American College of Sports Medicine Roundtable on Hydration and Physical Activity: Consensus Statements

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Introduction

An international panel of experts convened for an American College of Sports Medicine (ACSM) Roundtable dealing with Hydration and Physical Activity on December 8–9, 2003, in Boston, MA. The purpose of the meeting was to conduct an evidence-based analysis of hydration-related issues that have recently generated controversy or confusion in the scientific and lay communities. Some of the questions addressed by the Roundtable Panel included the following: How are euhydration and dehydration accurately determined in both laboratory and field settings? Are we unintentionally encouraging athletes to over-drink? How much fluid should an athlete consume each day? Under what circumstances does dehydration negatively affect health and performance? What are the best recommendations for fluid, electrolyte, and carbohydrate replacement before, during, and after exercise? Does dehydration contribute to collapse during and after exercise? Does dehydration contribute to the genesis of exertional heat stroke? How does exercise-related hyponatremia develop? and finally, How is hyponatremia best prevented?

This document summarizes the outcome of the Roundtable presentations and discussions using a format that reflects the evidence-based approach used during the 2-day meeting. Each of the consensus statements in this document bears a designation of A, B, C, or D (Table 1). These designators reflect strength of evidence determinations as noted below. The related references are not comprehensive, but are meant to provide key citations in support of the consensus statements. The Roundtable panel focused primarily on hydration issues related to athletes, but many of the consensus statements may also be applicable to military, occupational, fitness, and recreational settings.

Fluid and Electrolyte Requirements

Assessing body hydration status

During prolonged or strenuous physical activity, body water flux is primarily caused by sweat losses, although urine and respiratory fluid losses contribute to the final total body water status. Maintaining baseline euhydration status is important for day to day training safety and performance of athletes and active people. Dehydration is a body water deficit that occurs during physical activity and in athletes is usually characterized by hyperosmotic hypovolemia, although hypo-osmotic hypovolemia can occur in some situations. During hot weather training, dehydration occurs more frequently and has more severe consequences. A practical approach to monitor day to day fluid status is important for athletes who are training strenuously, especially in hot weather conditions or when wearing insulating clothing or equipment.

1. When fluid intake matches fluid loss, daily body mass will fluctuate by less than 1% and hydration status can be reliably estimated using as few as three consecutive days of first-morning body weights measured after voiding.
   i. Level of evidence: B
   ii. References: Cheuvront *et al.* [1], Casa *et al.* [2]
2. A body water deficit of greater than 2% of body weight marks the level of dehydration that can adversely affect performance.
   i. Level of evidence: A
   ii. References: Sawka [3], ACSM [4], Cheuvront *et al.* [5]
3. Several techniques have been used to measure and monitor hydration in the laboratory setting.

A. Total body water is best measured by isotope techniques.
   i. Level of evidence: A
   ii. References: Ritz [6]

B. Plasma osmolality is a reliable indication of hydration status. A euhydrated athlete should have a plasma osmolality between 280 mOsm/kg and 290 mOsm/kg.
   i. Level of evidence: A
   ii. References: Senay [7], Robertson *et al.* [8], Popowski *et al.* [9]

C. Fluid regulatory hormones can be confounded and alone are not good markers of hydration status.
   i. Level of evidence: B
   ii. References: Francesconi *et al.* [10], Montain *et al.* [11]

Table 1. Level of evidence guide

Evidence category	Level of evidence	Definition
A	Randomized controlled trials (rich body of data)	Substantial number of well-designed studies; substantial number of subjects; consistent pattern of findings
B	Randomized controlled trials (limited body of data)	Limited number of studies; includes post-hoc, field studies, subgroup, or meta-analyses; pertains when number of randomized controlled trials is small, results are inconsistent, or subject populations differed from the target population
C	Nonrandomized trials and observational studies	Evidence is from outcomes of uncontrolled or nonrandomized trials or from clinical observations or case studies
D	Panel consensus judgment	Used when guidance is needed, but literature is lacking; this is an expert judgment based on a synthesis of published evidence, panel consensus, clinical experience, and laboratory observations

(*Adapted from* Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obese Adults. http://www.nhlbi.nih.gov/guidelines/obesity/ob_exsum.pdf)

4. Several techniques have been used to estimate hydration in the field setting.

A. Urine-specific gravity, urine color, and urine osmolality are useful screening measures of hydration status. A euhydrated athlete will usually have a urine specific gravity of less than 1.020, a pale yellow urine color, and a urine osmolality of less than 700 mOsm/kg.

