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National Athletic Trainers' Association Position Statement: Fluid Replacement for Athletes

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Objective: To present recommendations to optimize the fluid-replacement practices of athletes.

Background: Dehydration can compromise athletic performance and increase the risk of exertional heat injury. Athletes do not voluntarily drink sufficient water to prevent dehydration during physical activity. Drinking behavior can be modified by education, increasing accessibility, and optimizing palatability. However, excessive overdrinking should be avoided because it can also compromise physical performance and health. We provide practical recommendations regarding fluid replacement for athletes.

Recommendations: Educate athletes regarding the risks of dehydration and overhydration on health and physical performance. Work with individual athletes to develop fluid-replacement practices that optimize hydration status before, during, and after competition.

Key Words: athletic performance, dehydration, heat illness, hydration protocol, hydration status, oral rehydration solution, rehydration

During exercise, evaporation is usually the primary mechanism of heat dissipation. The evaporation of sweat from the skin's surface assists the body in regulating core temperature. If the body cannot adequately evaporate sweat from the skin's surface, core temperature rises rapidly. A side effect of sweating is the loss of valuable fluids from the finite reservoir within the body, the rate being related to exercise intensity, individual differences, environmental conditions, acclimatization state, clothing, and baseline hydration status. Athletes whose sweat loss exceeds fluid intake become dehydrated during activity. Therefore, a person with a high sweat rate who undertakes intense exercise in a hot, humid environment can rapidly become dehydrated. Dehydration of 1% to 2% of body weight begins to compromise physiologic function and negatively influence performance. Dehydration of greater than 3% of body weight further disturbs physiologic function and increases an athlete's risk of developing an exertional heat illness (ie, heat cramps, heat exhaustion, or heat stroke). This level of dehydration is common in sports; it can be elicited in just an hour of exercise or even more rapidly if the athlete enters the exercise session dehydrated. The onset of significant dehydration is preventable, or at least modifiable, when hydration protocols are followed to assure all athletes the most productive and the safest athletic experience.

The purpose of this position stand is to 1) provide useful recommendations to optimize fluid replacement for athletes, 2) emphasize the physiologic, medical, and performance considerations associated with dehydration, and 3) identify factors that influence optimal rehydration during and after athletic participation.

RECOMMENDATIONS

The National Athletic Trainers' Association (NATA) recommends the following practices regarding fluid replacement for athletic participation:

1. Establish a hydration protocol for athletes, including a rehydration strategy that considers the athlete's sweat rate, sport dynamics (eg, rest breaks, fluid access), environmental factors, acclimatization state, exercise duration, exercise intensity, and individual preferences (see Table 1 for examples of potential outcomes).

