THE IMPACT OF HYDRATION ON ATHLETIC PERFORMANCE

RESEARCH FROM THE ACE SCIENTIFIC ADVISORY PANEL

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Maintaining optimal hydration is essential during exercise, as both dehydration and overhydration can be detrimental to performance and, if extreme, can have severe health consequences.

Dehydration occurs during high-intensity or long-duration exercise, especially in hot and humid conditions. Symptoms include thirst, flushed skin, apathy and discomfort. Exercise performance begins to decline once water loss exceeds 2% of an individual's body mass. In addition to physical impairments, dehydration also impairs cognitive function, including reaction time, task performance and mood state.

Overhydration occurs when plasma sodium concentration levels drop too low, either because water clearance by the kidneys is insufficient or water intake exceeds sweat losses. Signs include dizziness, nausea and puffiness, which worsen to confusion, vomiting and swelling of the hands and feet when plasma sodium concentration levels continue to drop. Overhydration is typically treated with hypertonic fluids or IV infusion.

Assessing hydration status involves monitoring changes in body weight, urine color and thirst, and can be used to help make individualized decisions for replacing fluids. People who exercise longer than 60 minutes, especially in hot and humid environments, may benefit from drinking fluids with added carbohydrates or electrolytes.

During exercise in hot conditions, sweat rates typically fall in the range of 1 to 2 L/h, but can be as high as 2 to 3 L/h in trained athletes.

KEY POINTS

- Deviations from optimal total body water, including dehydration and overhydration, may lead to performance decrements during exercise and, if extreme, can have potentially severe health consequences.
- Given competing demands for a limited blood volume, dehydration can induce cardiovascular and thermoregulatory strain during exercise, increasing the risk of heat illness.
- Excess fluid intake can lead to a life-threatening condition known as exercise-associated hyponatremia (EAH), which occurs when plasma sodium concentrations become too low.
- To minimize performance decrements, athletes should aim to maintain hydration (<2 percent body mass loss), while avoiding weight gain.
- For competitive athletes focused on performance, hydration-assessment methods (including monitoring changes in body weight) can be used to implement optimal hydration strategies.
- The addition of electrolytes and carbohydrates to fluids may provide additional benefits, especially for individuals with high salt content in their sweat or athletes competing in long-duration events.

BODY FLUID DYSREGULATION impairs mechanisms of thermoregulation and increases cardiovascular strain during exercise, which negatively impact exercise performance and may compromise positive training-induced hemodynamic adaptations. Maintaining optimal hydration is a challenge during exercise—especially exercise in the heat—due to the robust sweating response and associated water and sodium losses. Evaporation of sweat is the major avenue of heat dissipation during exercise and is necessary to limit the rise in core temperature. During exercise in hot conditions, sweat rates typically fall in the range of 1 to 2 L/h, but can be as high as 2 to 3 L/h in trained athletes.[1] This rate of fluid loss may result in severe dehydration and compromised performance if water loss is not replaced by adequate fluid intake. Although it occurs less commonly, *overhydration* during exercise may also lead to severe health consequences. Thus, it is important to prevent large fluid deficits while also avoiding excess fluid intake during exercise. However, the large inter-individual variability in sweat loss and habitual fluid consumption makes it impossible to establish a universal fluid-replacement strategy for all athletes. This review will discuss the physiological and performance consequences of both dehydration and overhydration, assessment techniques and current controversies surrounding the topic of fluid replacement.

Before discussing the physical and performance consequences of changes from *euhydration*, or optimal total body water, it is helpful to define the relevant terminology. *Hypohydration* and *hyperhydration* are defined as a body water deficit or excess, respectively. While hypohydration and *dehydration* are often used interchangeably and have similar physical and performance consequences, dehydration is defined as the acute process of losing body water. For purposes of this review, the term *underhydration* will be used when either hypo- or dehydration has the same consequences. Finally, because there is no single value that represents euhydration, alterations in body water are most often expressed as a percent change in body mass.

