is not affected by exercise at a 25% to 75% VO_2 max. More intense exercise (VO_2 max >80%) delays gastric emptying.[25] In well-trained athletes there is an increase in intestinal transit and capacity to absorb food and fluid. In a study of marathon runners by Carrio and colleagues,[26] 10 runners and 10 sedentary individuals of similar age and gender were fed an egg sandwich injected with an isotope marker after an 8-hour fast. Each of the subjects was measured for radioactivity retention in their stomach at three intervals of 30-minutes while at rest. The 10 runners in the group returned a week later to repeat this procedure. However, as soon as they finished consuming their egg sandwich and were initially measured for radioactivity in their stomachs, they ran 4 to 4.5 miles during a 30-minute interval. Each runner had their gastric contents measured after the interval and then repeated the run interval and test two more times (90 minutes running total with <1 minute pause for gastric testing). The runner's basal gastric emptying rates were significantly faster than the sedentary test subjects at rest and while exercising. This suggests that with practice, athletes can improve gastric motility, but further minimize their risk of dehydration and associated gastrointestinal upset.

Table 2
Sweat rate tracker

Date	Temperature Index	Type of Training	Duration in Minutes	Weight Before Start (lb)	Weight at Event End (lb)	Amount of Fluid Consumed (oz)	Amount of Fluid Lost by Urine (oz)	Amount of Sodium Consumed by Food or Fluids	Sweat Rate per Hour	Fluids Required for Rehydration

Conversion: 16 oz fluid = 1 lb.
Sweat rate calculations = (wt before − end wt) + (lb fluids consumed − lb urine loss)/(minutes of exercise/60).
Rehydration needs calculation = (wt before − end wt) × 16–24 oz.

Carbohydrate Replacement

Taking in glucose while exercising spares muscle glycogen and increases an athlete's endurance capacity. It is not necessary to consume carbohydrates unless the exercised performed is at 75% VO_2 max for less than an hour or unless the exercise duration will total more than 2 hours.[27] The amount of carbohydrate needed to sustain energy stores during prolonged exercise is 30 to 60 g of carbohydrate per hour. Carbohydrate from a single source, such as glucose, can only be oxidized at rates of approximately 60 g/h. However, when more than one type of carbohydrate is ingested (eg, combination of dextrose and fructose) the oxidation rate can increase slightly to 75 to 90 g/h.[27] Athletes should attempt the higher rate of carbohydrate oxidation with caution. Large amounts of carbohydrate intake during exercise may increase the incidence of gastrointestinal symptoms because of the decreased mesenteric blood flow to the intestines during high-intensity exercise, and especially in the presence of dehydration. Exercise performance and endurance capacity may be greatly enhanced with the increased oxidation of carbohydrate when exercise duration is high (>2.5 h).[28] For most athletes, it is recommended that they aim for 30 to 60 g of carbohydrate intake from varying sources during each hour of exercise.[13] To further minimize risk of gastrointestinal distress and to minimize the risk of energy deficits, it may be helpful to divide the 30 to 60 g of carbohydrate intake into smaller amounts (eg, 10–15 g carbohydrate every 15 minutes) to be ingested throughout the hour of activity.

When exercise is expected to last more than an hour, carbohydrate replacement should begin well before glycogen stores are emptied. McConell and colleagues[29] demonstrated that waiting until late in exercise (post 90 minutes cycling) to ingest carbohydrates impairs performance, compared with providing the same amount of carbohydrates at 15-minute intervals throughout exercise. Many factors affect how quickly glycogen stores are depleted, including amount of glycogen stores before exercise commencement, how well trained the athlete is, and the intensity of the exercise.[30] Athletes can increase their glycogen storage capacity with proper supercompensation strategies (carbohydrate loading) before exercise, which prolongs the necessity of carbohydrate intake.[31] Less-trained athletes use carbohydrate at a quicker rate than well-trained athletes. The more intense (higher VO_2 max required for sport performance) the exercise, the more rapidly carbohydrate stores are recruited. Because of the varying rates of carbohydrate use and glycogen storage capacities of each individual athlete, it is generally advised that for long durations or exercise, carbohydrate replacement should begin before a full hour of exercise being completed.

Practical Considerations for Achieving Nutrient Needs During Sport

Many athletes get little time during competition to pause for eating and drinking. Using a sport drink is an all inclusive way to meet the nutrient demands of an athlete during practice or competition. Sport drink can provide not only the necessary fluids and electrolytes for adequate hydration, they also supply carbohydrate. If carbohydrate is consumed in fluid form, the ideal concentration of the sport drink should be less than 6% carbohydrate.[32] During intense exercise fluid absorption in the small intestine is encouraged by including a small amount of glucose and sodium with fluid ingested. Sport drink is the fluid of choice if activity time is expected to last more than an hour. The small amount of carbohydrate in sport drinks, when consumed at adequate levels, is enough to sustain an athlete's stamina and allow them to perform at optimal capacity for their entire activity time.