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2. A proper hydration protocol considers each sport's unique features. If rehydration opportunities are frequent (eg, baseball, football, track and field), the athlete can consume smaller volumes at a convenient pace based on sweat rate and environmental conditions. If rehydration must occur at specific times (eg, soccer, lacrosse, distance running), the athlete must consume fluids to maximize hydration within the sport's confines and rules.
3. Fluid-replacement beverages should be easily accessible in individual fluid containers and flavored to the athlete's preference. Individual containers permit easier monitoring of fluid intake. Clear water bottles marked in 100-mL (3.4-fl oz) increments provide visual reminders to athletes to drink beyond thirst satiation or the typical few gulps. Carrying water bottles or other hydration systems, when practical, during exercise encourages greater fluid volume ingestion.
4. Athletes should begin all exercise sessions well hydrated. Hydration status can be approximated by athletes and athletic trainers in several ways (Table 2). Assuming proper hydration, pre-exercise body weight should be relatively consistent across exercise sessions. Determine the percentage difference between the current body weight and the hydrated baseline body weight. Remember that body weight is dynamic. Frequent exercise sessions can induce nonfluid-related weight loss influenced by timing of meals and defecation, time of day, and calories expended in exercise. The simplest method is comparison of urine color (from a sample in a container) with a urine color chart (Figure). Measuring urine specific gravity (USG) with a refractometer (available for less than $150) is less subjective than comparing urine color and also simple to use. Urine volume is another indicator of hydration status but inconvenient to collect and measure. For color analysis or specific gravity, use midstream urine collection for consistency and accuracy. Remember that body weight changes during exercise give the best indication of hydration status. Because of urine and body weight dynamics, measure urine before exercise and check body weight (percentage of body weight change) before, during, and after exercise sessions to estimate fluid balance.
5. To ensure proper pre-exercise hydration, the athlete should consume approximately 500 to 600 mL (17 to 20 fl oz) of water or a sports drink 2 to 3 hours before exercise and 200 to 300 mL (7 to 10 fl oz) of water or a sports drink 10 to 20 minutes before exercise.
6. Fluid replacement should approximate sweat and urine losses and at least maintain hydration at less than 2% body weight reduction. This generally requires 200 to 300 mL (7 to 10 fl oz) every 10 to 20 minutes. Specific individual recommendations are calculated based on sweat rates, sport dynamics, and individual tolerance. Maintaining hydration status in athletes with high sweat rates, in sports with limited fluid access, and during high-intensity exercise can be difficult, and special efforts should be made to minimize dehydration. Dangerous hyperhydration is also a risk if athletes drink based on published recommendations and not according to individual needs.
7. Postexercise hydration should aim to correct any fluid loss accumulated during the practice or event. Ideally completed within 2 hours, rehydration should contain water to restore hydration status, carbohydrates to replenish glycogen stores, and electrolytes to speed rehydration. The primary goal is the immediate return of physiologic function (especially if an exercise bout will follow). When rehydration must be rapid, the athlete should compensate for obligatory urine losses incurred during the rehydration process and drink about 25% to 50% more than sweat losses to assure optimal hydration 4 to 6 hours after the event.
8. Fluid temperature influences the amount consumed. While individual differences exist, a cool beverage of 10° to 15°C (50° to 59°F) is recommended.
9. The Wet Bulb Globe Temperature (WBGT) should be ascertained in hot environments. Very high relative humidity limits evaporative cooling; the air is nearly saturated with water vapor, and evaporation is minimized. Thus, dehydration associated with high sweat losses can induce a rapid core temperature increase due to the inability to dissipate heat. Measuring core temperature rectally allows the athlete's thermal status to be accurately determined. See the NATA position statement on heat illnesses for expanded information on this topic.
10. In many situations, athletes benefit from including carbohydrates (CHOs) in their rehydration protocols. Consuming CHOs during the pre-exercise hydration session (2 to 3 hours pre-exercise), as in item 5, along with a normal daily diet increases glycogen stores. If exercise is intense, then consuming CHOs about 30 minutes pre-exercise may also be beneficial. Include CHOs in the rehydration beverage during exercise if the session lasts longer than 45 to 50 minutes or is intense. An ingestion rate of about 1 g/min (0.04 oz/min) maintains optimal carbohydrate metabolism: for example, 1 L of a 6% CHO drink per hour of exercise. CHO concentrations greater than 8% increase the rate of CHO delivery to the body but compromise the rate of fluid emptying from the stomach and absorbed from the intestine. Fruit juices, CHO gels, sodas, and some sports drinks have CHO concentrations greater than 8% and are not recommended *during* an exercise session as the sole beverage. Athletes should consume CHOs at least 30 minutes before the normal onset of fatigue and earlier if the environmental conditions are unusually extreme, although this may not apply for very intense short-term exercise, which may require earlier intake of CHOs. Most CHO forms (ie, glucose, sucrose, glucose polymers) are suitable, and the absorption rate is maximized when multiple forms are consumed simultaneously. Substances to be limited include fructose (which may cause gastrointestinal distress); those to be avoided include caffeine, alcohol (which may increase urine output and reduce fluid retention), and carbonated beverages (which may reduce voluntary fluid intake due to stomach fullness).
11. Those supervising athletes should be able to recognize the basic signs and symptoms of dehydration: thirst, irritability, and general discomfort, followed by headache, weakness, dizziness, cramps, chills, vomiting, nausea, head or neck heat sensations, and decreased performance. Early diagnosis of dehydration decreases the occurrence and severity of heat illness. A conscious, cognizant, dehydrated athlete without gastrointestinal distress can aggressively rehydrate orally, while one with mental compromise from dehydration or gastrointestinal distress should be transported to a medical facility for intravenous rehydration. For a complete description of heat illnesses and issues

related to hyperthermia, see the NATA position statement on heat illnesses.

