Hydration and Exercise Performance

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Introduction

Water comprises approximately 2/3 of the human body and is a crucial element of almost all mammalian cells. Body water balance is a function of fluid intake and fluid loss. The vast majority of liquid enters the body through drinking and eating, although normal metabolic reactions also produce a small quantity of water. For average individuals at rest, most water exits the body as urine, but humans also lose small amounts of fluid through sweat, breath and feces. During day-to-day activities of normal living, thirst-induced fluid intake generally matches water losses (1), and the body remains in normal fluid balance (*euhydration*). Common conditions such as exercise, increased environmental temperature or humidity and disease exacerbate water loss; if liquids are not adequately replaced, the body transitions to a state of *hypohydration* (reduced total body water). Given the ubiquitous nature of water and the vital roles it plays in many biochemical reactions, it is not surprising that physiological function deteriorates during hypohydration (2, 3). Simply stated, the body functions less effectively and less efficiently without sufficient water. When individuals begin an exercise bout in a hypohydrated condition or allow hypohydration to develop during exercise, this decrease in physiological functioning directly reduces physical performance.

Endurance Exercise

Endurance exercises are rhythmic whole-body or large-muscle group activities that primarily stress the body's cardiovascular and respiratory systems (e.g. running, cycling and swimming). Although endurance exercise intensity and duration can vary greatly, the American College of Sports Medicine recommends healthy adults complete 20-60 minutes of continuous or intermittent exercise that elicits 55%-90% of maximum heart rate on 3-5 days per week (4). In temperate environments, hypohydration begins to noticeably inhibit endurance exercise performance when fluid losses exceed 2% of body mass (5, 6). This performance reduction is manifested as decreased maximal aerobic power (VO_2max) (7, 8), reduced time to exhaustion at a constant exercise intensity (9, 10) or increased time to complete a standardized exercise task (11). Total body water losses of less than 2% cause variable effects, depending on specific characteristics of the exercise task, subject population and method of achieving hypohydration. Three possible explanations clarify this threshold effect: 1) the body maintains a reservoir of extra water for times of need (much like storing excess energy as fat), 2) the body compensates for small water losses by subtly adjusting physiological function such that outward performance remains unaffected and/or 3) laboratory testing techniques are insufficiently sensitive to detect small decrements in exercise performance (12).

Several physiological mechanisms explain these detrimental effects of hypohydration on endurance exercise performance. Much of the water composing sweat is drawn from the liquid portion of the blood (plasma). Blood is the body's primary transportation system; during exercise, blood delivers oxygen, nutrients and hormones to active muscle tissue while concurrently removing carbon dioxide and other metabolic byproducts. Hypohydration-induced decreases in blood volume force the heart to work harder in propelling the remaining blood throughout the body. As a result, hypohydration increases heart rate at any submaximal intensity (13) and decreases cardiac output (the volume of blood pumped by the heart per minute) (14). This cardiovascular strain directly challenges normal physiological functioning, especially during intense exercise. Additionally, decreasing delivery of oxygen and nutrients to active muscle tissue interferes with normal muscle metabolism, increasing reliance on a finite quantity of stored carbohydrates (15).

Performing exercise in a hot environment exacerbates the negative effects of hypohydration. In addition to gases and nutrients, blood also transports the body's heat; when core temperature rises, vasodilation of peripheral blood vessels increases blood flow through the skin and maximizes heat loss to the environment. Given these multiple roles, two separate tissues compete for blood during exercise in the heat: active muscles (to feed their oxygen and nutrient demands) and skin (to dissipate heat). Independent of hypohydration, this competition decreases exercise performance because a finite blood volume cannot feed both tissues as effectively as either tissue separately (16, 17). Combining exercise-heat exposure with hypohydration only compounds these difficulties, as the same competition (caused by exercise in the heat) exists over a reduced blood volume (caused by the hypohydration). Three possible outcomes result, depending on exercise intensity and environmental conditions: 1) blood flow to muscle decreases, reducing delivery of oxygen and nutrients required to maintain normal metabolism (18), 2) blood flow to skin decreases, reducing heat loss to the environment and increasing core temperature (19) or 3) blood flow to both tissues decreases (20). Metabolic disturbances and raised core temperature each directly limit endurance exercise performance. Additionally, increasing core temperature can lead to exertional heat illnesses that range in severity from uncomfortable (e.g., heat cramps) to dangerous (e.g., heat syncope and heat exhaustion) to potentially fatal (e.g., heat stroke) (21). Changes in core temperature are especially important when examining hypohydration in a pediatric population, as children possess a less robust and effective thermoregulatory system than adults (22, 23).

Strength, Power and High-Intensity Muscular Endurance

Strength, power and high-intensity endurance exercises are activities that primarily stress the body's nervous and muscular systems (e.g. weightlifting). In general, these exercises require brief sessions (several seconds to several minutes) of focused effort separated by several minutes of rest. Although specific characteristics of these exercises vary greatly, the American College of Sports Medicine recommends healthy adults complete one or more sets of 8-10 repetitions of exercises that condition all the major muscle groups on 2-3 days per week (4). While many scientific reports have examined the influence of hypohydration on endurance exercise performance, many fewer have quantified the effects of reduced total body water on strength, power or short-duration bouts of maximal muscular activity. Those few studies successfully isolating the influence of total body water from other confounding factors (e.g. caloric restriction or increased body temperature) produce mixed results: some show that hypohydration decreases performance (24, 25), while others show that hypohydration has little effect (26, 27). Until scientists completely determine the influence of hypohydration on strength, power and high-intensity endurance performances, the best advice is practical: because hypohydration never improves physiological functioning (thus, never improves exercise performance), maintaining a euhydrated state will not impede exercise performance and may prevent the detrimental effects of hypohydration.

