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Exercise in the Heat. I. Fundamentals of Thermal Physiology, Performance Implications, and Dehydration

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Objective: To present the critical issue of exercise in the heat in a format that provides physiologic foundations (Part I) and then applies the established literature to substantial, usable guidelines that athletic trainers can implement on a daily basis when working with athletes who exercise in the heat (Part II).

Data Sources: The databases MEDLINE and SPORT Discus were searched from 1980 to 1999, with the terms "hydration," "heat," "dehydration," "cardiovascular," "thermoregulatory," "physiology," and "exercise," among others. The remaining citations are knowledge base.

Data Synthesis: Part I introduces athletic trainers to some of the basic physiologic and performance responses to exercise in the heat.

Conclusions/Recommendations: The medical supervision of athletes who exercise in hot environments requires an in-depth understanding of basic physiologic responses and performance considerations. Part I of this article aims to lay the scientific foundation for efficient implementation of the guidelines for monitoring athletic performance in the heat provided in Part II.

Key Words: cardiovascular, heat stress, thermoregulatory

Exercise in the heat, as compared with a neutral environment, causes many physiologic changes in the dynamics of the human body, including alterations in the circulatory, thermoregulatory, and endocrine systems. Many interrelated physiologic processes work together to sustain central blood pressure, cool the body, maintain muscular function, and regulate fluid volume. Attempting to sustain exercise (especially if it is intense) in a hot environment can overload the body's ability to properly respond to the imposed stress, resulting in hyperthermia, dehydration, deteriorated physical and mental performance, and a potentially serious (even fatal) exertional heat illness.

CIRCULATORY RESPONSES

The circulatory responses to exercise involve 3 important components: skin and muscle vasodilation, nonactive tissue vasoconstriction, and maintenance of blood pressure[1] (Figure 1). Skin vasodilation occurs in proportion to the degree of heat load (both exogenous and endogenous),[2,3] and the amount of blood supplied to the muscles is dictated by the intensity of the exercise. Constriction of the splanchnic vascular system (supplying the kidneys, stomach, and other abdominal organs), in addition to an overall increase in the cardiac output, allows increased blood flow to the active tissues.[4–7]

However, when intense exercise occurs in the heat, the cardiovascular (CV) system simply cannot meet the maximal demands of the skin (to decrease thermal load) and the muscle simultaneously.[1,8] Ultimately, maintenance of blood pressure will take precedence over skin blood flow (ie, body cooling) and muscle blood flow (ie, performance capacity), but simultaneously increases the rate of hyperthermia and metabolic inefficiency.[1,10,11] This prioritizing can result in hyperthermia, especially in populations committed to maximal physical exertion (soldiers, athletes, etc). The metabolic changes are reflected in an increased lactate level, which results from decreased hepatic blood flow; muscle vasoconstriction (which influences waste removal, oxygen delivery, buffering capacity, etc); and an increase in muscle temperature.[11] Variations in the onset of these changes can alter the rate at which the athlete experiences fatigue.

Decreased venous return reduces the stimulation of pressure-sensitive baroreceptors in the right heart and the pulmonary circulation.[12] Messages are then sent to the medullary CV control centers, which can cause muscle or skin vasoconstriction, or both, thereby preserving blood pressure and CV function.[1,13]

Minimal decreases in cardiac output have been found in subjects exercising at submaximal intensities in the heat.[1,13,14] An increase in heart rate compensates for the decreases in stroke volume, and CV capacity is not hindered, unless

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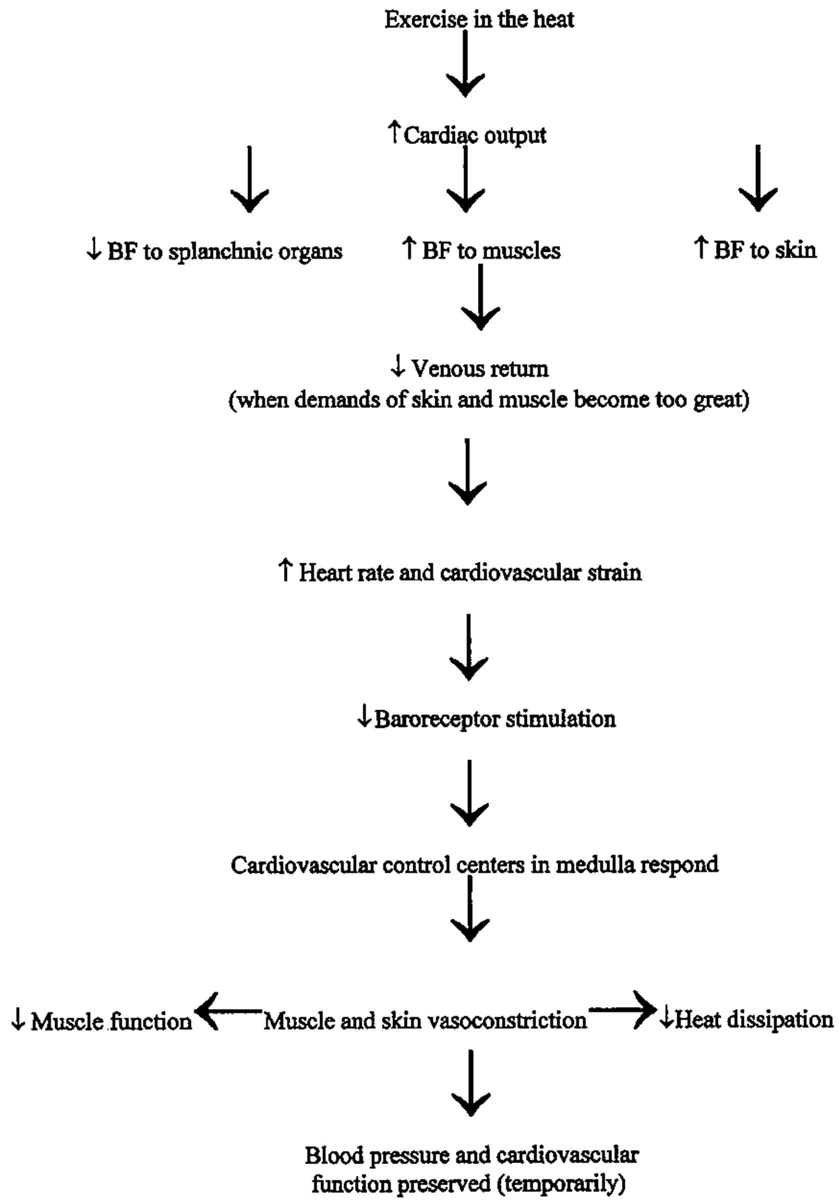


Figure 1. Potential circulatory responses to exercise in the heat.[1–7,9,12,13] BF, blood flow.

extreme sweat rates or lengthy exercise sessions, for example, induce significant dehydration. But when maximal exercise is attempted in the heat, the heart rate's finite limit does not compensate for the larger decreases in stroke volume, due mostly to shunting of blood to the skin and active muscle and to the progressive dehydration.[1,7,13] Rowell[1] concluded that the end result is decreases in both Vo_2 and performance capacity.