For children playing a sport that lasts less than an hour, water is all they require to perform at their best. For children who engage in vigorous sports (VO_2 max >75%), or a sport where nonstop play is required, or a sport that takes place in very hot and humid conditions a sport drink may be more beneficial than plain water. The American Academy of Pediatrics recently released a statement supporting water over sport drinks for most children's exercise. They highlight the fact that if conditions of sport do not necessitate the need for added carbohydrate and sodium in sport drinks, consumption of sport drinks during sport or outside of sport contribute to obesity and tooth decay in children.[33]

Athletes may be tempted to pour fluid over their body while exercising in the heat. To avoid heat stroke or other heat-related illnesses, athletes should be advised that it is more important to put water inside their body to stay cooler. Every 1% loss of body mass caused by dehydration during exercise causes a 0.27°F to 0.36°F rise in core body temperature.[34] This is especially important if exercise takes place in a humid environment, which may limit cooling of the body through evaporation.

In all types of exercise, physical work capacity, time to exhaustion, time trial performance, power output, and sport-related motor skills are improved when fluid losses are kept less than 2% of body weight and carbohydrate is also consumed.[35] When exercise is intense or will last longer than 1 hour, taking in fluid or carbohydrate independently enhances performance. If hydration and glucose replenishment are properly achieved during such exercise, performance is enhanced above the individual performance effect of each nutrient.[36] For optimal sport performance proper hydration and carbohydrate maintenance throughout exercise are necessary.

FUELING FOR RECOVERY

Part of ensuring that athletes are properly fueled for their next practice or competition is making sure they refuel depleted energy, fluid, and electrolyte stores after competition or practice. It may take 24 hours to do this.[30] Rapid repletion of muscle glycogen is especially important after exercise if an athlete must exercise more than once within a 24-hour period. The body recovers best when an athlete begins refueling as soon as they finish exercise.

Rehydration

Replacing fluids lost through sweat is top priority for recovery. It is common for athletes to remain mildly dehydrated after exercise despite their efforts to replace fluids. This can impair exercise performance in subsequent exercise. The American Dietetic Association recommends 16 to 24 oz of fluid be consumed for every 1 lb lost.[13] This is a rate of 100% to 150% of total body fluid lost. Consuming this amount of fluid over a longer period of time improves rehydration. It can take about 6 hours to reachieve proper losses during exercise.[37] Rapid rehydration does not work because of obligatory urine losses. Fluids with electrolytes are the best choice. Electrolytes, specifically sodium, are critical for preventing insensible losses by way of urine and for effectively increasing plasma volume.[38] Because urine losses seem to positively correlate with the amount of fluid ingested, but decrease as sodium consumption is increased, it is wise to liberally include sodium and extra fluid in recovery fuel choices.

In a rehydration study by Shirreffs and colleagues,[39] 12 cyclists were brought to just greater than 2% dehydration by exercise on 4 separate weeks. On each occasion, every subject was given fluids either in the amount of 50%, 100%, 150%, or 200% of body mass lost after exercise. Each week, six of the subjects received 23 mmol/L sodium in their fluid and the other six received a 61 mmol/L sodium concentration. At 7.5 hours after exercise, blood and urine samples were remeasured. Rehydration was almost achieved for the subjects in the lower sodium concentration group when they consumed either the 150% or 200% amount of fluid. A total of 91% of starting body mass was achieved with ingestion of each of those volumes, compared with only 39% recovery for the subjects that drank only 50% of lost mass, and 60% recovery for the subjects that rehydrated with 100% of mass lost. Full rehydration was achieved by subjects that received the higher sodium concentrated fluid and either the volume of 150% (107% mass recovered) or 200% (127% mass recovered) of body mass lost. Despite the higher sodium content, the subjects that only received fluid in volumes of 50% (regained 38% mass lost) or 100% (regained 81% mass lost) of mass loss did not achieve full rehydration.

An exact sodium recommendation has not been developed, but evidence is clear regarding sodium's role in encouraging plasma and total body rehydration by increased fluid intake and retention after dehydrating exercise. Because the amount of fluid needed is likely to be in excess of 16 oz, it may be helpful to choose fluids that have flavor and sodium.[40] This encourages athletes to drink more. Chilled beverages after exercise are also more generously consumed and are favorable.[13] Fluids increase blood volume and help circulate water and other nutrients needed to lower the body's core temperature quickly and return the body to homeostasis.

Refueling

When carbohydrate is supplemented immediately after exercise the rate of glycogen synthesis is increased.[41] Athletes that have continuously exercised for 90 minutes or more need 1.5 g/kg body weight of carbohydrate within 30 minutes.[42] The short window of time after exercise is ideal for glycogen resynthesis because blood flow to the muscles is still copious and there is greater insulin sensitivity. High glycemic carbohydrates in fluid or solid form are most quickly absorbed and shuttled into cells for most rapid muscle glycogen restoration.[43] Fructose is not as effective for restoring muscle glycogen immediately after exercise because it is taken by the liver for hepatic glycogen storage.[44] Athletes with shorter duration or less intense exertion do not require a formal recovery drink with as many carbohydrates.