i.Level of evidence: A

ii.References: Adolph [12], Popowski *et al.* [9], Armstrong *et al.* [13], Armstrong *et al.* [14], Shirreffs and Maughan [15], Bartok *et al.* [16]

B. Bioelectric impedance can provide an indication of total body water, but is a poor indicator of hydration status or of changes in hydration status.

i.Level of evidence: A

ii.References: O'Brien *et al.* [17,18], Armstrong *et al.* [19]

5. Practical field measurements of hydration should be used to measure or monitor hydration status in athletes.

A. Day to day body weight changes are an acute estimate of hydration changes, if careful baseline measures are obtained and confounding factors are controlled.

i.Level of evidence: A

ii.Reference: Cheuvront *et al.* [20]

B. A day to day decrease in body mass of greater than 1% below the baseline is a marker of dehydration.

i.Level of evidence: B

ii.References: Adolph and Dill [21], Adolph [22], Cheuvront *et al.* [1]

C. A combination of baseline first-morning, postvoiding weight and plasma osmolality of less than 290 mOsm/kg, urine osmolality of less than 700 mOsm/kg, urine specific gravity of less than 1.020, or pale yellow urine (the color of lemonade, 1–3 on the Urine Color Chart) can give a prediction of a euhydrated condition in most athletes.

i.Level of evidence: A

ii.References: Ritz [6], Popowski *et al.* [9], Senay [7], Armstrong *et al.* [13], Bartok *et al.* [16], Shirreffs and Maughan [15], Casa *et al.* [2], Cheuvront *et al.* [1]

D. The difference in pre- and postactivity body weight is a reasonable estimate of acute body water losses and estimates the volume of fluid replacement needed to approximate euhydration, assuming that exercise began in a euhydrated state.

i.Level of evidence: B

ii.Reference: Cheuvront *et al.* [20]

E. Clinical signs and symptoms such as thirst, dizziness, headache, tachycardia, oral mucosal surface moisture, skin turgor, and others should not be ignored, but are too generalized to be of predictive use and the assessment of dehydration via these signs and symptoms is too imprecise to accurately assess the presence of hydration in an athlete.

i.Level of evidence: D

ii.References: Barkin and Ward [23], Engel *et al.* [24]

Daily fluid and electrolyte requirements

Individual fluid and electrolyte needs are widely variable during physical exercise due to differences in metabolic rate, body mass and size, environmental conditions (*eg*, temperature, humidity, wind, solar load, clothing worn), heat acclimatization status, physical fitness, activity duration, and genetic variability. For example, during a marathon, sweat rates may vary from less than 500 mL/h to more than 2 L/h. Similarly, sweat sodium concentration may vary from less than 20 mEq/L (460 mg/L) to more than 80 mEq/L (1840 mg/L). An individualized replacement recommendation is prudent for athlete safety during activities where a large sweat loss (*eg*, > 1L) is expected. Athletes should learn to estimate sweat rate to optimize hydration strategies for long-duration activities.

1. Dehydration results from sweat, respiration, urine, and insensible skin losses that are not replaced.

A. For inactive persons in temperate conditions, daily water needs can be as small as 1 to 2 L, but extended periods of intense exercise can increase daily water requirements to more than 10 L. However, for most moderately active people, daily water needs typically range between 3 and 5 L.

i.Level of evidence: B

ii.References: Institute of Medicine [25], Lentner [26], Leiper *et al.* [27,28]

B. During vigorous physical activity, hourly sweat losses from 0.5 to 2.0 L/h are common, with other extremes possible.

i.Level of evidence: A

ii.References: Rehrer and Burke [29]

C. Athletes often dehydrate involuntarily during exercise. Thus, during intense physical activity and environmental stress, fluid losses commonly exceed replacement, resulting in an acute fluid deficit.

i.Level of evidence: A

ii.References: Rehrer and Burke [29], Maughan *et al.* [30], Adolph [12]

2. Exercise in specific environments or conditions can further exacerbate fluid loss.

A. Athletes involved in long-duration activities should attempt to replace sweat losses during activity, but should not exceed the volume of sweat lost during the activity. The minimum fluid replacement goal during most activities is to limit fluid deficits to less than 2% of baseline, euhydrated body weight.

i.Level of evidence: B

ii.Reference: Cheuvront *et al.* [5]

B. Sweat sodium concentration during exercise can range from about less than 20 to more than 80 mmol/L or about 1 to 5 g of table salt per liter of sweat. An athlete with an average sweat rate of 1 L/h can lose approximately 2 to 10 g of table salt in a 2-hour practice.

i.Level of evidence: B

ii.References: Maughan *et al.* [30], Shirreffs *et al.* [31]