THERMOREGULATORY RESPONSES

The circulatory and thermoregulatory responses are interrelated, with each influencing and being influenced by the other. The degree of stress imposed by exercise in a hot environment is determined by the thermal load. Heat gain must be equaled (or closely matched) by heat dissipation if the athlete wishes to continue exercising at a consistent performance level. Exogenous factors that contribute to heat acquisition include ambient temperature, wind speed, humidity, solar radiation (direct and indirect), ground thermal radiation, and clothing.[15] Ambient temperature and humidity are the major contributors; lack of wind in the presence of high humidity and high ambient temperature can impose severe heat stress because copious sweating is not cooling the body (sweat is not evaporating from the skin), which exacerbates the hyperthermia.[16] The predominant endogenous factor is the metabolic heat from contracting muscle (capable of increasing 15 to 20 times during exercise in healthy young adults), which is profoundly influenced by the intensity of the exercise.

The body attempts to balance internal temperature by dissipating heat via conduction, convection, evaporation, and radiation.[15,17] Heat dissipation while exercising depends on the ambient temperature. As ambient temperature rises, radiation and convection decrease markedly; heat loss by conduction is insignificant at almost all times.[15,18] Convection is compromised by a temperature gradient change between the peripheral blood vessels and the skin. Heat loss from evaporation thus becomes the predominant heat-dissipating mechanism for a subject exercising in a hot environment. In a hot, dry environment, evaporation can account for as much as 98% of cooling, whereas in a hot, wet environment, evaporation is still nearly 80% (the rest is largely convection and radiation).[18] The sweating response is critical to whole-body cooling during exercise in the heat; any disturbance in this mechanism (eg, high humidity, dehydration) can have profound effects on physiologic function and athletic performance. The reader is referred to Stitt[17] and Werner[15] for in-depth analyses of the heat balance equations, but, in short, heat acquisition (from exogenous and endogenous sources) must be matched by the combined 4 heat-dissipation pathways to maintain thermal balance: heat storage = heat production minus heat dissipation or plus heat acquisition. This may be expressed as $\pm S = (M - W) \pm C \pm K \pm R - E$, where S is body heat storage, M is metabolic heat production, W is external work, and C, K, R, and E represent convection, conduction, radiation, and evaporation, respectively.[17,19]

When heat dissipation fails to equal heat acquisition, hyperthermia increases skin blood flow, and, depending on the environmental conditions, heat release via convection, radiation, and evaporation.[19] Skin blood flow changes are regulated not just by body temperature, but also by blood pressure, brain blood flow temperature, skin-core temperature gradients, muscle metabolism, etc. As discussed previously, maintenance of blood pressure takes precedence over heat dissipation.

Kenney and Johnson[2] and Sawka and Wenger[7] reported on the integration of these regulatory processes, in addition to the important role of the efferent mechanisms controlling skin blood flow (ie, passive withdrawal of constrictor tone, reflex vasoconstriction, and active vasodilation). The inherent changes in sweating rate and body cooling associated with skin blood flow changes assist in controlling hyperthermia (the primary controller of sweating rate). Nadel[10] and Sato[20] offer the best explanation of eccrine sweat secretion. Warmer air temperatures are associated with increased sweating.[21] Since only evaporation is an efficient mode of heat dissipation in this situation, physiologic strain is exacerbated by the decreased extracellular fluid volume associated with copious sweating. In the short term, the body is being cooled, but increased dehydration alters CV functional capacity, which can lead to decreased skin blood flow and sweating rate as the body attempts to maintain the central circulation and blood pressure.

In a cooler environment (with a larger temperature gradient between skin blood flow and skin temperature), the body can avoid hyperthermia while minimizing fluid losses via convection and radiation. In a warm, humid environment, all the critical variables work against the exercising individual: convection and radiation are nearly nonexistent,[10] and evaporation is thwarted by a small water vapor pressure gradient.[7] With no heat dissipation, dehydration occurs, and the core temperature rises at a potentially dangerous rate.[22] The decreased physiologic function associated with hyperthermia is well documented,[23] and the rate of onset of hyperthermia can be influenced by fitness,[15] acclimation,[24] type of exercise,[25] age,[26] and numerous other factors.

PERFORMANCE IMPLICATIONS

The additive effect of the stresses imposed by exercise in the heat will ultimately compromise athletic performance. In addition, exercise in the heat often causes dehydration (since rates of sweating are rarely matched by rates of rehydration), which further exacerbates the situation.[27,28] It is extremely difficult to separate the effects of heat and dehydration, since they often occur in parallel during prolonged exercise, but some researchers have attempted to match sweat loss with fluid intake during exercise. Rowell et al[29] found large reductions in stroke volume despite maintained central blood volume. Enhanced physical fitness and heat acclimatization increase heat tolerance independently but similarly and optimize heat tolerance when combined.[30]

Sawka et al[31] reported a 7% decrease in maximal aerobic power in the heat as compared with euhydrated subjects in cool temperatures. Febbraio et al[32] and Galloway and Maughan[33] showed the effects of increasing temperature on the capacity to exercise to exhaustion. Febbraio et al[32] found that subjects could exercise for 95 minutes at 37°F (2.78°C), 75 minutes at 68°F (20°C), and only 33 minutes at 104°F (40°C), indicating an inverse linear relationship between ambient temperature and performance capacity. The 20-minute difference in the 2 cooler environments is an important reminder that extreme heat is not necessary for potential performance decrements. Galloway and Maughan[33] concurred, reporting that subjects exercised for 92 minutes at 52°F (11.11°C), 83 minutes at 70°F (21.11°C), and 51 minutes at 86°F (30°C). These studies supported the concept of Sawka et al[34] that heat stress and dehydration can act independently to compromise physiologic function when the extreme demands for skin blood flow cause decreased cardiac output, which in turn limits the supply of oxygenated blood to the entire body. When heat stress and dehydration occur together (as they often do), this physiologic condition is exacerbated. In addition to performance decrements, the potential for an exertional heat illness increases as the environmental conditions worsen. The American College of Sports Medicine[22] provided a concise analysis of how to determine when the environmental conditions preclude physical activity and what procedures should be followed to ensure safe participation in a hot environment (to be addressed in part II).

DEHYDRATION AND EXERCISE

Each physiologic system in the human body is influenced by severe dehydration. The degree of dehydration will dictate how much these systems are compromised. Figure 2 describes similar terms used to describe water losses and gains. The work of Sawka and colleagues[34–36] is definitive in the domain of hypohydration and its impact on performance and physiologic function. Their laboratory, located within the US Army Research Institute of Environmental Medicine in Natick, MA, is one of the preeminent locations in the world for investigating the human body's capacity to perform exercise in a variety of environments.