12. Inclusion of sodium chloride in fluid-replacement beverages should be considered under the following conditions: inadequate access to meals or meals not eaten; physical activity exceeding 4 hours in duration; or during the initial days of hot weather. Under these conditions, adding modest amounts of salt (0.3 to 0.7 g/L) can offset salt loss in sweat and minimize medical events associated with electrolyte imbalances (eg, muscle cramps, hyponatremia). Adding a modest amount of salt (0.3 to 0.7 g/L) to all hydration beverages would be acceptable to stimulate thirst, increase voluntary fluid intake, and decrease the risk of hyponatremia and should cause no harm.
13. Calculate each athlete's sweat rate (sweating rate = pre-exercise body weight − postexercise body weight + fluid intake − urine volume/exercise time in hours) for a representative range of environmental conditions, practices, and competitions (Table 3). This time-consuming task can be made easier by weighing a large number of athletes before an intense 1-hour practice session and then reweighing them at the end of the 1-hour practice. Sweat rate can now be easily calculated (do not allow rehydration or urination during this 1 hour when sweat rate is being determined to make the task even easier). This calculation is the most fundamental consideration when establishing a rehydration protocol. Average sweat rates from the scientific literature or other athletes can vary from 0.5 L/h to more than 2.5 L/h (0.50 to 2.50 kg/h) and are not ideal to use.
14. Heat acclimatization induces physiologic changes that may alter individual fluid-replacement considerations. First, sweat rate generally increases after 10 to 14 days of heat exposure, requiring a greater fluid intake for a similar bout of exercise. An athlete's sweat rate should be reassessed after acclimatization. Second, moving from a cool environment to a warm environment increases the overall sweat rate for a bout of exercise. The athlete's hydration status must be closely monitored for the first week of exercise in a warm environment. Third, increased sodium intake may be warranted during the first 3 to 5 days of heat exposure, since the increased thermal strain and associated increased sweat rate increase the sodium lost in sweat. Adequate sodium intake optimizes fluid palatability and absorption during the first few days and may decrease exercise-associated muscle cramping. After 5 to 10 days, the sodium concentration of sweat decreases, and normal sodium intake suffices.
15. All sports requiring weight classes (ie, wrestling, judo, rowing) should mandate a check of hydration status at weigh-in to ensure that the athlete is not dehydrated. A USG less than or equal to 1.020 or urine color less than or equal to 4 should be the upper range of acceptable on weigh-in. Any procedures used to induce dramatic dehydration (eg, diuretics, rubber suits, exercising in a sauna) are strictly prohibited.
16. Hyperhydration by ingesting a pre-exercise glycerol and water beverage has equivocal support from well-controlled studies. At this time, evidence is insufficient to endorse the practice of hyperhydration via glycerol. Also, a risk of side effects such as headaches and gastrointestinal distress exists when glycerol is consumed.
17. Consider modifications when working with prepubescent and adolescent athletes who exercise intensely in the heat and may not fully comprehend the medical and performance consequences of dehydration. Focus special attention on schedules and event modification to minimize environmental stress and maximize time for fluid replacement. Make available the most palatable beverage possible. Educate parents and coaches about rehydration and the signs of dehydration. Monitor and remove a child from activity promptly if signs or symptoms of dehydration occur.
18. Large-scale event management (eg, tournaments, camps) requires advance planning. Ample fluid and cups should be conveniently available. With successive practice sessions during a day or over multiple days (as in most summer sport camps), check hydration status daily before allowing continued participation. Be aware of unhealthy behaviors, such as eating disorders and dehydration in weight-class sports. Use extra caution with novice and unconditioned athletes, and remember, many athletes are not supervised on a daily basis. If the WBGT dictates, modify events (change game times or cancel) or change game dynamics (insert nonroutine water breaks, shorten game times). Recruit help from fellow athletic trainers in local schools, student athletic trainers, and athletes from other sports to ensure that hydration is maintained at all venues (ie, along a road race course, on different fields during a tournament). Be sure all assistants can communicate with the supervising athletic trainer at a central location. For successive-day events, provide educational materials on rehydration principles to inform athletes and parents of this critical component of athletic performance.
19. Implementing a hydration protocol for athletes will only succeed if athletes, coaches, athletic trainers, and team physicians realize the importance of maintaining proper hydration status and the steps required to accomplish this goal. Here are the most critical components of hydration education:

- Educate athletes on the effects of dehydration on physical performance.
- Inform athletes on how to monitor hydration status.
- Convince athletes to participate in their own hydration protocols based on sweat rate, drinking preferences, and personal responses to different fluid quantities.
- Encourage coaches to mandate rehydration during practices and competitions, just as they require other drills and conditioning activities.
- Have a scale accessible to assist athletes in monitoring weight before, during, and after activity.
- Provide the optimal oral rehydration solution (water, CHOs, electrolytes) before, during, and after exercise.
- Implement the hydration protocol during all practices and games, and adapt it as needed.
- Finally, encourage event scheduling and rule modifications to minimize the risks associated with exercise in the heat.

BACKGROUND AND LITERATURE REVIEW

Dehydration and Exercise

Physiologic Implications. All physiologic systems in the human body are influenced by dehydration.[1,2] The degree of

Table 1. Sample Hydration Protocol Worksheet

Parameter to Consider	Example A: College Soccer, Katie (60 kg)*	Example B: High School Basketball, Mike (80 kg)*
1) WBGT	28.3°C (83°F)	21.1°C (70°F)
2) Sweat rate†	1.7 L/h	1.2 L/h
3) Acclimatized	Yes	No
4) Length of activity	2 45-minute halves	4 10-minute quarters
5) Intensity	Game situation (maximal)	Game situation (maximal)
6) Properly prehydrated	No (began −2% body weight)	Yes
7) Individual container	Yes	No (just cups)
8) Type of beverage	5% to 7% CHO‡ solution	5% to 7% CHO solution
9) Assess hydration status	At halftime (with scale)	No
10) Available breaks	Halftime	Quarters, half, timeouts
11) Amount given	Maximal comfortable predetermined amount given at half time (about 700 to 1000 L)	200 mL at quarter breaks 400 mL at half time 100 mL at 1 timeout/half
12) End hydration status	−4.8% body weight	Normal hydration
13) Hydrated body weight	60 kg	80 kg
Pre-exercise body weight	58.8 kg	80 kg
Halftime body weight	57.5	No measure
Postexercise body weight	57.1	80.1 kg

*Assumptions: Both are starters and play a full game.
†Sweat rate determined under similar parameters described in example (ie, acclimatization state, WBGT, intensity, etc) under normal game conditions (ie, no injury timeouts, overtime, etc).
Note: Keep results on record for future reference.
‡CHO, carbohydrate.