A moderate amount of protein should be combined with the fluid, electrolytes, and carbohydrates to promote muscle protein synthesis and enhance muscle glycogen availability.[45,46] Including a small amount (0.2 g/kg) improves muscle tissue repair more effectively than carbohydrate alone.[47] Choosing protein hydrolysates may further improve muscle uptake and use of protein immediately after exercise.[48,49] Moore and colleagues[50] found that ingesting 20 g of intact protein after resistance exercise was optimal for enhancing muscle and albumin protein synthesis. Protein consumed in greater amounts than this may promote irreversible oxidation and no further increase in protein synthesis.

If an athlete can consume fluid, electrolytes, 10 to 20 g protein, and 100 to 200 g carbohydrate (or specific amount according to their body weight, sport intensity, and duration) within 30 minutes of finishing exercise, they are most likely to limit fatigue and strain on their body. Choosing a drink rich in carbohydrates and moderate in protein, such as a fruit and yogurt smoothie, or low-fat chocolate milk, is an easy way to shuttle in the necessary nutrients for recovery.

The recovery drink should be followed by a complete meal or multiple snacks and ample fluids to achieve full recovery need repletion. If an athlete has 24 hours before their next exercise session, the meal, snack, and fluid choices can be consumed a few times in large quantities or in several smaller quantities, according to what is convenient and comfortable to the athlete. If exercise must be commenced again within 8 hours, a more structured schedule is advised to optimize necessary nutrient intake.[51] Including produce in meal and snack choices is a natural way to provide antioxidants, vitamins, and minerals to aid in tissue repair and recovery. What is most important is that the total food and fluid choices provide enough carbohydrate and fluid to sufficiently restore muscle glycogen and hydration status before the athlete's next exercise session.

Practical Considerations for Eating and Drinking After Exercise

Many athletes feel entitled to eat or drink whatever they desire after what they perceive as great effort in sport. This can often lead to postexercise recovery food and fluid choices to include fatty foods along with alcoholic beverages. Athletes should be warned that choosing beverages with greater than 4% alcohol content may delay physical recovery from exercise.[52] This is especially prudent for college athletes because they have a greater propensity compared with nonathletes to engage in drinking, especially binge drinking.[53] There is no evidence that including fat as part of sport recovery enhances recovery or further sport performance. Calories consumed in the form of alcohol or fat may take away from needed calories coming from carbohydrate, which are priority for proper muscle glycogen synthesis.

Table 3
Fueling sport performance summary

	Needs Before Exercise	Needs During Exercise	Needs for Recovery After Exercise
Exercise <75% Vo_2 max or <2 h			
Timing	<1–4 h prior	As needed throughout exercise	According to convenience of athlete
Amount of nutrient required	1 g CHO/kg body wt + 16–24 oz fluid for each hour before exercise start	Water and electrolytes in the amount equal to losses	Complete meal or snack that is high in carbohydrate and contains protein and electrolytes
Strength-based exercise			
Timing	Just before exercise start	As needed throughout exercise	According to convenience of athlete
Amount of nutrient required	10–20 g protein + 35 g CHO	Water equal to amount lost during exercise	Complete meal or snack that is high in carbohydrate and contains protein
Exercise >75% Vo_2 max or >2 h			
Timing	<1–4 h prior	Within 1 h of exercise start, and then every hour following	Within 30 min of finishing
Amount of nutrient required	1 g CHO/kg body wt + 16–24 oz fluid for each hour before exercise start	30–60 g CHO/hr + fluid and sodium to match losses (or at least within 2% of fluids lost)	1.5 g CHO/kg body wt + 10–20 g protein + 100%–150% body mass lost in fluids that contain electrolytes

Abbreviation: CHO, carbohydrate.

The sport nutrition supplement industry was a $27.8 billion dollar market in 2007. Its global market growth is expected to achieve $91.8 billion by 2013 (based on a compound annual growth rate of 24.1%).[54] Athletes are lured in by the promises of the latest and greatest to help them more easily achieve their best in athletic performance. Because much of physical adaptation occurs in the recovery process in response to the exercise performed,[55] the market is rife with specially engineered recovery powders, pills, and processed foods. Research shows that such products offer no advantage over whole food choices for recovery.[56] Getting the proper nutrients, whether from engineered or natural sources, is what is important. Engineered recovery products can offer convenience, but are considerably more expensive compared with the cost of getting the same nutrients by whole food.

SUMMARY

No matter the sport, the main principal for using sports nutrition to peak athletic performance is to avoid nutrition-related deficits (**Table 3**). This includes ensuring that day-to-day energy balance is met, hydration and glycogen stores are not deficient before and during exercise, and nutrition stores are restored at a rate consistent with demands of exercise.

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