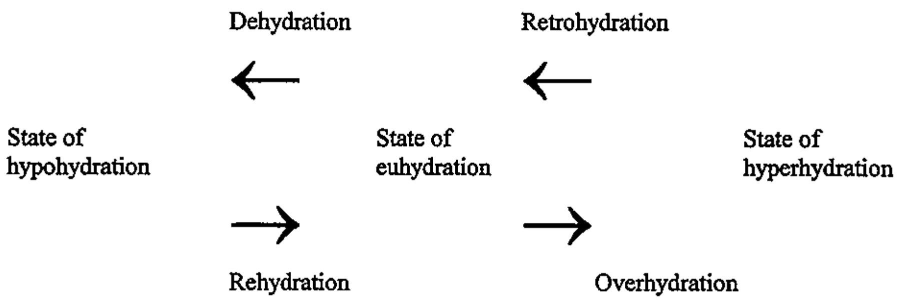
Physiologic Changes

Isolating which particular physiologic changes contribute to decrements in performance is difficult, if not impossible. The interrelation of the human body's systems means that any change in one system influences others. However, recent research has begun to uncover what occurs when an athlete becomes dehydrated during exercise. Dehydration induces changes in the thermoregulatory, cardiovascular, plasma, gastrointestinal, endocrine, muscular, and metabolic responses to exercise.[37,38]

As discussed earlier, the CV system of a hypohydrated, exercising subject attempts to maintain cardiac filling pressure while sacrificing peripheral circulation,[1] but hypohydration in combination with heat dissipation at the skin and increased muscle blood flow limits CV capacity, regardless of how much blood is shunted from the periphery to the central circulation.[1,39,40] Increased viscosity and decreased volume of blood returning to the heart decrease filling pressure, and in turn, stroke volume.[14,41,42] To counteract these changes, heart rate rises to its limit, but then cardiac output begins to fall, signaling CV system responses, which limit skin and muscle function.[34,43] The end result is a diminished ability to dissipate heat, and thus, heat production exceeds heat loss. Excess heat in combination with decreased muscle perfusion limits performance and causes thermal strain.[1,35]

Exercising while dehydrated has some effects on the thermoregulatory system[34,44–49] (Table) and may negate the physiologic advantages resulting from increased fitness[24,50] and heat acclimatization.[24,51] Sawka et al[36] noted decreased heat tolerance (by more than half) in subjects dehydrated by 8% of body weight and found that soldiers became exhausted at lower core temperatures when hypohydrated. While 8% is an extreme amount of dehydration rarely encountered in sports, the study emphasizes the decreased heat tolerance associated with dehydration.

The human body is composed of about 65% water, separated into extracellular (plasma and interstitial) and intracellular fluid.[52] At rest with normal hydration, about 45% of body weight is intracellular fluid, 15% is interstitial fluid, and 5% is plasma.[52] Exercise, heat stress, and dehydration all influence the redistribution of body fluids with changes in hydrostatic and osmotic pressure.[52,53] For instance, because sweat is hypotonic to plasma, the dehydrated athlete experiences plasma hyperosmolality, which affects the distribution of fluids.[35] Mild dehydration causes mostly extracellular space fluid losses, but, as dehydration worsens, proportionally more fluid is lost from the intracellular space.[54,55] Nose et al[56] reported that the loss of intracellular and extracellular fluid is largely from muscle and skin. This selective regulation of body fluids preserves the internal environment of the most essential organs: for instance, the brain and liver.[35] Changes in the distribution of body fluids are associated with the ability to mobilize fluids from the intracellular space, which is intimately linked with sweat sodium concentrations.[57] Thus, the de-



Euhydration: steady-state condition of normal body water
Hypohydration: steady-state condition of decreased body water
Hyperhydration: steady-state condition of increased body water
Dehydration: water loss leading to hypohydration
Retrohydration: water loss from a state of hyperhydration leading to euhydration
Rehydration: adding water from a state of hypohydration to move toward euhydration
Overhydration: fluid intake that exceeds euhydration, leading to hyperhydration

Figure 2. Clarification of terms to describe body water losses and gains during exercise. Adapted with permission from Epstein and Armstrong.[86] The term "retrohydration" is used courtesy of P. M. Meenen, July 1999.

Thermoregulatory Effects of Exercise in the Dehydrated State[34,44–49]

↓ Sweating rate at given core temperature	↓ Maximal sweating rate
↓ Skin blood flow at given core temperature	↓ Maximal skin blood flow
↑ Core temperature at which sweating begins	↑ Core temperature at given exercise intensity
↑ Core temperature at which skin blood flow increases	

creased sweat sodium concentrations noted after heat acclimatization may help to conserve plasma volume during dehydration. Ultimately, the fluid redistribution that results from dehydration causes a hypovolemic hyperosmolality,[58] which stimulates the volume and fluid receptors in the body to conserve fluid and stimulate rehydration.[52]

Plasma changes have been cited as the major cause for the thermoregulatory changes during hypohydration. Hyperosmolality[59–61] and hypovolemia[46,62] are likely responsible for the changes noted in skin blood flow and sweating rate and the resultant rises in core temperature.[9,35,40] Fortney et al[46] have argued that hypovolemia is primarily responsible for the thermoregulatory changes by reducing central blood volume, which may alter the feedback to the hypothalamus via the atrial baroreceptors. The hypothalamic thermoregulatory centers may then decrease the blood volume perfusing the skin in an attempt to reestablish a normal central blood volume. Some studies have provided support for this hypothesis,[63,64] but it is clearly not the only variable influencing thermoregulation during hypohydration.

Two primary hypotheses have been proposed to explain the role of hyperosmolality on the thermoregulatory system. The first is a strong osmotic pressure influence of the interstitium, which may limit the available fluid sources for the eccrine sweat glands.[65] While this pressure is likely to exert some influence, it seems more feasible that brain regulation, the second hypothesis, has the largest contribution. The neurons surrounding the thermoregulatory control centers in the hypothalamus are quite sensitive to osmolality.[66,67] Thus, changes in the plasma perfusing the hypothalamus can affect body water regulation and the desire for fluid consumption.[40,43] The human body is well equipped to identify small changes in the internal environment and to respond with appropriate modifications. While research may someday identify a proportional contribution to the age-old question of hyperosmolality versus hypovolemia, it is most likely that both will always be considered major contributors to the mechanisms that perturbate body fluid regulation.

Potential muscle changes associated with dehydration include an increased rate of glycogen synthesis,[11,48] compromised buffering capacity of the muscle tissue,[38] elevated muscle temperature,[68] and decreased substrate exchange.[11,38] These factors are caused by a decrease in blood flow perfusing the muscle tissue, which may alter the dynamics during the recovery between contractions.[69] These muscle changes seem to occur when exercise exceeds 30 seconds, which is reasonable from a metabolic perspective.[70] These arguments would support the notion that strength during short-term activity is not affected until dehydration becomes more pronounced, largely due to the fact that the muscle energetics of very short-term activity are, for the most part, self-contained, and thus, not as influenced by changes in blood flow.[38]

Performance Implications

Research investigating the role of dehydration on muscle strength has yielded conflicting results. Some studies have shown performance decrements,[71–74] while others have shown no changes.[14,75] However, when strength decrements were found, they usually occurred when dehydration exceeded a 5% reduction in body weight.[34,49] In addition, dehydration resulting from fluid restriction seems to be more harmful than that caused by exercise and heat stress; thus, the fluid restriction may be partially inducing a caloric deficit.[34]

The research on muscle endurance is a bit more conclusive. A sampling of the numerous studies[14,72,76–79] that have addressed the influence of dehydration on muscle endurance reveals, generally speaking, that 3% to 4% dehydration elicits a performance decrement, but some studies investigating greater levels of dehydration did not find any differences in performance.[34] Horswill[38] concluded that, in wrestlers (who are frequently hypohydrated), combined hypohydration and maximal or near-maximal muscle activity exceeding 30 seconds may combine to decrease performance. Environmental conditions may also play an important role in muscle endurance,[34,68] and, since greater hypohydration often occurs in hot conditions, more studies should investigate this relationship.