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RESEARCH REVIEW

Underhydration

Evaporation of sweat is one of the primary mechanisms of heat loss during exercise. Dehydration typically occurs during high-intensity[2] or long-duration exercise,[1] and results from large sweat losses in the absence of adequate fluid consumption. Symptoms of underhydration include thirst, flushed skin, apathy and discomfort. With severe underhydration, individuals experience dizziness, headaches, nausea, chills and vomiting.[3] Due to the significant water loss in sweat, evaporative cooling leads to *hypovolemia*, or reduced blood volume, which is a major cause of excess physiological strain during an exercise bout. In addition to water loss, there is an obligatory loss of ions, primarily sodium and chloride, in sweat. During exercise, sweat sodium concentrations can range from 20 to 80 mmol/L, which amounts to roughly 1 to 5 grams of salt per liter of sweat.[4,5] Thus, the loss of water and electrolytes from sweat is significant, but is also highly variable due to differences in genetics, training status, acclimatization status, clothing and the environment. Sweating increases in hot and humid environments, but the portion of the sweat that evaporates is reduced when the relative humidity is high or when an individual is wearing sweat-restrictive fabrics.[6] Trained and/or heat acclimatized individuals have more dilute sweat and higher sweating rates compared to untrained or unacclimatized individuals.[7,8] Sports medicine professionals, as well as the individual exerciser him- or herself, should consider these factors when considering fluid-replacement strategies.

The blood-flow demands of exercising skeletal muscle during exercise are further increased by the need to pump large volumes of blood to the skin for convective and evaporative heat loss. The loss of blood volume resulting from dehydration places significant thermal strain on the body. Dehydration reduces the body's ability to direct fluids to sweat glands, which compromises the sweating response and leads to greater increases in core temperature. As a result, the whole-body sweating rate at a given core temperature is lower in an underhydrated state.[9] Additionally, hypovolemia impairs blood flow to the skin, the major avenue of convective heat loss from the body. The onset of both vasodilation in the skin and the sweating response are delayed to a higher core temperature threshold during exercise in an underhydrated state.[9] As such, underhydration significantly attenuates both evaporative and convective heat loss, which can contribute to serious heat illness. Further, one of the major hemodynamic adaptations of exercise training is the expansion of plasma volume for circulation to the skin during exercise.[10] Training in an underhydrated state limits plasma volume expansion, thus offsetting potential training-induced improvements in skin blood flow during exercise.[11]

In addition to thermoregulatory effects, underhydration increases the strain on the cardiovascular system. The reduction in circulating blood volume decreases the return of blood back to the heart, thus reducing stroke volume, or the amount of blood pumped from the heart per contraction.[12] Heart rate must then increase further in order to maintain cardiac output.[12] However, during severe underhydration, the demands on the heart may become large enough that cardiac output actually begins to decline. As a result, blood flow to not only the skin, but also to active skeletal muscle, can be compromised.[13] In other words, exercise combined with heat stress results in a competition between the central and peripheral (skin and muscle) circulation for a limited blood volume, which is heightened by the hypovolemia associated with underhydration. The magnitude of thermal and cardiovascular strain becomes progressively greater with increasing levels of underhydration.[14,15]

Although not universally accepted as fact, the physiological consequences of underhydration may significantly impact athletic performance, particularly with high-intensity exercise and/or long-duration exercise.[2,16–19] Proposed mechanisms of impaired performance include increased thermal and cardiovascular strain, changes in central nervous system function and metabolic alterations such as increased glycogen utilization.[9] Identification of the level of underhydration at which performance impairments

become apparent can be challenging due to difficulties in determining baseline hydration, the potential lack of precision necessary to detect changes in performance and the use of different tasks and methodologies to induce hypohydration (e.g., fluid restriction, exercise or diuretics). However, the general consensus among researchers is that, in moderate to hot environments, performance decrements begin to occur once underhydration exceeds 2 percent body mass.[20–22] At this level of underhydration, individuals display shorter exercise times to exhaustion and higher perceived exertion ratings.[2,19,23,24] Inconsistencies in the published impact of underhydration on exercise are likely due to variations in definitions, assessment of hydration status, environmental conditions and large individual variation in initial total body water and tolerance to dehydration. Given the severe levels of dehydration observed in some elite athletes during competition, the possibility remains that these individuals are able to better tolerate underhydration with minimal declines in performance.