C. An endurance athlete with a sweat rate of 1 L/h who exercises for 5 hours can lose 5 to over 30 g of table salt during the event.

i.Level of evidence: C

ii.References: Maughan *et al.* [30], Shirreffs *et al.* [31]

D. General prescriptive guidelines for fluid and electrolyte replacement practices for athletes are not meaningful across or even within sports due to considerable variability in the sweat losses of athlete and sports-specific differences in the factors that influence fluid intake during exercise. Education messages should encourage athletes to recognize their individual needs based on sweat losses and to target issues that influence fluid intake during activity, For example, opportunities to drink, availability of fluids, and the culture and rules of the sport can all influence intake and these factors should be taken into account when designing fluid and electrolyte replacement regimens.

i.Level of evidence: D

Diet effects on water requirements

Body water is replaced by beverage consumption and by ingestion of foods that contain water. A balanced diet that provides about 2500 to 3000 kcal will generally provide about 1 liter of water per day from food alone. In addition, the consumption of food stimulates drinking. Although foods and beverages provide fluids, their composition can influence fluid requirements by altering fluid retention.

1. A normal balanced diet will usually replace sodium lost in activity except for low-sodium diets (less than about 3 g/d) early in heat exposure and for athletes with very high sweat sodium losses.

i.Level of evidence: A

ii.References: Armstrong *et al.* [32], Glace *et al.* [33], Rehrer [34], Twerenbold *et al.* [35]

2. Caffeine, alcohol, and protein can modestly increase urine water losses.

A. Caffeine ingestion has a modest diuretic effect in some individuals but does not affect water replacement in habitual caffeine users, so caffeinated beverages (*eg*, coffee, tea, soft drinks) can be ingested during the day by athletes who are not caffeine naïve.

i.Level of evidence: B

ii.References: Eddy and Downs [36], Armstrong [37], Institute of Medicine [25], Maughan and Griffin [38]

B. Caffeinated drinks are not recommended when rapid rehydration after exercise is desired because caffeine can promote modest diuresis in some individuals.

i.Level of evidence: B

ii.Reference: Gonzalez-Alonso *et al.* [39]

C. Concentrated alcohol solutions (spirits or hard liquors) have a significant diuretic effect and should not be used when rapid and complete rehydration is desired.

i.Level of evidence: C

ii.References: Wen *et al.* [40], Mills *et al.* [41], Eggleton [42]

D. Alcohol concentrations like those in beer may not adversely affect long-term rehydration status in athletes, but should not be relied upon when rapid and complete rehydration is desired.

i.Level of evidence: C

ii.References: Wen *et al.* [40], Shirreffs and Maughan [43]

3. High-fiber diets (more than 20–30 g/d) can increase fecal water loss and minimally increase water needs.

i.Level of evidence: B

ii.Reference: McEligot *et al.* [44]

4. High-protein diets require an extra 40 to 60 mL water intake to clear each additional gram of urea nitrogen (protein is 16% nitrogen). The extra fluid loss is trivial under normal circumstances, but may increase dehydration in athletes who are purposefully restricting fluid intake in an attempt to lose weight.

i.Level of evidence: B

ii.Reference: Lloyd *et al.* [45]

Fluid replacement after activity

Fluid and solute replacement after activity is essential to restoring homeostasis. An athlete involved in vigorous training or competition with sessions that are spaced at less than 24 hours requires more structured replacement strategies than the athlete who has more than 24 hours between sessions. Large-volume fluid intake immediately following activity increases urine production, whereas spacing the fluid intake in even portions over longer periods improves rehydration. In addition to replacing body water, extracellular sodium losses also need to be replaced under these circumstances.

1. The difference in pre- and postexercise body weights is a measure of dehydration for a given exercise session (*see* 5A under *Assessing Body Hydration Status*).

i.Level of evidence: A

ii.Reference: Cheuvront *et al.* [20]

2. Rehydration strategies depend on the magnitude of the fluid deficit incurred and the time interval for rehydration prior to the next exercise session.