Table 2. Indexes of Hydration Status

Condition	% Body Weight Change*	Urine Color	USG†
Well hydrated	+1 to −1	1 or 2	<1.010
Minimal dehydration	−1 to −3	3 or 4	1.010–1.020
Significant dehydration	−3 to −5	5 or 6	1.021–1.030
Serious dehydration	>5	>6	>1.030

*% Body weight change = [(pre-exercise body weight − postexercise body weight)/pre-exercise body weight] × 100.
†USG, urine specific gravity.
See Figure for urine color chart and references. Please note that obtaining a urine sample may not be possible if the athlete is seriously dehydrated. These are physiologically independent entities, and the numbers provided are only general guidelines.

dehydration dictates the extent of systemic compromise. Isolating the physiologic changes that contribute to decrements in performance is difficult, as any change in 1 system (ie, cardiovascular) influences the performance of other systems (ie, thermoregulatory, muscular).[3]

The body attempts to balance endogenous heat production and exogenous heat accumulation by heat dissipation via conduction, convection, evaporation, and radiation.[4] The relative contribution of each method depends on the ambient temperature, relative humidity, and exercise intensity. As ambient temperature rises, conduction and convection decrease markedly, and radiation becomes nearly insignificant.[4,5] Heat loss from evaporation is the predominant heat-dissipating mechanism for the exercising athlete. In warm, humid conditions, evaporation may account for more than 80% of heat loss. In hot, dry conditions, evaporation may account for as much as 98% of cooling.[5] If sufficient fluids are not consumed to offset the rate of water loss via sweating, progressive dehydration will occur. The sweating response is critical to body cooling during exercise in the heat. Therefore, any factor that limits evaporation (ie, high humidity, dehydration) will have profound effects on physiologic function and athletic performance.

Water is the major component of the human body, accounting for approximately 73% of lean body mass.[6] Body water is distributed within and between cells and in the plasma. At rest, approximately 30% to 35% of total body mass is intracellular fluid, 20% to 25% is interstitial fluid, and 5% is plasma.[6,7] Water movement between compartments occurs due to hydrostatic pressure and osmotic-oncotic gradients.[6,7] Because sweat is hypotonic relative to body water, the elevation of extracellular tonicity results in water movement from intracellular to extracellular spaces.[6–9] As a consequence, all water compartments contribute to water deficit with dehydration.[6,10] Most of the resultant water deficits associated with dehydration, however, come from muscle and skin.[11] The resulting hypovolemic-hyperosmolality condition is thought to precipitate many of the physiologic consequences associated with dehydration.[12]

A major consequence of dehydration is an increase in core temperature during physical activity, with core temperature rising an additional 0.15 to 0.20°C for every 1% of body weight lost (due to sweating) during the activity.[13,14] The added thermal strain occurs due to both impaired skin blood flow and altered sweating responses,[15–21] which is best illustrated by the delayed onset of skin vasodilation and sweating when a dehydrated person begins to exercise.[6] These thermoregulatory changes may negate the physiologic advantages resulting from increased fitness[21,22] and heat acclimatization.[21,23] Additionally, heat tolerance is reduced and exercise time to exhaustion occurs at lower core temperatures with hypohydration.[24]

Accompanying the increase in thermal strain is greater cardiovascular strain, as characterized by decreased stroke volume, increased heart rate, increased systemic vascular resistance, and possibly lower cardiac output and mean arterial pressure.[25–31] Similar to body temperature changes, the magnitude of cardiovascular changes is proportional to the water

Table 3. Sample Sweat Rate Calculation*

A	B	C	D	E	F	G	H	I	J
		Body Weight							
Name	Date	Before Exercise	After Exercise	ΔBW (C-D)	Drink Volume	Urine Volume†	Sweat Loss (E+F−G)	Exercise Time	Sweat Rate (H/I)
		kg	kg	g	mL	mL	mL	min	mL/min
		(lb/2.2)	(lb/2.2)	(kg × 1000)	(oz × 30)	(oz × 30)	(oz × 30)	h	mL/h
		kg	kg	g	mL	mL	mL	min	mL/min
		(lb/2.2)	(lb/2.2)	(kg × 1000)	(oz × 30)	(oz × 30)	(oz × 30)	h	mL/h
		kg	kg	g	mL	mL	mL	min	mL/min
		(lb/2.2)	(lb/2.2)	(kg × 1000)	(oz × 30)	(oz × 30)	(oz × 30)	h	mL/h
		kg	kg	g	mL	mL	mL	min	mL/min
		(lb/2.2)	(lb/2.2)	(kg × 1000)	(oz × 30)	(oz × 30)	(oz × 30)	h	mL/h
Kelly K.‡	9/15	61.7 kg	60.3 kg	1400 g	420 mL	90 mL	1730 mL	90 min	19 mL/min
		(lb/2.2)	(lb/2.2)	(kg × 1000)	(oz × 30)	(oz × 30)	(oz × 30)	1.5 h	1153 mL/h