The research concerning maximal aerobic power and the physical work capacity for extended exercise is also relatively conclusive and consistent. Maximal aerobic power usually decreases when dehydration exceeds a 2% to 3% reduction in body weight, and, when performed in the heat, the decrements are exaggerated.[34] Nearly every study that has examined physical work capacity has shown some degree of performance decrement.[34] Even with only 1% to 2% hypohydration in a cool environment,[80,81] a decrement is noted. Pinchan et al[82] and Walsh et al[83] noted decreases in physical work capacity with less than 2% dehydration during intense exercise in the heat. As expected, when dehydration increased, physical work capacity decreased, sometimes by as much as 35% to 48%,[84] and physical work capacity often decreased even when maximal aerobic power did not change.[80,81,85] Buskirk and Puhl[69] suggested that some of these decrements with low to moderate levels of hypohydration may be partly due to an increased perception of fatigue. The degree of change in physiologic function will be dependent on various exercise parameters, including intensity, duration, environmental stress, and individual factors.

CONCLUSION

Exercise in the heat triggers a disturbance of the internal environment of the human body. Understanding the responses requires an astute ability to focus on many independent physiologic processes that function cooperatively. The athlete wishes for these systems to rise to any challenge, but often excessive heat, dehydration, or both cause some degree of decrement in performance. The ensuing part of this 2-part series about exercise in the heat attempts to identify ways in which athletic trainers and athletes can work toward minimizing the decrement by maximizing heat dissipation and body fluid balance.

ACKNOWLEDGMENT

I would like to dedicate this paper to the memory of my former supervisor, Dean Leo W. Anglin, Jr, PhD. I would later learn that he took his final breaths as I wrote this article. He was a visionary in the field of education, and the passion that drove him was contagious. I shall strive in his memory.

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Exercise in the Heat. II. Critical Concepts in Rehydration, Exertional Heat Illnesses, and Maximizing Athletic Performance

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Objective: To acquaint athletic trainers with the numerous interrelated components that must be considered when assisting athletes who exercise in hot environments. Useful guidelines to maximize performance and minimize detrimental health consequences are presented.

Data Sources: The databases MEDLINE and SPORT Discus were searched from 1980 to 1999, with the terms "body cooling," "dehydration," "exercise," "heat illnesses," "heat," "fluid replacement," "acclimatization," "hydration," "rehydration," "performance," and "intravenous," among others.

Data Synthesis: This paper provides an in-depth look at issues regarding physiologic and performance considerations related to rehydration, strategies to maximize rehydration, modes of rehydration, health consequences of exercise in the heat, heat acclimatization, body cooling techniques, and practice and competition modifications.

Conclusions/Recommendations: Athletic trainers have a responsibility to ensure that athletes who exercise in hot environments are prepared to do so in an optimal manner and to act properly to avoid the potentially harmful heat illnesses that can result from exercise in the heat.

Key Words: body cooling, dehydration, heat acclimatization, hydration, intravenous

For an athlete who becomes dehydrated while exercising, rehydration is critical to maintaining athletic performance and physiologic function. Many factors contribute to the amount of rehydration, including the environment, the timing of rehydration in relation to the exercise session, and the contents of the rehydration beverage. Ingesting fluid to reestablish normal hydration is both complicated and essential for the competitive athlete.

REHYDRATION AND EXERCISE

Factors Influencing Rehydration

Armstrong and Maresh[1] addressed many of the critical environmental and host factors that influence the process of rehydration. The degree of environmental stress is influenced by such factors as temperature, humidity, wind speed, and radiation. The extent of environmental stress directly influences the degree of physiologic change (eg, sweating rate, hyperosmolality of extracellular fluids, etc). These physiologic changes in turn affect the rehydration process.[2,3] Welch et al[4] provided support for the influence of environmental stress on rehydration by noting a substantial increase in fluid intake when ambient temperature rose above 25°C.

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Similarly, environmental stress affects certain psychological variables. A dehydrated athlete exercising in the heat prefers ingesting cold fluid.[5,6] Armstrong and Maresh[1] also noted individual differences in learned behavior. An athlete who understands how proper rehydration can enhance subsequent performance is more apt to consume fluid before significant dehydration occurs. Thus, appropriate education of young athletes by knowledgeable sport supervisors is essential.

The physical characteristics of the rehydration beverage can also dramatically influence the extent of fluid replacement.[1,5,7] Salinity, color, mode, sweetness, temperature, flavor (eg, grape is preferred), carbonation, and viscosity all affect how much the athlete drinks.[7–9]

Since most fluid consumed by athletes is with meals, the thirst response at meals and the presence of ample fluid during meals are critical in rehydration.[8] And since fluid losses of 1% to 2% of body weight are necessary to elicit a thirst response, an athlete who participates in frequent practices or competitions may become chronically dehydrated.[10]

It is important to note that dehydration resulting from sodium depletion does not elicit a thirst response.[1] Reduced mouth dryness and increased stomach distention also decrease the desire to drink, even though significant dehydration may still be present. However, this form of dehydration is relatively rare and develops in 3 to 5 days in athletes who train in the heat many hours each day.

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.[1] For example, industrial laborers need frequent breaks to rehydrate because they must remain focused on a specific task. This need for mental 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 bottle allows the cyclist to rehydrate while remaining focused on terrain, speed, gears, braking, and exertion.

The critical message from the cited research regarding rehydration is an appreciation of the many interrelated variables that contribute to the degree of fluid consumed in response to exercise-induced dehydration.[11] Athletic trainers should be conscious of these and other possible factors that may undermine the rehydration process for the athletes they supervise.

Hydration Before Exercise

The athlete should begin exercising well hydrated.[8] Many athletes who perform repeated bouts of exercise on the same day or on consecutive days become chronically dehydrated. When a hypohydrated athlete begins to exercise, physiologic mechanisms are altered. Cardiovascular (CV) strain is increased, core temperatures rise more quickly and to higher levels, and the ability to dissipate heat by skin blood flow and sweating rate is limited, resulting in performance decrements,[12,13] the extent of which are related to the thermal load.[14] Athletes may require substantial assistance in obtaining fluids, as evidenced by the phenomena of voluntary dehydration (when individuals drink insufficient quantities to replace fluid losses) and involuntary dehydration,[15] as well as societal habits.[16]

To ensure proper hydration when exercise begins, the American College of Sports Medicine (ACSM)[8] has provided guidelines for fluid ingestion, which include consuming 500 mL of fluid 2 hours before an event to assure proper hydration (ie, normal fluid volume and osmolality) and ample time to urinate excess fluid. In addition, CV strain is reduced and core temperatures are lower when fluid is ingested 60 minutes before exercise.[17,18] Mandatory pre-exercise hydration is physiologically advantageous and more practical than ad lib hydration, which is well documented to be insufficient.[19,20] Ingesting a nutritionally balanced diet and fluids during the 24 hours before an exercise session is also crucial, given that a large portion of rehydration occurs during meals.