A. Athletes often wait until mealtime to fully replace water and electrolyte losses. Fortunately, normal food and fluid intake is usually sufficient to replace water and electrolyte losses when exercise sessions are more than 24 h apart.

i.Level of evidence: B

ii.Reference: Casa *et al.* [2]

B. Rehydration within 6 hours of exercise requires ingestion of water and sodium in excess of the existing body deficits to compensate for normal fluid needs and obligatory urine loss. This represents an empiric replacement volume of 125% to 150% of the decrease in body mass with the equivalent of 50 to 100 mmol/L of sodium will most effectively replace the deficit.

i.Level of evidence: B

ii.References: Mitchell *et al.* [46,47], Shirreffs *et al.* [48], Adolph [22]

C. Ingesting 2 L of fluid in 500 mL aliquots spaced every 20 to 30 minutes is more effective for rehydration than drinking the same volume in a single bolus immediately after the exercise session. Rapid replacement of fluid after exercise stimulates increased urine production, resulting in less body water retention.

i.Level of evidence: B

ii.References: Kovacs *et al.* [49], Wong *et al.* [50], Archer and Shirreffs [51], Adolph [22]

3. Salt concentration of the rehydration beverage is an important consideration.

A. Salty foods (*eg*, pretzels) or salty fluids such as soup bouillon (100 mmol/L) and tomato juice (100 mmol/L) consumed before or with other fluids including sports drinks (20 mmol/L or greater) provide a sodium source, promote fluid retention, and stimulate fluid intake.

i.Level of evidence: B

ii.References: Maughan *et al.* [52], Ray *et al.* [53], Adolph [22]

B. Rehydration fluids should attempt to balance the need for sodium content with the necessity of palatability.

i.Level of evidence: B

ii.References: Wemple *et al.* [54], Maughan and Leiper [55], Adolph [22]

C. The primary impetus for rehydration is sodium-chloride replacement, but minerals such as potassium, and possibly also magnesium, are important in restoring intracellular hydration and can be replaced by a balanced diet.

i.Level of evidence: D

ii.References: Leiper *et al.* [27,28], Shirreffs [56]

4. Intravenous fluid replacement may be required and prudent in certain circumstances.

A. Intravenous fluid replacement may be required following activity in athletes who develop nausea, vomiting, or diarrhea, or who for some reason cannot ingest fluids. If the signs of dehydration are not obvious on exam, serum sodium level should be checked before attempting agressive fluid replacement.

i.Level of evidence: C

ii.References: Maughan and Murray [57], Hiller [58], Noakes *et al.* [59], Noakes *et al.* [60], Reynolds and Schumaker [61]

B. Intravenous fluid replacement is not generally recommended, but is utilized during half-time breaks in American football, soccer, and other sports for athletes who are severely dehydrated due to heavy sweating and the inability to match fluid intake with sweat losses. If intravenous fluids must be used, consider replacing a portion of the rehydration fluids orally.

i.Level of evidence: D

ii.References: Casa *et al.* [62], Maughan and Murray [57]

Performance Considerations

Athletes who incur substantial fluid deficits during physical activity may experience some loss of performance capacity, especially in long-duration events that take place in the heat. Many physiologic factors contribute to the performance decrements associated with dehydration and result in degraded physical and mental performance, increased cardiovascular strain, changes in metabolism, and decreased heat tolerance.

1. Mental performance can be degraded by dehydration at rest and during exercise.

A. Heat stress and increasing body temperature impair mental performance. The decrement is greater with increasing duration and increasing task complexity. Attention and vigilance are the first attributes to be affected.

i.Level of evidence: B

ii.References: Ramsey and Kwon [63], Vasmatzidis *et al.* [64], Rodahl [65], Hancock [66], Hancock and Vasmatzidis [67]

B. Dehydration negatively affects short-term memory, working memory, psychomotor and visual motor skills, arithmetic ability, and mood.

i.Level of evidence: B

ii.References: Gopinathan *et al.* [68], Sharma *et al.* [69], Cyan *et al.* [70], Anslie *et al.* [71], Sawka *et al.* [72]

C. Dehydration of more than 2% to 3% of body mass increases the subjective perception of the exercise difficulty.

i.Level of evidence: A

ii.References: Coyle and Montain [73], Maresh *et al.* [74], Barr *et al.* [75], Montain and Coyle [76], Riebe *et al.* [77]

D. Drinking carbohydrate beverages (to provide 30–60 g carbohydrate/h) during vigorous exercise can delay mental fatigue and improve cognitive function, mood, motor skill performance, and perceived exertion better than drinking the same volume of water.

i.Level of evidence: B

ii.References: Burgess *et al.* [78], Coggan and Coyle [79], Coyle and Montain [80], Utter *et al.* [81], Felig *et al.* [82], Coyle *et al.* [83], Kang *et al.* [84], Welsh *et al.* [85], Lieberman *et al.* [86], Davis *et al.* [87], Nicolas *et al.* [88], Below *et al.* [89]

E. Caffeine ingested before or during exercise in amounts of 2 mg/kg body mass or more (*eg*, 2 mg/kg = 140 mg in a 70-kg athlete) can reduce some deficits in mental performance and mood during prolonged intense exercise and heat stress. However, there is a wide variation in individual dose response to caffeine such that side effects of anxiety and tremor may interfere with performance in some individuals while not adversely affecting others.

i.Level of evidence: C

ii.References: Leiberman *et al.* [90,91], Maughan and Griffin [38], Armstrong [37]

2. Dehydration of more than 2% of body mass can compromise physiologic function and impair exercise performance capacity. Greater levels of dehydration further exacerbate the negative responses.