*Reprinted with permission from Murray R. Determining sweat rate. *Sports Sci Exch*. 1996;9(Suppl 63).
†Weight of urine should be subtracted *if urine was excreted prior to postexercise body weight.*
‡In the example, Kelly K. should drink about 1 L (32 oz) of fluid during each hour of activity to remain well hydrated.

deficit. For example, heart rate rises an additional 3 to 5 beats per minute for every 1% of body weight loss.[14] The stroke-volume reduction seen with dehydration appears to be due to reduced central venous pressure, resulting from reduced blood volume and the additional hyperthermia imposed by dehydration.[6,14,25,32–34]

Both hypovolemia[7,17,35,36] and hypertonicity[7,35,37–39] have been suggested as mechanisms for the altered thermoregulatory and cardiovascular responses during dehydration. Manipulation of each factor independently has resulted in decreased blood flow to the skin and sweating responses.[28,34] Some authors[17,35] have argued that hypovolemia is primarily responsible for the thermoregulatory changes by reducing cardiac preload and may alter the feedback to the hypothalamus via the atrial pressure receptors (baroreceptors). The hypothalamic thermoregulatory centers may induce a decrease in the blood volume perfusing the skin in order to reestablish a normal cardiac preload. Some studies[40,41] have provided support for this hypothesis, but it is clearly not the only variable influencing thermoregulation during hypohydration. Two hypotheses explain the role of hyperosmolality on the thermoregulatory system. Peripheral regulation may occur via the strong osmotic pressure influence of the interstitium, limiting the available fluid sources for the eccrine sweat glands.[42] However, while this peripheral influence is likely, it seems more feasible that central brain regulation plays the largest role.[7] The neurons surrounding the thermoregulatory control centers in the hypothalamus are sensitive to osmolality.[43,44] Changes in the plasma osmolality of the blood perfusing the hypothalamus affect body water regulation and the desire for fluid consumption.[28,32,45] It is likely that both hypovolemia and hypertonicity contribute to body fluid regulation.

Potential changes at the level of the muscle tissue include a possible increased rate of glycogen degradation,[18,46,47] elevated muscle temperature,[48] and increased lactate levels.[49] These changes may be caused by a decrease in blood perfusion of the muscle tissue during the recovery between contractions.[50]

The psychological changes associated with exercise in a dehydrated state should not be overlooked. Dehydration increases the rating of perceived exertion and impairs mental functioning.[14,51] Dehydration also decreases the motivation to exercise and decreases the time to exhaustion, even in instances when strength is not compromised.[52–54] These are important factors when considering the motivation required by high-level athletes to maintain maximal performance.

Performance Implications. Studies investigating the role of dehydration on muscle strength have generally shown decrements in performance at 5% or more dehydration.[15,33,55–58] The greater the degree of dehydration, the more negative the impact on physiologic systems and overall athletic performance.

Most studies[30,55,59–62] that address the influence of dehydration on muscle endurance show that dehydration of 3% to 4% elicits a performance decrement, but in 1 study,[33] this finding was not supported. Interestingly, hypohydrated wrestlers who were working at maximal or near-maximal muscle activity for more than 30 seconds had a decrease in performance.[63] The environmental conditions may also play an important role in muscle endurance.[33,48]

The research concerning maximal aerobic power and the physical work capacity for extended exercise is relatively consistent. Maximal aerobic power usually decreases with more than 3% hypohydration.[6] In the heat, aerobic power decrements are exaggerated.[33] Even at 1% to 2% hypohydration in a cool environment,[64,65] loss of aerobic power is demonstrated. Two important studies have noted a decrease in physical work capacity with less than 2% dehydration during intense exercise in the heat.[66,67] When the percentage of dehydration increased, physical work capacity decreased by as much as 35% to 48%,[68] and physical work capacity often decreased even when maximal aerobic power did not change.[46,64,65] Hypohydration of 2.5% of body weight results in significant performance decrements while exercising in the heat, regardless of fitness or heat acclimation status, although enhanced fitness and acclimation can lessen the effects of dehydration.[69] Partial rehydration will enhance performance during an ensuing exercise session in the heat, which is important when faced with the reality of sports situations.[49,70] The performance decrements noted with low to moderate levels of hypohydration may be due to an increased perception of fatigue.[50]

Rehydration and Exercise

Factors Influencing Rehydration. The degree of environmental stress is determined by temperature, humidity, wind speed, and radiant energy load, which induce physiologic changes that affect the rehydration process.[71–73] Fluid intake increases substantially when ambient temperature rises above 25°C; the rehydration stimulus can also be psychological.[74,75] An athlete exercising in the heat will voluntarily ingest more fluid if it is chilled.[76–78] Individual differences in learned behavior also play a role in the rehydration process.[71] An athlete who knows that rehydrating enhances subsequent performance is more apt to consume fluid before significant dehydration occurs, so appropriate education of athletes is essential.