In addition to compromised endurance performance, several studies have shown impairments in anaerobic performance.[25,26] The mechanisms underlying anaerobic performance decrements are not well understood but are likely due to reductions in muscle strength and power.[26] Underhydration also impairs cognitive function, including reaction time, task performance and mood state.[27,28] Reductions in cerebral blood flow and oxygenation[29] and/or diminished psychological drive are evident in underhydration and could therefore mediate these performance decrements.

Overhydration

Just as deficits in body water can be detrimental to health and performance, overhydration can also have severe consequences. As outlined in the *Statement of the 3rd International Exercise-Associated Hyponatremia Consensus Development Conference*, excess fluid intake may lead to a condition known as exercise-associated hyponatremia (EAH), which is defined as a plasma sodium concentration below 135 mmol/L.[30] Although the incidence is rare, EAH can occur when (1) water clearance by the kidneys is insufficient or (2) water ingestion exceeds sweat losses.[31–34] Less likely in acclimatized individuals, the loss of salt-concentrated sweat, as occurs in "salty sweaters," may also lead to extracellular sodium dilution and increase the risk of EAH.[32] EAH is observed most commonly in slower-paced participants who consume fluids frequently throughout the course of long-duration events (>4 hours).[35,36] With excess fluid intake, the solute concentration of the extracellular space decreases, causing water to move into the cells and, ultimately, intracellular swelling. This intracellular swelling can lead to severe edema, particularly in the cerebral and pulmonary circulations. Whether the cause of EAH relates solely to the volume of fluid ingested, or whether the type of fluid can play a role, has been debated by researchers. The bulk of the evidence indicates that the volume, but not the fluid composition, is associated with hyponatremia and is likely the primary factor leading to EAH.[35]

> *With excess fluid intake, the solute concentration of the extracellular space decreases, causing water to move into the cells and, ultimately, intracellular swelling.*

Symptoms of EAH begin to appear when plasma sodium concentration drops below 130 mmol/L and include dizziness, nausea and puffiness.[35,36] When plasma sodium concentrations fall below 125 mmol/L, symptoms become increasingly severe and include swelling in the hands and feet, confusion, vomiting, delirium and disorientation. If plasma sodium drops below 120 mmol/L, the chances of cerebral edema, brainstem herniation and death increase significantly. Many symptoms of EAH (vomiting, headache and fatigue) are non-specific and mimic those of underhydration. Therefore, plasma sodium or body-weight measurements may be required to determine if an individual is suffering from EAH or dehydration.[30] EAH is typically treated by ingestion of hypertonic fluids, or, in severe cases, sodium replacement through IV infusion to redistribute fluid from the intracellular to the extracellular space and reduce swelling.

HYDRATION STATUS ASSESSMENT AND FLUID REPLACEMENT

Assessing hydration status is important for developing individualized hydration strategies. However, many reliable scientific methods are time-consuming or expensive. Additionally, some assessment techniques largely reflect changes in hydration status rather than providing an absolute value for diagnosis. Despite these limitations, there are several methods that can be used, sometimes in combination, that provide athletes and health professionals with valuable information for decision-making strategies. Individual measures, such as changes in body weight, urine color and thirst, are non-invasive and inexpensive cues of altered hydration status. Measuring changes in body weight from a reliable baseline can provide a valid indication of fluid-replacement needs during exercise. Body-weight changes should be measured on three consecutive days to account for daily weight fluctuations. Using refractometry to measure urine-specific gravity, or the concentration of urine relative to that of distilled water, is also relatively inexpensive, simple and reliable. However, it is important to note that urine-assessment techniques estimate hydration status roughly three to four hours prior to measurement. Other techniques include urine or plasma solute concentration, but these are generally expensive and time consuming.

It is recommended that athletes aim to keep body-mass losses lower than 2 percent while avoiding weight gain.[22] Maintaining less than a 2 percent body-mass deficit during exercise maintains cardiac output and skin blood flow, and limits the rise in core temperature.[37] Optimal hydration strategies during exercise are frequently debated by scientific researchers and health professionals. The two most often cited fluid-replacement strategies are (1) to determine expected sweat losses given the exercise task and environmental conditions in order to plan a drinking schedule and (2) to drink according to thirst, or ad libitum. The sensation of thirst is typically delayed in performance athletes; therefore, it is often not recommended to use thirst as a rehydration strategy for elite athletes. Recreationally active individuals can typically rely on thirst, which is stimulated at approximately 2 percent hypohydration, as this level of underhydration will have minimal effect on recreational exercise performance and limit the risk of EAH. After exercise, it is recommended to consume 100 to 150 percent of measured fluid losses due to bolus-induced diuresis, the increased urine production resulting from consumption of large volumes.[38] Given the underhydration-induced impairments in exercise performance, the idea that pre-exercise hyperhydration could reduce the adverse consequences of dehydration has also emerged. However, evidence largely indicates that pre-exercise hyperhydration provides limited significant thermoregulatory or endurance-performance benefits during exercise relative to euhydration.[39]