A. Dehydration decreases cardiac output, skin blood flow, and sweat production and accelerates the rise in body temperature associated with exercise in the heat.

i.Level of evidence: A

ii.References: Armstrong *et al.* [92], Sawka and Coyle [93]

B. The greater the level of dehydration, the greater the hyperthermia and cardiovascular strain.

i.Level of evidence: A

ii.References: Sawka *et al.* [94], Montain and Coyle [76], Montain *et al.* [95]

C. There are no thermoregulatory or performance benefits to overhydration before or during activity, provided adequate fluid can be ingested during exercise.

i.Level of evidence: B

ii.References: Latzka *et al.* [96], Latzka *et al.* [97], Wingo *et al.* [98], Sawka and Coyle [93]

D. Maintaining hydration at less than a 2% body mass deficit during exercise helps preserve heart rate, stroke volume, cardiac output, skin blood flow, normal core temperature, and lactate metabolism.

i.Level of evidence: A

ii.Reference: Armstrong *et al.* [92]

E. Minimizing hydration to less than 2% body mass and ingesting carbohydrate improves total physical work capacity, increases time to exhaustion, improves time trial performance, improves power output, and maintains motor skills related to sports performance (*eg*, soccer dribbling and tennis stroke accuracy).

i.Level of evidence: A

ii.References: Armstrong *et al.* [99], Below *et al.* [89], Walsh *et al.* [100]

F. Partial rehydration will still maintain performance over no rehydration if an athlete cannot match fluid intake to fluid losses during exercise.

i.Level of evidence: B

ii.References: Casa *et al.* [62], Montain and Coyle [76]

G. Drinking carbohydrate-electrolyte beverages enhances performance compared with drinking the same volume of water during prolonged (~ 45–50 min) exercise or in high-intensity, intermittent exercise. In brief, the performance benefits of hydration and carbohydrate intake are independent and additive.

i.Level of evidence: A

ii.References: Davis *et al.* [87,101], Welsh *et al.* [85], Burgess *et al.* [102], Coggan and Coyle [79], Coyle and Montain [80], Utter *et al.* [81], Felig *et al.* [82], Coyle *et al.* [83], Kang *et al.* [84], Below *et al.* [89]

3. Occupational work performance can be compromised by dehydration.

A. Dehydration of more than a 2% loss in body mass lowers heat tolerance and reduces work capacity when uncompensable heat stress occurs.

i.Level of evidence: B

ii.References: Cheung and McLellan [103–105], McLellan *et al.* [106], Sawka *et al.* [72], Latzka *et al.* [97]

B. Reducing dehydration by ingesting fluid before and at regular intervals during exercise delays fatigue and increases work capacity when uncompensable heat stress occurs.

i.Level of evidence: B

ii.References: Cheung and McLellan [103], McLellan *et al.* [106], McLellan and Cheung [107], Cheung and McLellan [104,105], Sawka *et al.* [72]

C. Adequate fluid replacement increases the body temperature that can be tolerated prior to heat intolerance and exhaustion during uncompensable heat stress.

i.Level of evidence: B

ii.References: McLellan *et al.* [106], McLellan and Cheung [107]

D. Carbohydrate-electrolyte beverages that include desirable flavor, carbohydrate, and sodium chloride increase voluntary fluid intake compared with plain water in both occupational and athletic settings.

i.Level of evidence: A

ii.References: Clapp *et al.* [108], Mudambo *et al.* [109], Wilmore *et al.* [110]

Hydration and Health

Exertional muscle cramps

Severe muscle cramps that occur during exercise are often called *heat cramps* because they occur more frequently with heat stress. The cause of muscle cramps during and immediately after exercise is not known, but is thought to be related to salt loss, dehydration, and muscle fatigue accompanying exercise. These cramps are possible during any type of sport, but are more common in football "two-a-days," tennis matches in hot environments, 100-mile cycling races, and late in tropical triathlons. Similar cramps can occur in winter sports, such as in long-distance cross-country skiers and in ice hockey players. This paradox—heat cramps in winter sports—suggests that even when the macroclimate is cool, the microclimate of some athletes can be hot, and that heat cramps can be considered sweat cramps. An alternate explanation could be that muscle fatigue, salt loss, and fluid losses induced by prolonged exercise and not entirely dependent on environmental heat stress cause severe muscle cramping.