The physical characteristics of the rehydration beverage can dramatically influence fluid replacement.[71,75,78] Salinity, color, sweetness, temperature, flavor, carbonation, and viscosity all affect how much an athlete drinks.[16,75,79–85] Since most fluid consumed by athletes is with meals, the presence of ample fluid during meals and adequate amount of time to eat are critical to rehydration.[79] When access to meals is limited, a CHO-electrolyte beverage will help maintain CHO and electrolyte intake along with hydration status.[86]

Other factors that contribute to fluid replacement include the individual's mood (calmness is associated with enhanced rehydration) and the degree of concentration required by the task.[71] For example, industrial laborers need frequent breaks to rehydrate because they must remain focused on a specific task. This need for concentration may explain why many elite mountain bikers use a convenient back-mounted hydration system instead of the typical rack-mounted water bottle. The back-mounted water reservoir may allow the cyclist to enhance rehydration while remaining focused on terrain, speed, gears, braking, and exertion.[87] Accessibility to a fluid and ease of drinking may explain why athletes consume more fluid while cycling compared with running in a simulated duathlon.[88]

Hydration before Exercise. An athlete should begin exercising well hydrated. Many athletes who perform repeated bouts of exercise on the same day or on consecutive days can become chronically dehydrated. When a hypohydrated athlete begins to exercise, physiologic mechanisms are compromised,[64,89,90] and the extent of the dysfunction is related to the degree of thermal stress experienced by the athlete.[91] Athletes may require substantial assistance in obtaining fluids as evidenced by the phenomena of voluntary (when individuals drink insufficient quantities to replace fluid losses) and involuntary dehydration.[92]

Athletes should ingest 500 mL of fluid 2 hours before the event (which allows ample time to urinate excess fluid) to ensure proper hydration and physiologic function at the onset of exercise.[79,93,94] Mandatory pre-exercise hydration is physiologically advantageous and more effective than hydration dictated by often insufficient personal preference.[95,96] Ingesting a nutritionally balanced diet and fluids during the 24 hours before an exercise session is also crucial. Increasing CHO intake before endurance activity may be beneficial for performance[97–99] and may even enhance performance for activities as short as 10 minutes,[100] but it may have a limited effect on resistance exercise.[101]

There has been recent interest in potential benefits of purposefully overhydrating before exercise to postpone the onset of water deficit.[33,102–108] While an enhanced hydration state is often reported with glycerol use, this does not always translate into a performance improvement.[109] A recent study[110] found increased exercise time and plasma volume during exercise to exhaustion in the heat when subjects were rehydrated with water and glycerol before exercise as compared with rehydration using an equal volume of water without glycerol. However, another study[111] found no benefits of glycerol ingestion when the ensuing exercise took place in a thermoneutral environment. Hyperhydrating before exercise, even without glycerol, may enhance thermoregulatory function[112] and limit the performance decrements normally noted with dehydration[109] while exercising in the heat (WBGT > 25°C). A key point is that the benefits associated with glycerol use seem to be negated when proper hydration status is maintained during exercise.[113] However, many athletes are unable to maintain hydration, so hyperhydration may be beneficial in extreme conditions when fluid intake cannot match sweat loss.

Rehydration during Exercise. Proper hydration during exercise will influence cardiovascular function, thermoregulatory function, muscle functioning, fluid volume status, and exercise performance. This topic has been extensively reviewed through the years, but some recent compilations are especially notable.* Proper hydration during exercise enhances heat dissipation (increased skin blood flow and sweating rate), limits plasma hypertonicity, and helps sustain cardiac output.[79,119,120] The enhanced evaporative cooling that can occur (due to increased skin blood flow and maintained perfusion of working muscles) is the result of sustained cardiac filling pressure.[26] Rehydration during exercise conserves the centrally circulating fluid volume and allows maximal physiologic responses to intense exercise in the heat.

Two important purposes of rehydration are to decrease the rate of hyperthermia and to maintain athletic performance.[35,121] A classic study[122] showed that changes in rectal temperature during exercise depended on the degree of fluid intake. When water intake equaled sweat loss, rise in core temperature was slowest when compared with ad libidum water and no-water groups. This benefit of rehydration on thermoregulatory function is likely due to increased blood volume,[123] reduced hyperosmolality,[124] reduced cellular dehydration,[125] and improved maintenance of extravascular fluid volume.[126] Some studies[127,128] have not shown a physiologic or performance benefit when rehydration occurred during a 1-hour intense exercise session in mild environmental conditions. The likely reason for a lack of benefit in these studies was the fact that the exercise session did not elicit enough sweat loss to cross the physiologic threshold of percentage of body weight loss (eg, −2%) that would negatively influence performance and physiologic function. For example, in 1 of the studies,[127] the subjects had only lost 1.5% of body weight at the completion of the exercise session.