Electrolytes (either in foods or fluids) are necessary to regain normal hydration after exercise-induced dehydration.[8] This is not surprising because excessive sweating during exercise alters both plasma osmolality and electrolyte levels (primarily sodium) due to salt levels in sweat. The inclusion of sodium will enhance both water retention and the taste of the beverage.[8]

Another consideration in pre-exercise hydration is hyperhydration. Sawka et al[21] reported that thermal strain, CV strain, or both may be reduced during exercise while hyperhydrated. Obviously a hyperhydrated individual will eventually excrete the excess volume, but recent experiments[22–24] with glycerol in the hyperhydrating solution reduced the volume excreted, allowing a true state of hyperhydration to be maintained. Leutkeimer and Thomas[25] reported improved cycle performance time with hyperhydration, which supports many of the physiologic findings, but the jury is still out on the ergogenic effects of hyperhydration.[21] Recently, Kavouras et al[26] found increased exercise time and plasma volume during exercise to exhaustion in the heat when subjects were rehydrated (from a previous dehydration) with water and glycerol before exercise, as compared with rehydration using an equal volume of water without glycerol.

Rehydration During Exercise

Proper maintenance of hydration status during exercise will influence CV, thermoregulatory, fluid volume, performance, and other variables favorably. These factors also depend on whether the exercise is occurring in a hot or cool environment. This topic has been extensively reviewed through the years, but some reports are especially notable.[1,8,27–31]

The physiologic benefits associated with maintaining fluid volume are well documented. As mentioned earlier, proper hydration during exercise enhances heat dissipation (increased skin blood flow and sweating rate), limits plasma hypertonicity, and helps sustain cardiac output.[8,32] 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.[33] Rehydration allows for conservation of the central blood volume and optimal physiologic responses to intense exercise in heat. Rehydration during exercise in a cool or neutral environment seems to minimally affect plasma volume, while primarily allowing intracellular and interstitial fluid volumes to be maintained.[27] With exercise in a warm environment, plasma volume responses are somewhat variable, but plasma volume is better maintained with rehydration than without.[14,27] In other words, the athlete may still be hypovolemic after substantial rehydration, but the plasma volume is closer to being restored. Equally critical is the role rehydration has in preventing hyperosmolality and cellular dehydration.[27] Also, the rate of alteration in CV strain is positively correlated with environmental temperature and relative exercise intensity,[34] and the onset of CV drift is preventable with proper rehydration.[28]

Rehydration limits the degree of hyperthermia and maintains athletic performance. A classic study by Pitts et al[35] was one of the first to show 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 lib water and no-water groups. This benefit of rehydration on physiologic function is likely due to increased blood volume,[36] reduced hyperosmolality,[37] reduced cellular dehydration,[38] and improved maintenance of extravascular fluid volume.[29,39]

The ACSM[8] addressed the importance of proper rehydration in the position stand "Exercise and Fluid Replacement." Athletes will not rehydrate to pre-exercise levels during exercise due to choice,[7,40] availability, the circumstances of competition,[8] or a combination of these factors, which leads to dehydration and hindered exercise performance. Athletes should aim to drink quantities equal to sweat loss, and although they rarely meet this goal, studies have shown that athletes can readily handle these large volumes (>1 L/h).[8,41,42] Appealing to individual taste preferences may encourage athletes to drink more fluids, and carbohydrate and electrolytes (especially sodium) in the rehydration drink will restore physiologic function and enhance performance if the exercise task exceeds 45 to 50 minutes in duration and/or is extremely intense (eg, interval training).[8,30,31,41,43–45]

Rates of gastric emptying and intestinal absorption should also be considered.[31,46–48] Volume,[49] fluid temperature, environmental stress,[50] fluid composition (including osmolality and calorie content), and exercise intensity[50] are some of the most important factors[8] in determining the rates of gastric emptying and small intestine absorption (the primary site of fluid absorption). The single most important factor in gastric emptying may be the volume of fluid in the stomach.[51,52] The ACSM[8] recommended maintaining 400 to 600 mL of fluid in the stomach (or the maximum tolerated) to optimize gastric emptying. If carbohydrates are in the fluid, the carbohydrate concentration should be 4% to 8%; concentrations higher than 8% slow the rate of fluid absorption.[53] Intense exercise (>80% of $\dot{V}O_{2max}$, when the risk of hyperthermia is highest) may also decrease the rate of gastric emptying.[46] Frequent ingestion (every 15 to 20 minutes) of a moderate fluid volume (200 mL) may be ideal but is not feasible in sports lacking frequent or regular rest periods. The rates of gastric emptying and intestinal absorption likely influence the speed of movement of the ingested fluids into the plasma volume.[54] Since the rates are similar for water and a 6% carbohydrate solution, fluid replacement and energy replenishment are equally achievable.[54]

Every athlete will benefit from attempting to match fluid intake with sweating rate and urine volume. Because individual differences exist for gastric emptying and availability of fluids during particular sports, rehydration procedures and gastric tolerance should be monitored and modified accordingly in practice so as to maximize performance in competition. Research I have done with track athletes, road runners, and mountain bikers shows that this is a difficult but worthwhile task.

Rehydration After Exercise

Replenishing fluid volume[55,56] and glycogen stores is critical in the recovery of many body processes. This topic has been insightfully reviewed by Maughan et al.[55] Rehydration after exercise is also critical and should be addressed independently of hydration before and during exercise.

Based on volume and osmolality, water may not be the best fluid to drink after exercise to replace the fluids that are lost via sweating.[1,57–59] 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 (keeping vasopressin and aldosterone levels low) and increasing the drive to drink.[1,38,55,59–61] Including carbohydrates in the rehydration solution may improve the rate of intestinal absorption of sodium and water[31,55] and replenishes glycogen stores.[31,62,63] Replenishing glycogen stores will enhance performance in subsequent exercise sessions.[64] While a normal diet commonly restores proper electrolyte concentrations,[65] many athletes are forced to rehydrate between exercise sessions in the absence of meals.[55] In addition, some athletes' meals are eaten many hours after an exercise session, which may compromise electrolyte availability during rehydration after intense exercise in hot conditions.

Fluid replacement after exercise should equal sweat losses, but the athlete who follows this rule will actually remain dehydrated due to urine losses. An insightful study by Shirreffs et al[60] reported that ingesting fluids with a high sodium concentration equal to 150% of weight loss was the optimal rehydration amount when hydration status was considered 6 hours after exercise.

INTRAVENOUS REHYDRATION AND EXERCISE

Most studies have explored the efficacy of intravenous infusion to rapidly restore hydration in unconscious patients or those with hemorrhage or heat illness.[66,67] The use of intravenous fluid to rapidly restore physiologic function when health is severely compromised is a proven and useful treatment. But, recently, some athletes have used intravenous rehydration to maximize rehydration before an ensuing exercise session. Some recent studies have addressed intravenous infusion to rehydrate athletes before an exercise session.[68–75] Castellani et al[69] and Riebe et al[75] were the first to assess intravenous rehydration as a potential ergogenic aid while properly controlling concentration, volume, and timing in dehydrated athletes before an exercise bout. A later study from the same laboratory decreased the amount of time for rehydration to better simulate many sports environments.[68]

Nose et al[71] found that CV and thermoregulatory strain were reduced with a 0.9% NaCl infusion during exercise at 60% $\dot{V}O_{2max}$ in an air temperature of 30°C. As expected, improved hydration led to improved heart rate, core temperature, forearm blood flow, and plasma volume response. Deschamps et al[70] also found lower heart rate and core temperature with a better-maintained plasma volume when 0.9% NaCl was intravenously infused during exercise at 84% $\dot{V}O_{2max}$ at 24°C. No differences were found in time to exhaustion, perhaps because the mild temperature did not put an intense demand on skin blood flow. Neither study included an oral rehydration group for comparison.