1. Severe muscle cramps that occur during exercise are related to large losses of salt in sweat, dehydration, and muscle fatigue.

A. Athletes prone to muscle cramps during and after exercise tend to sweat more heavily and lose considerably more sodium in sweat than those who do not experience cramps.

i.Level of evidence: C

ii.References: Bergeron [111], Stofan *et al.* [112]

B. The incidence of muscle cramping during and after exercise in hot conditions can be reduced by increasing dietary salt content and remaining well hydrated during exercise by ingesting beverages containing salt.

i.Level of evidence: D

ii.References: Bergeron [113], Anderson and Eichner [114]

C. Heat cramps usually occur late during practice or competition, implicating muscle fatigue as a factor.

i.Level of evidence: D

ii.References: Bergeron [113], Schwellnus [115]

D. There is little evidence that supplementing with potassium, magnesium, or quinine is effective in reducing the risk of muscle cramps associated with exercise.

i.Level of evidence: D

ii.Reference: Bergeron [113]

2. Exercise-associated muscle cramps can be treated effectively with oral beverages that contain 50 to 100 mmol/L of sodium chloride (salt) and/or intravenous infusion of normal saline.

i.Level of evidence: D

ii.References: Bergeron [113], Anderson and Eichner [114]

Serious exertional heat illness

Serious heat illness includes the conditions of heat exhaustion and heat stroke. Exertional heat illness can occur during physical exercise when the combination of heat gain from metabolic and environmental sources exceeds the body's capacity to remove excess heat and, as a result, the core temperature rises. In addition, some cases of serious heat illness are probably associated with increased susceptibility of body tissues to heat stress rather than an inability to thermoregulate. Although severe exertional heat illness occurs more frequently in hot-humid and hot-dry environments during high-intensity or fast-pace activity, heat stroke can occur at ambient temperatures as low as 10 °C (50 °F). Clothing and equipment that inhibit body heat loss increase body heat storage and fluid losses. Symptoms of heat illness are nonspecific and include exhaustion, fatigue, feeling hot or cold or lightheaded, nausea, stomach cramps, headache, muscle cramps, and palpitations. Elevated body temperature leads to altered mental status, central nervous system (CNS) changes, altered vital signs, hyperventilation, vomiting, muscle spasms, diarrhea, tachycardia, and inability to walk. The symptoms of heat stroke, although defined by significant CNS involvement and usually accompanied by evidence of other tissue and organ injury, are often nonspecific and can be misinterpreted as severe heat exhaustion if core (rectal) temperature is not measured to confirm body temperature elevation. Common CNS changes associated with exertional heat stroke are confusion, amnesia, sensory motor deficits, visual disturbance, disorientation, impaired concentration, headache, inability to walk, dizziness, seizure, delirium, stupor, and coma, but initial lucid intervals are possible.

1. Exertional heat stroke can occur in hot conditions without dehydration if the heat from muscle work cannot be removed from the body at a rate sufficient to prevent a progressive rise in core temperature.

i.Level of evidence: B

ii.References: Armstrong *et al.* [116], Brodeur *et al.* [117], Noakes *et al.* [118], Sonna *et al.* [119]

2. Dehydration increases the risk of heat exhaustion and heat stroke during and immediately after activity.

A. Dehydration compromises cardiac output and the capacity of the cardiovascular system to transport metabolic heat to the body surface.

i.Level of evidence: A

ii.References: Sawka and Coyle [93], Kenney *et al.* [120], Montain and Coyle [76], Casa *et al.* [2], Nadel *et al.* [121], Montain *et al.* [122]

B. Dehydration increases the risk of heat injury by reducing blood flow, making it more difficult to perfuse vulnerable tissues.

i.Level of evidence: B

ii.References: Gonzalez-Alonso *et al.* [123], Bouchama and Knochel [124], Hall *et al.* [125]

C. Fluid loss from vomiting or diarrhea increases the risk of exertional heat illness.

i.Level of evidence: D

ii.References: Group consensus, Whang [126]

3. Maintaining normal hydration levels reduces the risk of exertional heat illness.

A. Maintaining normal hydration levels supports cardiovascular function, heat transport, and sweating capacity.

i.Level of evidence: A

ii.References: Sawka *et al.* [72], Montain and Coyle [76], Adolph [12], Ladell [127]

4. Athletes with severe heat exhaustion and exertional heat stroke during or following prolonged exertion often require a large volume of fluid to replace losses. Severe heat illness victims are often dehydrated and have difficulty sustaining adequate cardiac output.