Athletes generally do not rehydrate to pre-exercise levels during exercise due to personal choice,[75,129] fluid availability,[129] the circumstances of competition,[79] or a combination of these factors. Athletes should aim to drink quantities equal to sweat and urine losses, and while they rarely meet this goal, athletes can readily handle these large volumes (>1 L/h).[130–132] Additionally, athletes may not need to exactly match fluid intake with sweat loss to maintain water balance given the small contribution of water from metabolic processes.[133]

Appealing to individual taste preferences may encourage athletes to drink more fluids. In addition, including CHOs and electrolytes (especially sodium and potassium) in the rehydration drink can maintain blood glucose, CHO oxidation, and electrolyte balance and can maintain performance

*References 6, 27, 71, 76, 79, 107, 108, 114–118.

if the exercise session exceeds about 50 minutes in duration.[79,118,130,134–152] Also, recent evidence[153,154] indicates that athletes performing extremely intense intermittent activity with total exercise times of less than 50 minutes may benefit from ingestion of CHOs in the rehydration beverage.

Rates of gastric emptying and intestinal absorption should also be considered.[118,155–160] Fluid volume,[161] fluid calorie content, fluid osmolality, exercise intensity,[162] environmental stress,[162] and fluid temperature[107] are some of the most important factors[28] in determining the rates of gastric emptying and small intestine absorption (the small intestine is the primary site of fluid absorption). The single most important variable may be the volume of fluid in the stomach.[163,164] Maintaining 400 to 600 mL of fluid in the stomach (or the maximum tolerated) will optimize gastric emptying.[79] If CHOs are included in the fluid, the concentration should be 4% to 8%. Concentrations higher than 8% slow the rate of fluid absorption.[165,166] Intense exercise (>80% of VO_2 max) may also decrease the rate of gastric emptying.[155] Frequent ingestion (every 15 to 20 minutes) of a moderate fluid volume (200 mL) may be ideal, but it is not feasible in sports with extended periods between breaks. The rates of gastric emptying and intestinal absorption likely influence the speed of movement of the ingested fluids into the plasma volume.[167] Since the gastric emptying and intestinal absorption rates are not compromised with the addition of a 6% carbohydrate solution as compared with water, fluid replacement and energy replenishment are equally achievable.[116,167–171] The rate of gastric emptying is slowed[163,172] by significant dehydration (>4%), which complicates rehydration and may increase gastrointestinal discomfort.[163,172] Regardless, rehydration will still benefit the athlete's hydration status.[172]

Rehydration during exercise is also influenced by the state of acclimatization of the athlete. Heat acclimatization is achieved after 5 to 10 days of training in a hot environment and will increase sweat rate, decrease electrolyte losses in the sweat, and allow athletes to better tolerate exercise in the heat.[173,174] Heat acclimatization modestly increases rehydration needs due to greater sweating. Fortunately, an athlete who is heat acclimatized has fewer deficits associated with dehydration[175] and tends to be a "better" voluntary drinker (ingests fluid earlier and more often).[1,34]

An athlete who exercises for more than 4 hours and hydrates excessively (well beyond sweat loss) only with water or low-solute beverages may be susceptible to a relatively rare condition known as symptomatic hyponatremia (also known as water intoxication).[76,108,176,177] Ultimately, the body cannot excrete the consumed fluid rapidly enough to prevent intracellular swelling, which is sufficient to produce neuropsychological manifestations. Patients present with serum sodium levels below 130 to 135 mmol/L, and the sequelae of hyponatremia can result in death if not treated.[177] The condition can most likely be avoided if sodium is consumed with the rehydration beverage and if fluid intake does not exceed sweat losses.[76,79,108]

Every athlete will benefit from attempting to match intake with sweating rate and urine losses. Individual differences exist for gastric emptying and availability of fluids during particular sports. Rehydration procedures should be tested in practice and individually modified to maximize performance in competition.[97,108,116,156]

Rehydration after Exercise. Replenishing fluid volume[178,179] and glycogen stores is critical in the recovery of many body processes, including the cardiovascular, thermoregulatory, and metabolic activities.[71,97,178,180,181]

Based on volume and osmolality, the best fluid to drink after exercise to replace the fluids that are lost via sweating may not be water.[71,182–184] Consuming water alone decreases osmolality, which limits the drive to drink and slightly increases urine output. Including sodium in the rehydration beverage (or diet) allows fluid volume to be better conserved and increases the drive to drink.[71,125,178,184–186] Including CHOs in the rehydration solution may improve the rate of intestinal absorption of sodium and water[118,178] and replenishes glycogen stores.[118,187,188] Replenishing glycogen stores can enhance performance in subsequent exercise sessions[189,190] and may enhance immune function.[191] While a normal diet commonly restores proper electrolyte concentrations,[192] many athletes are forced to rehydrate between exercise sessions in the absence of meals.[178] In addition, some athletes' meals are eaten as long as 6 hours after an exercise session, which may compromise electrolyte availability during rehydration after intense exercise in hot conditions.