Assuming hypohydration detrimentally affects strength, power and high-intensity endurance, mechanisms involving disturbed metabolism or attenuated heat transfer (see above) cannot account for performance reductions because short duration, high-intensity activities (e.g. weightlifting) have minor metabolic requirements and are too brief to develop a significant heat load. Accordingly, many scientists suggest that hypohydration directly affects the nervous system, the muscular system or the connection between them (2, 28). Any disruption to the generation of an electrical nervous signal, the transmission of that signal from the nervous system to the muscle or the muscle's response to that signal will clearly alter exercise performance (both endurance and resistance exercises). Because the loss of water from any cell changes how that cell functions (29), this suggestion seems likely; unfortunately, little experimental evidence exists to support or refute these claims (30, 31).

Practical Recommendations

During Exercise

During exercise, when sweat rate increases and the body readily loses water, hypohydration will result if fluids are not replaced. As thirst poorly indicates hydration status during and after exercise, the average person might become hypohydrated if he or she relies only on thirst to dictate drinking frequency and volume during exercise (32-35). While small degrees of hypohydration (less than 1%-2% loss of body mass) will likely not affect gross physiological function, the best recommendation to maintain health and performance is to *minimize hypohydration during exercise by attempting to match sweat loss with fluid intake* (36, 37). Consuming less fluid than is lost promotes the deleterious effects of hypohydration, but drinking more fluid than is lost can also be dangerous. Profuse overconsumption of fluids (especially pure water) dilutes the body's sodium supply. This condition, known as hyponatremia, leads to fatigue, lightheadedness, cramping, nausea, dizziness, confusion, disorientation and, in the most severe cases, seizures, coma and death. Fortunately, hyponatremia is rare and normally results only after several hours of focused fluid intake, so the average exerciser is much less likely to experience this problem than individuals who drink fluids to excess throughout endurance events such as marathons or long-duration triathlons (21).

To match fluid intake to sweat loss, first determine sweat rate during exercise. Sweat rate is easily measured by obtaining body mass (without clothes) before and after exercise. Assuming no other additions (food intake or drinking) or subtractions (urine or feces) from the body, sweat loss constitutes nearly all the body mass lost during an average exercise bout (less than 2 hours). After measuring body mass before and after exercise, calculate the amount of sweat lost per hour using the following equation: *Because one liter of sweat has a mass of approximately one kilogram, the amount of body mass lost (in kilograms) roughly equals the volume of sweat lost (in liters).*

Most individuals can sweat one to two liters of fluid per hour during exercise, but this value can vary dramatically based on genetics, environmental conditions, acclimatization to the heat, fitness level and exercise intensity (38) [the highest reported sweat rate in the scientific literature is 3.7 liters per hour (39)]. During subsequent similar exercise bouts, advice is to drink small volumes (100-200 mL) of a cool, palatable beverage intermittently (every 10-15 minutes) during exercise. This might feel uncomfortable initially, but the body quickly adapts to fluid ingestion during exercise. Over the next several exercise sessions, one should gradually increase the volume of fluid consumed per drink until fluid intake matches sweat losses. Although some individuals may be unable to completely match sweat losses with fluid intake during exercise (for example, due to gastrointestinal discomfort or high sweat rates), minimizing hypohydration most effectively maintains health and exercise performance.

After Exercise

It is important to drink extra liquids after exercise, especially if fluid intake during exercise failed to match sweat losses. Because the body constantly loses water as urine, a greater volume of liquid than was lost during exercise must be ingested to achieve euhydration (40). Adding a small amount of salt to the fluid and/or consuming some food with the fluid enhances absorption and retention of fluids, promoting better hydration (41).

Beverage Choice

During and after exercise, intake of fluids other than pure water might prove beneficial. Research demonstrates that ingestion of solutions containing additional carbohydrates and electrolytes (i.e. sports drinks) assists in maintaining hydration and exercise performance in many situations (42). Carbohydrate-electrolyte solutions potentially benefit hydration during exercise because 1) the flavor and enhanced electrolyte concentration promote greater drinking (43), and 2) the carbohydrates and electrolytes contained within the solution improve intestinal absorption of the fluid (44). Additionally, the carbohydrate contained within sports drinks provides another energy source, suggesting that sport drinks will help maintain performance during exercises where fuel availability might be a limiting factor (e.g. a marathon). Although research supporting the effectiveness of carbohydrate-electrolyte solutions during short duration, high-intensity exercise bouts is equivocal, commercially available sports drinks are unlikely to impede performance or inhibit hydration. In other words, sports drinks will almost never hurt, but potentially provide some benefit during almost all exercises. One notable exception: when individuals exercise primarily to lose weight, the extra calories contained within the sports drink (typically 50-70 kcal per 8 fl. oz) will counter the exerciser's goal of consuming fewer calories for weight reduction.

Key Points

- Water is vital: the body functions less effectively and less efficiently without sufficient water.
- Hypohydration of more than 2% body mass loss negatively affects endurance exercise performance.
- It is unclear to what degree hypohydration inhibits strength, power or high-intensity endurance.
- To maintain health and performance, one should minimize hypohydration during exercise by attempting to match sweat loss with fluid intake.
- Except when the primary goal of exercise is weight reduction, consumption of carbohydrate-electrolyte solutions (i.e. sports drinks) might assist in maintaining hydration and exercise performance.

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