It is impossible to recommend a universal replacement strategy for all physically active individuals given the high individual genetic variability in sweat rate, sweat sodium losses, heat acclimatization status, training status and daily fluid consumption. However, routine measurements of body weight pre- and post-exercise can be useful for estimating fluid replacement needs.[40] It is important to keep in mind that those exercising for long durations, in extremely hot weather or in sweat-restrictive fabrics may have considerably different fluid-replacement needs. Many football players with high body weights wearing full uniforms during two-a-day practices, for example, can sweat as much as 8 L/day.[41]

Recreationally active individuals typically do not require additives to water. However, added carbohydrates and/or electrolytes in fluids or diets can provide additional benefits during (1) exercise sessions lasting longer than one hour or (2) sessions that include high-intensity, stop-and-go intervals, especially in hot and humid environments.[42–45] Individuals with higher sweat rates or sweat sodium concentrations in particular may require additional electrolytes during exercise. Added sodium in replacement beverages stimulates thirst, enhances fluid retention and improves palatability, all of which result in higher fluid intakes.[46,47] The addition of low concentrations (e.g., <6 percent) of carbohydrates aids in maintaining blood glucose concentration and carbohydrate oxidation, without compromising gastric emptying.[48,49] While the optimal beverage composition cannot be established for all athletes in all exercise occasions, it is recommended that individuals strive to replace all fluid and electrolytes lost during exercise.

Special Populations

Special attention is warranted for several populations at increased risk for underhydration. The elderly, in particular, may require alternative fluid-intake recommendations. As people age, the sensation of thirst decreases in response to hypovolemia.[50] The elderly are able to eventually restore body-water homeostasis after fluid loss, but often at a slower pace. Several medications (e.g., diuretics, sedatives and laxatives) may also make this population more susceptible to underhydration. In addition to the physiological- and pharmacological-based risk for dehydration, the onset of dementia affects the ability of the elderly to adequately consume fluids when needed.

At the other end of the age spectrum, children may require special attention for increased thermal risk due to their susceptibility to voluntary dehydration, as they often do not drink adequate volumes of fluid when given free access to fluids during exercise.[51] Young children may have underdeveloped sweating mechanisms and thus lower sweat losses compared to adults.[50] As a result, body temperature increases to a greater extent in children at a given level of dehydration compared to healthy adults. Providing palatable drinks containing sodium and carbohydrates is a useful strategy for increasing voluntary fluid intake in children.[52,53]

Close monitoring should also be given to individuals with sickle cell trait. These individuals are heterozygous for a disorder of the blood in which red blood cells take on a "sickle" shape. Underhydration in this clinical population increases the risk of rhabdomyolysis, or the breakdown of muscle cells and the subsequent release of damaged cell components. Cystic fibrosis (CF) represents yet another clinical population that often has a greater difficulty maintaining hydration and therefore typically has a reduced tolerance to heat stress. During exercise in the heat, CF patients have elevated sweat sodium and chloride concentrations, resulting in a serum solute concentration that is much lower than healthy individuals.[54] Given that an increase in body fluid solute concentration is a trigger for thirst, CF patients often have a reduced stimulus to intake fluids.[55]

SUMMARY

Deviations from normal total body water can have significant physiological consequences that have the potential to contribute to performance decrements, as well as health consequences. During exercise, individuals should strive to maintain normal hydration (<2 percent body mass loss), while avoiding weight gain. The addition of electrolytes and carbohydrates to ingested fluids may provide additional benefits, particularly for "salty sweaters" or those competing in long-duration events. For competitive athletes focused on performance, reliable and inexpensive hydration-assessment methods, such as monitoring changes in body weight, can be used to implement optimal hydration strategies.

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