i.Level of evidence: C

ii.References: Shadid *et al.* [128], Seraj *et al.* [129], Adolph [12]

5. Other equally important risk factors for exertional heat stroke are fast-paced exercise, inadequate acclimatization to heat and humidity, inadequate conditioning, alcohol consumption the day prior to training or competition, ephedra-containing supplement use, recent illness, high body mass, poor fitness, a variety of medications, and hard training in heat/humidity on the previous day.

i.Level of evidence: B

ii.References: Armstrong *et al.* [130], Noakes *et al.* [118], Gardner *et al.* [131], Phinney *et al.* [132], Kark *et al.* [133], Armstrong and Maresh [134], Crandall *et al.* [135]

6. Athletes acclimatized to heat have a reduced risk of heat illness.

A. Five to 10 days of heat exposure and training will acclimatize athletes to heat, with physiologic adaptations that include improved cardiovascular stability, earlier sweating, increased sweat volume and distribution over the body, and decreased sodium concentration in sweat.

i.Level of evidence: A

ii.References: Armstrong *et al.* [136], Buskirk *et al.* [137], Pandolf *et al.* [138], Armstrong *et al.* [139], Wyndham *et al.* [,140141], Allan and Wilson [142], Lind and Bass [143], Houmard *et al.* [144], Bass *et al.* [145], Wenger [146]

B. Dehydration will negate many of the thermoregulatory advantages conferred by heat acclimatization and physical training.

i.Level of evidence: A

ii.References: Buskirk *et al.* [137], Sawka *et al.* [147]

7. The morbidity and mortality for exertional heat stroke cases is reduced when the problem is promptly recognized and treated with rapid reduction of core temperature. Submerging the trunk and limbs or trunk alone in an ice or cold water bath is the fastest method to reduce core body temperature. In addition, skin cooling reduces the cardiovascular strain by transferring blood from the periphery to central circulation. Other means to rapidly cool the body, such as ice packing the trunk, groin, neck, and axilla regions, or wrapping in ice water towels or sheets are less effective, but often adequate, treatment strategies.

i.Level of evidence: B

ii.References: Costrini [148], Armstrong *et al.* [116], Brodeur *et al.* [117], Clements *et al.* [149], Proulx *et al.* [150], Casa and Armstrong [151], Casa and Roberts [152], Inter-Association Task Force on Exertional Heat Illnesses Consensus Statement [153]

Exertional hyponatremia

The rapid dilution of serum sodium from normal levels of 135 to 145 mEq/L to levels below 130 mEq/L may lead to sufficient intracellular swelling to alter CNS function; a syndrome caled *symptomatic hyponatremia*. During prolonged activity, serum sodium can be diluted by excessive fluid intake alone or combined with a sodium deficit of the extracellular fluid due to sweat loss. Symptoms of hyponatremia are similar to dehydration, exertional heat exhaustion, and exertional heat stroke, and may include confusion, disorientation, progressively worsening headache, nausea, vomiting, aphasia, impaired coordination, muscle cramps, and muscle weakness. Complications of severe hyponatremia include cerebral and pulmonary edema that can result in seizure, coma, and cardiorespiratory arrest. Although exertional hyponatremia is generally treatable without long-term sequelae, deaths have occurred when blood sodium levels fall rapidly to low levels (*eg*, < than 120 mEq/L).

1. Exertional hyponatremia can occur as a result of excessive fluid ingestion alone or avid fluid ingestion combined with high sweat sodium losses.

A. Prolonged periods of excessive drinking can result in hypervolemia that dilutes the serum sodium to dangerously low levels.

i.Level of evidence: A

ii.References: Twerenbold *et al.* [35], Hew *et al.* [154], Armstrong *et al.* [155], Speedy *et al.* [156], Montain *et al.* [157], Speedy *et al.* [158], O'Brien *et al.* [159]

B. Large salt loss in sweat, such as occurs in "salty sweaters" (60–110 mEq Na+/L sweat), will contribute to the dilution of extracellular sodium and will reduce the amount of fluid intake necessary to produce symptomatic hyponatremia.

i.Level of evidence: A

ii.References: Vrijens and Rehrer [160], Smith *et al.* [161], Montain *et al.* [157]

C. Individuals who carry a gene for cystic fibrosis may lose excessive salt in sweat and be more prone to substantially dilute extracellular sodium with avid drinking.

i.Level of evidence: B

ii.References: Smith *et al.* [161], Orenstein *et al.* [162], Bar-Or *et al.* [163]

2. Exertional hyponatremia is relatively rare and appears to be most common during endurance activities such as running events lasting longer than 4 hours, tri-

athlons lasting longer than 9 to 13 hours, and prolonged military training.