Rowell et al[72] used intravenous infusion to study CV function during exercise because the infusion negated sweating losses and allowed better assessment of "normal" CV function. These responses would be expected to be different from those that occurred when an individual was allowed to become dehydrated while exercising. Hamilton et al[73] found an enhanced CV response for those subjects who received intravenous infusion versus oral ingestion during exercise at 70% $\dot{V}O_{2max}$ at 22°C. This was the first study to find an advantage for intravenous infusion over oral ingestion. However, the mode cannot be isolated as the cause of the difference because glucose was included in the intravenous infusion and not in the oral drink. Once again, because the intravenous rehydration occurred during exercise, the results have limited applications for athletes. In contrast, Montain and Coyle[74] found lower rates of perceived exertion and core temperature after oral ingestion, compared with intravenous infusion, during exercise at 65% $\dot{V}O_{2max}$ and an ambient temperature of 33°C. Once again, the fluid concentrations were different, and the rehydration occurred during exercise.

Castellani et al[69] and Riebe et al[75] made important progress into the potential ergogenic roles of oral and intravenous rehydration before exercise. Subjects were exercised to dehydration of −4% body weight and then were treated with no fluid, intravenous infusion (0.45% NaCl), or oral saline (0.45% NaCl). After resting for 75 minutes, they exercised at 50% $\dot{V}O_{2max}$ at 36°C for 90 minutes. The authors found lower heart rates at some time points for the intravenous group, possibly the result of an exaggerated norepinephrine response in the oral trial. In addition, lower ratings of perceived exertion and thirst were reported for the oral trial. Intravenous infusion may mediate physiologic variables, whereas the oral ingestion may be beneficial psychologically, but no performance difference was noted between IV and oral rehydration.

What would happen if an athlete exercised immediately after intravenous rehydration? Recently, Casa et al[68] reported physiologic advantages during exercise to exhaustion (about 30 minutes) in a 36°C environment after oral compared with intravenous rehydration (same amounts and concentrations of fluid). These advantages included lower rectal temperatures, blood lactate levels, and skin temperatures, among others, when rehydration occurred orally as compared with intravenously. Although the finding was not significant ($P = .07$), exercise time to exhaustion increased 5 minutes after oral rehydration. Some of the discrepancy in performance time may have had a psychological root.[6] Unique to this study was the brief 20-minute rehydration period, which is similar to breaks in many sports (eg, halftime during a soccer game). Intravenous rehydration, as commonly practiced by many athletes attempting to maximize rapid fluid replacement during their breaks, may not be beneficial and may actually be a hindrance to maximizing athletic performance. Although not yet supported by research, some combination of oral and intravenous rehydration may prove to be optimal.

EXERTIONAL HEAT ILLNESSES

Motivated athletes, soldiers, or industrial laborers who are exercising at a high intensity or for prolonged periods of time can experience an excessive rise in core body temperature associated with increasing dehydration. An exertional heat illness reduces physical work capacity and, in some cases, can lead to a medical emergency and even death. All athletes, coaches, and medical staff should know about the different heat illnesses, their pathophysiology, common signs and symptoms, and prevention.

Recent reviews[66,76–80] provide excellent information regarding the etiology, diagnosis, treatment, and prevention of exertional illnesses. Although the *International Classification of Diseases*[81] lists 10 separate categories of heat illness, the 3 most common resulting from strenuous physical exertion are heat cramps, heat exhaustion, and heatstroke.

The least serious, heat cramps, is likely the result of an NaCl deficit.[77] Athletes with heat cramps usually sweat copiously (ie, lose large amounts of NaCl), replace sweat losses with a hypotonic fluid, or both. The resultant decrease in plasma NaCl may alter the degree of intramuscular water expansion[78,80,82] due to changed sodium-potassium pump kinetics and the resultant action potential changes across the cell membrane. Changes in the internal environment about the cell membrane may influence the muscle contraction by elevating resting calcium levels and inducing additional calcium release from the sarcoplasmic reticulum, ultimately resulting in random muscle contractions.[83] Heat-acclimatized athletes appear to have a reduced incidence of heat cramps,[78,80] although some experts disagree.[84]

Heat exhaustion is the most common heat illness.[66,77] It usually occurs when unacclimatized individuals exercise strenuously in the heat and lose large amounts of water and electrolytes in sweat. Heat exhaustion is usually classified as either water or salt depletion. Water-depletion heat exhaustion has a more rapid onset and is more likely to progress to heatstroke if not treated.[66,79] Continued exercise in the heat and increased dehydration limit the ability of the cardiac output to meet muscle and skin blood flow requirements.[76] Eventually, and by definition, the athlete is unable to continue exercising in the heat.[77]

Exertional heatstroke can occur in the absence of significant dehydration,[76,80] the result of either overloading or failure of the thermoregulatory system in response to intense exercise, usually in a hot environment.[77] The metabolic requirements of working muscle and cooling skin, exacerbated by temperature and humidity extremes, can overwhelm the capacity to dissipate heat. The body preferentially maintains arterial blood pressure over thermoregulation and skin dilation.[85–87] Ultimately, heat production exceeds heat dissipation, and core temperature rises dramatically, until dangerous hyperthermia exists.[78,84,86]

Signs, Symptoms, and Treatment

Unlike typical exercise-induced cramps, heat cramps are usually not spread throughout the entire muscle; instead, individual muscle bundles contract in a spastic manner.[78] A low plasma sodium level, decreased urinary NaCl, and urinary specific gravity >1.016[79,88] also indicate heat cramps. Treatment includes the ingestion of salt tablets in water (2 10-grain salt tablets dissolved in 1 L of water) or intravenous saline if nausea and vomiting are present.[79]

Heat exhaustion is characterized by headache, extreme weakness, dizziness, vertigo, "heat sensations" on the head or neck, nausea, vomiting, profuse sweating, syncope, elevated pulse rate, and low blood pressure.[76–78,89] Compared with heatstroke, mental function and thermoregulation are mildly impaired. Water-depletion heat exhaustion usually occurs after exercise starts; salt-depletion heat exhaustion usually occurs after several days of exercising in a hot environment.[79] Treatment includes immediate rest, cooling (eg, ice bags, moving the athlete to the shade, etc), and rehydration. Rehydration consists of cool water (1.5 L of water and 2 gm NaCl per hour of intense exercise[79]) and should aim to restore sweat losses and normal plasma NaCl. If nausea and vomiting are present, intravenous saline infusion is recommended.[76]