While replenishing fluid to equal sweating losses is often recommended, this formula does not replace urine losses. Ingestion equal to 150% of weight loss resulted in optimal rehydration 6 hours after exercise.[185]

Assessment of Hydration Status. Body weight changes, urine color, subjective feelings, and thirst, among other indicators, offer cues to the need for rehydration.[193] When preparing for an event, an athlete should know the sweat rate, assess current hydration status, and develop a rehydration plan. Determinations of sweat rate can be made.[18,134] Hydration status can be assessed by measuring body weight before and after exercise sessions; monitoring urine color, USG, or urine volume; or using a combination of these factors.[194,195] A urine color chart is included in this manuscript (Figure).[196] The general indexes of hydration status are provided in Table 3. A refractometer offers a precise reading of USG and can be used as a general indicator of hydration state. A reading of less than 1.010 reflects a well-hydrated condition, while a reading of more than 1.020 reflects dehydration.[134] Urine osmolality and urine conductivity may also be useful tools in assessing hydration status.[197]

The hydration plan should take into account the length of the event, the individual's sweat rate, exercise intensity, the temperature and humidity, and the availability of fluids (is fluid constantly available, as in cycling, or is it consumed in a large bolus during a break?). Habits of the coach or athlete, or both, may need to be altered in order to maximize the hydration process. Any plan for rehydrating during competition should be instituted and perfected during practice sessions; it should also be individually implemented, given the large variation among people in what constitutes a "comfortable" amount of rehydration.[198,199] A sample hydration protocol for preparing an elite athlete for an event has been documented.[200]

Composition of Rehydration Fluid. During exercise, the body uses 30 to 60 g of CHOs per hour that need to be replaced to maintain CHO oxidation and delay the onset of glycogen depletion fatigue.[201–205] Thus, including 60 g of CHOs in 1 L of fluid will not hinder fluid absorption and provides an adequate supply of CHOs during or while recovering from an exercise bout. The CHO concentration in the ideal fluid-replacement solution should be in the range of to 6% to 8% (g/100 mL).[117] The simple sugars, glucose or sucrose in simple or polymer form, are the best additives to the replacement fluid. Absorption is maximized if multiple forms of CHO are ingested simultaneously (ie, fluid is absorbed more quickly from the intestine if both glucose and fructose are present than if only glucose is present).[107,116,206] The amount of fructose in the beverage should be limited to about 2% to 3% (2 to 3 g/100 mL of the beverage), since larger quantities may play a role in decreasing rates of absorption and oxidation and causing gastrointestinal distress.[107,207] Ultimately, CHO composition depends on the relative need to replace fluids or CHOs. During events, when a high rate of fluid intake is necessary to sustain hydration, the CHO composition should be kept low (eg, <7%) to optimize gastric emptying and fluid absorption. During conditions when high rates of fluid replacement are not as necessary (ie, during recovery from an exercise session, mild environmental conditions, etc), the carbohydrate concentration can be increased to optimize CHO delivery with minimal risk of jeopardizing the hydration status.

Small quantities of sodium may enhance palatability and retention, stimulate thirst, and prevent hyponatremia in a susceptible individual.* Sodium concentration should be approximately 0.3 to 0.7 g/L.[72,80,108,157,208] Other valuable sources of practical information concerning the composition of rehydration beverages and rehydration in general are available.†

Recognizing Dehydration in Athletes. The early signs and symptoms of dehydration include thirst and general discomfort and complaints. These are followed by flushed skin, weariness, cramps, and apathy. At greater water deficits, dizziness, headache, vomiting, nausea, heat sensations on the head or neck, chills, decreased performance, and dyspnea may be present.[5,79,211,212] The degree of dehydration, the mental status, and the general medical condition of the athlete will dictate the mode, amount, type, and rate of rehydration. Identifying the early signs of dehydration can limit the onset or degree of an exertional heat illnesses.[5,79,211,212] A comprehensive review of the prevention, identification, and treatment of the exertional heat illness can be found in the position stands by the NATA and the American College of Sports Medicine.[211,213]

Event Management. Some events are conducted under environmental conditions that are extreme and force the athlete to reduce intensity or risk a heat illness. These hazardous heat stresses can be avoided by scheduling athletic events during the coolest part of the day or a cooler time of the year.[211,214] The reality of sport administration is that many events take place regardless of the environmental conditions. Individuals supervising an event in a hot humid environment must ensure that athletes have ample access to fluids, are encouraged to match fluid intakes with sweat losses, and are monitored for dehydration and exertional heat illness. Whenever possible, minimize the exercise intensity of athletes in the extreme heat, since this is the largest contributor to dehydration and heat illness. When successive exercise sessions occur on the same day or on ensuing days, hydration status, sleep, meals, and other factors that maximize performance and enhance safety should be maintained. Given the variety of events an athletic trainer may supervise, we cannot formulate an event management recommendation for all sports. However, the general concepts are interchangeable across sports and venues. For example, game modifications such as decreasing the length of play or inserting nontraditional water breaks (especially in youth sports and practice situations) will reduce the rate of heat illness. Closely monitoring environmental conditions via the WBGT or the heat index will allow an informed approach to hydration and sweat modification. Athletes who are educated on how to prevent and recognize dehydration are empowered to participate actively in implementing their own hydration protocols, thereby enhancing both performance and safety. The person responsible for the medical supervision of an event should have a detailed plan to address facilities, equipment, supplies, staffing, communication systems, education, and implementation of event policy.[213,215–220]

*References 38, 80, 108, 131, 157, 185, 208.

†References 18, 76, 107, 118, 156, 159, 160, 168, 178, 205, 209, 210.

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