A. Exertional hyponatremia is more common in slow-paced participants as they appear to take more frequent advantage of water availability and consume larger volumes when they drink than do faster-paced participants.

i.Level of evidence: C

ii.References: Speedy *et al.* [156], Davis *et al.* [164], Hew *et al.* [154], Speedy *et al.* [158]

B. Women seem to be at greater risk of developing exertional hyponatremia because their fluid intake sometimes exceeds their sweat rate and because

their smaller body mass (and total body water) can be more easily affected by over-drinking.

i.Level of evidence: C

ii.References: Davis *et al.* [164], Speedy *et al.* [156], Speedy *et al.* [158]

C. The incidence of symptomatic hyponatremia during endurance exercise events such as the marathon and triathlon is generally low (probably less than one in 1000 finishers), although isolated ultradistance races have produced higher incidence rates (40–50 in 1000 finishers).

i.Level of evidence: C

ii.References: Hew *et al.* [154], Noakes *et al.* [60], Speedy *et al.* [156], Armstrong [165]

3. Educational materials regarding prevention of hyponatremia should be provided to competitive and recreational athletes as well as occupational workers performing prolonged work lasting in excess of 3 to 4 hours.

A. Fluid intake during exercise should never exceed sweat loss. The difference between body weight (nude) before and after exercise gives an estimate of sweat rate and hence of fluid replacement volumes. Weight gain during activity indicates excessive fluid intake.

i.Level of evidence: A

ii.Reference: ACSM [4]

B. Athletes performing prolonged exercise lasting in excess of 3 to 4 hours should ingest snacks or fluids containing sodium to help offset the loss of salt in sweat. This is especially recommended for individuals who know that they lose excessive amounts of salt in their sweat.

i.Level of evidence: C

ii.Reference: Montain *et al.* [157]

Special populations: children and older adults

Hydration is a particular concern for children and the elderly because these groups are more susceptible to heat illness due to less effective thermoregulatory responses. The response of children and the elderly to dehydration is different from that of young adults; elderly individuals are often not able to maintain hydration as easily during exercise and children are at increased risk for numerous reasons.

1. Thermoregulatory systems in children are not as developed as in adults, and children are less heat tolerant than adults to a high climatic heat stress. Sweat rate and sweat rate per body surface area are less in children than adults, which decreases evaporative heat loss for cooling when exercising in a hot environment. the large surface area to body mass ratio in children increases their rate of heat absorption from hot environments.

i.Level of evidence: B

ii.References: Araki *et al.* [166], Bar-Or [167]

2. Children often do not voluntarily drink adequate amounts of fluid during physical activity and can dehydrate easily during activity.

A. Dehydrated children become hyperthermic faster than dehydrated adults in the same environment.

i.Level of evidence: B

ii.Reference: Bar-Or *et al.* [168]

B. Even a 1% to 2% reduction in body mass reduces aerobic performance in 10- to 12-year-old boys.

i.Level of evidence: C

ii.Reference: Wilk *et al.* [169]

C. Children will voluntarily drink more fluid during exercise in warm or hot environments when provided with a sports drink than when plain water is given. Voluntary drinking is further enhanced with the addition of 6% carbohydrate and at least 18 mmol/L Na (~ 100 mg/240 mL).

i.Level of evidence: B

ii.Reference: Rivera-Brown *et al.* [170]

D. Children with cystic fibrosis voluntarily drink less during exercise because their high sweat sodium loss reduces the osmotic drive to drink.

i.Level of evidence: B

ii.References: Bar-Or *et al.* [163], Kriemler *et al.* [171]

E. A flavored drink containing 50 mmol/L NaCl and 6% carbohydrate stimulates thirst in patients with cystic fibrosis.

i.Level of evidence: B

ii.Reference: Kriemler *et al.* [171]

3. Older adults (> 60 years) are less heat tolerant than younger adults in response to exercise heat stress and have higher heart rates, lower stroke volume, lower cardiac output, higher mean skin and core temperatures, and lower sweat rates than younger adults.

i.Level of evidence: A

ii.References: Kenney and Hodgson [172], Minson and Kenney [173]

4. Older adults (> 60 years) usually drink enough to remain well hydrated in free-living environments. However, when dehydrated, older adults rate their perception of thirst lower than younger adults and drink less as a result.

i.Level of evidence: B

ii.References: de Castro [174], Kenney and Chui [175], Spangler *et al.* [176]

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