Heatstroke is a medical emergency and should be treated as such.[76,77] Immediate recognition of symptoms and initiation of treatment are necessary to maximize the odds for a complete restoration of normal physiologic function.[76,79,90–93] Negligence on the part of the supervisors or medical staff can result in potentially fatal consequences.[94,95] The diagnosis of exertional heatstroke includes thermoregulatory failure and obvious mental impairment.[76,79] Rectal temperature higher than 39°C to 40°C, elevated serum enzymes (eg, aspartate aminotransferase), hypotension, vomiting, diarrhea, coma, and convulsions may also occur. Sweating may be present, and dehydration is likely, but not essential.[79] The gold standard for the immediate treatment of exertional heatstroke, due to its superior whole-body cooling and lowest mortality rates, is cold and ice-water immersion (approximately 5°C to 15°C).[66,77,79,96] The speed with which the athlete can be cooled is critical to the survival rate.[79] If available equipment does not allow immersion, ice packs on the neck, axillae, proximal femurs, and behind the knees, etc, or fans, or a combination of these, will assist in cooling. Secondary interventions include intravenous infusions; quantity should be based on the degree of dehydration.[66] Serum enzyme levels should be monitored for continued rises for several days.[79]

Prevention Techniques

Prudent preparation by knowledgeable athletes, coaches, and medical staff can prevent most heat illnesses[76,97] (Table 1). The emphasis in prevention should be on establishing rehydration procedures that match sweat losses, modifying or rescheduling practices or competitions in extreme conditions,[76] monitoring athletes, and recognizing physiologic limitations when exercising in hot weather. The coaches and medical staff should

- know the signs and symptoms of heat illness;
- provide an ample supply of proper rehydration beverages;
- offer numerous and regular rehydration breaks;
- organize whole-body cooling equipment and supplies;
- be willing to modify the established practice schedule;
- have a plan in case heat illness occurs.[66,76,77,80]

Table 1. Risk Factors Associated with Heat Illness[76,79,80,89,97]

Increased Risk	Decreased Risk
Increasing age	Acclimatization
Alcohol use	Adequate hydration
Creatine use (?)*	Adequate sleep
Drug abuse	Adequate nutrition
Obesity	Decreased WBGT†
Skin conditions (eg, sunburn)	Improved physical fitness
Increased intensity of exercise	Frequent rest breaks during exercise
Increased duration of exercise	Presence of ATCs (?)*
Previous heat illness	

* Question mark indicates future research needs to be done/new idea.
†WBGT, wet-bulb globe temperature.

An environmental symptoms questionnaire may help in the early identification of a heat illness.[98–100] Casa et al[100] reported that scores on an environmental symptoms questionnaire indicated a faster onset of symptoms with an increasing degree of dehydration during exhaustive exercise in the heat.

MAXIMIZING ATHLETIC PERFORMANCE IN THE HEAT

Any athlete, soldier, or industrial laborer who must perform vigorous physical activity in a hot environment can use various coping strategies to maximize performance.

Heat Acclimatization

The process by which the human body makes certain physiologic modifications to reduce the stress of an environment is called acclimatization.[101] The International Union of Physiological Sciences considers "acclimation" the proper term when physiologic changes occur in a controlled environment (eg, heat or hyperbaric chamber) and "acclimatization" accurate when the changes occur in a natural environment (eg, living on a mountain, training in Miami). Bean and Eichna[102] demonstrated decreased thermal and CV strain after acclimatization in the heat. Decreased heart rate and rectal temperature indicated lessened physiologic strain. Other studies have provided strong evidence for the positive physiologic changes associated with acclimatization.[10,103–105]

Armstrong and Dziados[106] suggested plateau days at certain critical physiologic levels during acclimatization. For example, heart rate, plasma volume, and perceived exertion changes are usually completed by 3 to 6 days, while rectal temperature and electrolyte concentration changes may take several additional days. Increased sweating rate seems to be the final adaptation to plateau, often taking up to 2 weeks. However, 9 to 10 days appear sufficient to attain many of the physiologic benefits associated with acclimatization.

Armstrong and Maresh[107] provided valuable recommendations for heat acclimatization (Table 2). The bottom line is that proper heat acclimatization is an important training component when competition will take place in a hot environment. The United State Olympic Committee endorsed many of Armstrong and Maresh's[107] recommendations in preparation for the Barcelona Olympics.[45]

Amount of Rehydration

It is absolutely imperative that an athlete know the rate at which he or she loses fluid via sweat at various practice intensities and during competition. Body weight changes, urine color, subjective feelings, and thirst, among other indicators, offer cues to the need for rehydration. Temperature, humidity, wind speed, intensity, duration of exercise, individual sweating rate differences, and other factors also affect hydration before, during, and after exercise in the heat.

The ACSM's position stand,[8] "Exercise and Fluid Replacement" is the current gold standard for rehydration requirements (Table 3). Recent compilations by Horswill[108] and Shi and Gisolfi[109] are also valuable sources when attempting to maximize rehydration. Perhaps the simplest yet most fundamental goal is the avoidance of voluntary dehydration by encouraging athletes to drink beyond thirst satiation and to replace lost body weight.[110]

While preparing for an event, an athlete should be able to determine sweating rate, assess hydration status, and develop a rehydration plan. Determinations of sweating rate can be made according to Armstrong[45] or Murray.[16] Hydration status (ie, percentage of dehydration) can be assessed by measuring body weight before and after exercise sessions or simply by monitoring urine color.[111,112] A refractometer can provide a precise measurement (urinary specific gravity <1.010 indicates a hydrated state).[45] The hydration plan should take into account the length of the event, the individual's sweating rate, exercise intensity, average 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?). Any plan for rehydrating during competition should be instituted and perfected during practice sessions. Armstrong et al[113] provide a plan for an elite athlete preparing for an event, and Armstrong and Maresh[1] offer an exhaustive list of the environmental and host factors that can influence the rehydration process.

Table 2. Recommendations for Heat Acclimatization[107]

1. Attain adequate fitness in cool environments before attempting to heat acclimatize.
2. Exercise at intensities >50% $\dot{V}O_{2max}$ and gradually increase the duration (up to 90 min/d) and intensity of the exercise sessions during the first 2 wk.
3. Perform highest-intensity workouts during the cooler morning or evening hours and other training during the hottest time of the day.
4. Monitor body weight to ensure that proper hydration is maintained as sweat rate increases.
5. Monitor rectal temperature to ensure that body temperature stays within safe limits.
6. Athletes who live in a cool environment but will travel to a hot environment for competition can induce partial acclimatization by wearing insulated clothing, although they should leave some skin surface uncovered and monitor rectal temperature to avoid hyperthermia.

Table 3. Basic Rehydration Recommendations of the American College of Sports Medicine[8] and Recent Developments[45]

1. Consume a nutritionally balanced diet and maintain normal hydration in the 24 h before an event and/or training session.
2. Consume about 500 ml of fluid in the 2 h before an event, which will allow adequate time to excrete excess fluid before the event begins.
3. Consume enough fluids during exercise to equal the amount of fluid lost from sweating. If this is not feasible, drink to tolerance.
4. The fluid should be cool (approximately 15°C), flavored to maximize palatability, and accessible in ample quantity in convenient containers.
5. For activities lasting about 50 min or more or those of an extremely intense nature, or both, use sport drinks instead of water to encourage proper muscle glycogen levels in addition to adequate hydration.
6. For activities of about an hour or more, include sodium to increase palatability, to enhance fluid retention, and to prevent hyponatremia.

Composition of Rehydration Fluid

The ACSM[8] recommended that 30 to 60 g/h of carbohydrates be replaced to maintain the rate of carbohydrate oxidation and delay the onset of fatigue (prevent glycogen depletion). Diluting the carbohydrate in 1 L of fluid will not hinder fluid absorption. The carbohydrate concentration should ideally be close to 6% ($g \cdot 100\ mL^{-1}$) and should not exceed 8%. The simple sugars (glucose or sucrose) or a starch (such as maltodextrin) are the best carbohydrate forms, and a combination of multiple types of carbohydrates will speed gastric emptying and intestinal absorption. Fructose should not be the primary source of carbohydrates, given the gastrointestinal stress it may cause. If the athlete's diet is sufficient in sodium, adding sodium to the rehydration solution will not enhance intestinal absorption, but it may enhance fluid palatability and fluid retention and prevent hyponatremia (ie, water intoxication: replacing large amounts of fluid losses with water in the absence of electrolytes) in a susceptible individual. Sodium concentration should be approximately 0.5 to 0.7 g/L. Other valuable sources of practical information concerning rehydration are available.*

Body Cooling Techniques

The athlete can enhance body cooling by wearing light-colored, loose-fitting clothing made of fibers that wick sweat

*References 16, 29, 31, 55, 108, 109, 114, 115.

Table 4. When Athletes Exercise in the Heat: A Checklist for the ATC

1. Pre-event preparation
   - _____ Am I challenging unsafe rules (eg, a 10K track runner may not be able to receive fluids; can these rules be changed to maximize safety?)?
   - _____ Am I encouraging athletes to drink before the onset of thirst?
   - _____ Am I familiar with which athletes have a history of a heat illness?
   - _____ Am I discouraging alcohol, caffeine, and drug use before and during exercise?
   - _____ Am I encouraging proper acclimatization procedures?
2. Checking hydration status
   - _____ Do I know the pre-exercise weight of the athletes I work with (to allow percentage of dehydration to be determined during and after practice or competition)?
   - _____ Are the athletes familiar with how to assess urine color? Is a urine color chart accessible?
   - _____ Do the athletes know their sweat rates so they know how much to drink during exercise?
   - _____ Is a refractometer present to double-check hydration status?
3. Environmental assessment
   - _____ Am I regularly checking the wet-bulb globe temperature (WBGT) during the day?
   - _____ Am I knowledgeable about the risk categories of a heat illness based on the WBGT?
   - _____ Are alternate plans made in case a high WBGT forces a rescheduling of events or practices?
4. Coaches' and athletes' responsibilities
   - _____ Are the coaches and athletes educated about the signs and symptoms of heat illnesses?
   - _____ Are athletes properly prehydrated for the activity?
   - _____ Am I double-checking to make sure coaches are allowing ample rest and rehydration breaks?
   - _____ Are modifications being made to reduce risk in the heat (eg, decrease in intensity, change practices to morning or evening, more frequent breaks, elimination of double sessions, reduction or change in equipment, clothing requirements, etc)?
   - _____ Are rapid weight-loss practices in weight-class sports adamantly disallowed?
5. Event management
   - _____ Have I checked to make sure proper amounts of fluids will be available and accessible?
   - _____ Are carbohydrate-electrolyte drinks available at events and practices lasting longer than 50 to 60 minutes and those that are extremely intense in nature?
   - _____ Am I aware of the factors that may increase the likelihood of a heat illness?
   - _____ Am I promptly rehydrating athletes to pre-exercise weight after an exercise session?
   - _____ Are shaded or indoor areas used for practices when possible, to minimize thermal strain?
6. Treatment considerations
   - _____ Am I familiar with the most common early signs and symptoms of a heat illness?
   - _____ Do I have the proper field equipment and skills to assess a heat illness?
   - _____ Is an emergency plan in place in case an immediate evacuation is needed?
   - _____ Is a kiddy pool available in situations of high risk in order to initiate immediate cold/ice-water immersion of heatstroke patients?
   - _____ Are ice bags available for immediate cooling when ice-water immersion is not possible?
   - _____ Have shaded, air-conditioned, and cool areas been identified to use when athletes need to cool down, recover, or receive treatment? Are fans available to assist evaporation when cooling?
   - _____ Am I properly equipped to assess high core temperatures?
7. Other situation-specific considerations

from the body. Avoiding the sun's direct rays will limit the radiant heat load.

Athletes who must exercise for multiple sessions in the heat can use ice packs (under the arm, in the groin, behind the neck and the knees) to speed the decrease in core temperature and enhance physiologic capacity during the next session. While cooling, they should sit in the shade or in an air-conditioned room in front of a fan (to increase evaporation), drink cool fluids beyond thirst satiation, rest (to decrease the metabolic rate), replace glycogen stores, and refill coolers or water bottles for the next exercise bout. If a severe case of dehydration must be reversed rapidly, intravenous fluids are recommended.[76]

The fine-mist showers and cool sponges found at many athletic events do little to cool the body's core.[113] Instead, the focus should be on replenishing lost fluids.[113] As discussed earlier, all athletes and support staff must know the signs and symptoms of heat illness in order to recognize and treat problems as early as possible.[8,76,89] In the event that an athlete becomes severely hyperthermic or develops heatstroke, cold water or ice-water immersion provide the fastest whole-body cooling.[76,77,96] The simplest way to distinguish heatstroke from heat exhaustion in the field involves observing mental acuity. If disorientation, unconsciousness, bizarre behavior, or coma exist, heat stroke should be expected (rectal temperatures >39°C to 40°C), and cooling should be instituted immediately, in response to this medical emergency.

Practice and Competition Modifications

The ACSM's position stand,[76] "Heat and Cold Illnesses During Distance Running," offers valuable guidelines to counteract critical levels of environmental conditions that may increase the risk of heat illness and hinder performance. Although the position stand focuses on running, the information is easily transferable to other sports, and the organization strategies apply to any competition director or coach who supervises athletes practicing or competing in a hot environment. Some of the factors that must be considered by an ATC when supervising exercise in the heat are summarized in Table 4.

If the time of competition is fixed (ie, more difficult to reschedule than a practice), then participants, coaches, and medical staff must be alert to the possibility of cancellation or postponement and the need to practice extreme caution. Athletes who practice in extreme heat should plan lower-intensity training sessions for the heat of the day (to maximize acclimatization) and higher-intensity sessions for the early morning or evening (avoiding the 11:00 AM to 3:00 PM time period, shadeless fields or roads, and black ground surfaces).

Ample fluids should be easily accessible. In sports where athletes compete in weight classes, special care should be taken[116] to ensure that athletes do not rapidly lose weight (increasing the risk for heat illness, since much of the weight loss is water) or use rubber suits or saunas to enhance sweating, since core temperatures may become dangerously high in a short period of time. All too often, the quest for athletic success is accompanied by dangerous training techniques. The recent deaths of 3 collegiate wrestlers, which were due largely to a combination of thermal overload with dehydration, attest to this fact.[117,118]

CONCLUSION

The information presented in these 2 review articles is aimed toward assuring that athletic trainers are knowledgeable and prepared to actively construct protocols for many aspects of exercising in the heat. The goals of maximizing athletic performance and minimizing the health risks of the athletes we supervise must always focus on health first and on performance second.

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