

Dehydration, Hyperhydration, and Hyponatremia in Tropical Climates

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Summary. Six statements are presented with supporting data: (1) An important number of athletes train and compete in hot and humid conditions that impair their performance; (2) dehydration should be avoided when exercising in the heat; (3) many athletes arrive hypohydrated for their workouts or competitions; (4) complete rehydration is possible for some individuals; (5) quick post-exercise rehydration remains a challenge; and (6) exercise-associated hyponatremia is not likely to happen in the heat.

Exercise in the heat. This presentation is one of several topics related to exercise in the heat. In this context, it is important to start by understanding just how hot are the environmental conditions that athletes may face while competing and training in a tropical climate. The most widely used environmental heat stress index is the Wet Bulb Globe Temperature (WBGT). WBGT is a weighted average of dry bulb temperature (T_{db}), wet bulb temperature –which is sensitive to relative humidity and to wind speed (T_{wb}), and the radiation heat measured by the globe temperature (T_g), according to the formula:

$$WBGT = 0.7 T_{wb} + 0.2 T_g + 0.1 T_{db} \quad (3)$$

The American College of Sports Medicine (ACSM) has published updated, more detailed guidelines for the risk of heat illness during prolonged exercise using WBGT as the reference index. The specific guidelines should be consulted⁽³⁾, but for the sake of this paper, when WBGT is between 23°C and 28°C, the risk is high, and beyond 28°C it is very high.

WBGT has been measured during a wide variety of sports events and training activities; when other simultaneous data are collected, such as sweat rates, dehydration, and core temperatures for exercising individuals, it is possible to give a better picture of the type of challenge faced by these athletes. A recent paper by Aragón-Vargas et al.⁽²⁾ reported a professional football (soccer) game played in Nicoya, Costa Rica, under extreme heat stress: average WBGT was 31.9°C ($T_{db} = 34.9^\circ\text{C}$, or $\approx 95^\circ\text{F}$; $T_g = 48.8^\circ\text{C}$, or $\approx 120^\circ\text{F}$; and relative humidity = 35.4%). Average dehydration for the players was 3.4% of body mass (BM), in spite of aggressive drinking before and during the game. At the end of the game, at least 9 players had core temperatures higher than 39°C.

Figure 1 shows data for another professional football game played at an average WBGT of 26.8°C, in the city of Liberia, in Costa Rica (unpublished). Average dehydration was 2.74% BM (range: 1.4-3.9% BM) and the average fluid replacement was 43.8% of sweat

loss. While the heat stress was not as high as the other study, an important number of players were hyperthermic by the end of the game (7 players had core temperatures > 39.0°C). These conditions are challenging, and require close attention to hydration.

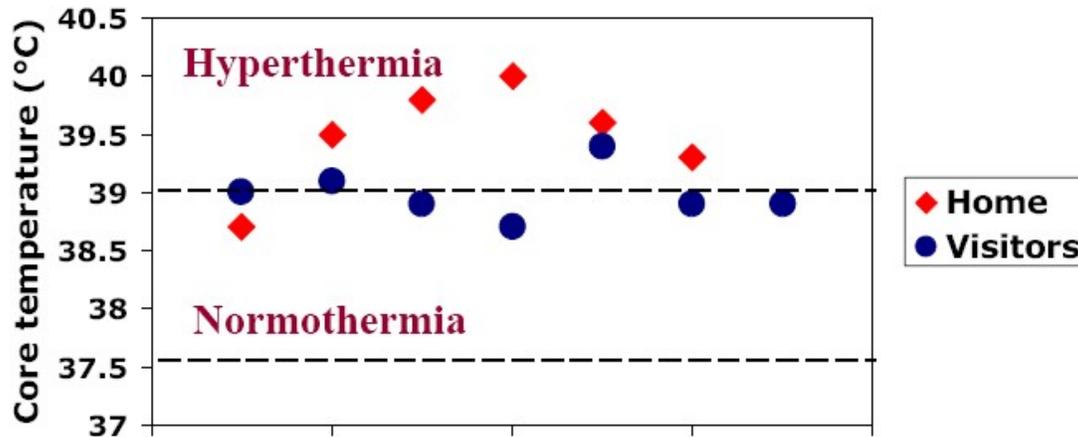


Figure 1. **Individuals**

Figure 1. Core temperature at the end of a professional tournament football game between Liberia and ADR, $n = 13$, WBGT = 26.8°C. Core temperatures were measured with ingested capsules, using a CorTemp™ CT-2000 recorder to manually register each measure in triplicate.

The case for avoiding dehydration. Depending on environmental heat stress, degree of acclimatization to exercise in the heat, and exercise duration and intensity, a mild to moderate dehydration may or may not represent a problem to the athlete. After a few decades of strong emphasis on the importance of hydration for good performance and for the prevention of heat illness, the pendulum swung back to the other extreme, with an important number of scientists arguing that moderate dehydration may not be so problematic after all. Coyle⁽⁸⁾ has explained that if the environment is cold or temperate (up to 22°C), dehydration up to about 2% BM has little impact on performance.

Too many people have interpreted that statement as meaning that 2% BM dehydration is safe, both from the point of view of performance as well as health. However, Coyle stated in the same paper that when people exercise in a hot environment, that is, $T_{db} > 30^{\circ}\text{C}$, “dehydration by 2% of body weight impairs absolute power production and predisposes individuals to heat injury” (p. 39). Therefore, it makes sense that when athletes train or compete in the heat, they should attempt to objectively match sweat loss with fluid intake; thirst alone has been shown not to be a reliable guide.⁽¹⁵⁾ Practical matters, as well as specific sport rules, will dictate how close athletes will be to meeting their goal.

Laboratory data is clear on the detrimental effect of dehydration on performance. A classic paper by Scott Montain and Ed Coyle⁽¹¹⁾ looked at this issue by having the study

subjects exercise for 2 hours at a moderate intensity in the heat ($T_{db} = 32^{\circ}\text{C}$), while drinking different amounts of fluid and therefore achieving different levels of dehydration. The study design allowed the authors to show a dose-response relationship between dehydration and peripheral blood flow, esophageal temperature, submaximal heart rate, and cardiac output. In a similar study, Coyle and Montain⁽⁹⁾ concluded that trained cyclists pedaling in the heat ($T_{db} = 33^{\circ}\text{C}$, 50% r.h.) for two hours will see a heart rate increase of 8 beats per minute, together with a rectal temperature increase of 0.3°C , for every 1000 mL of dehydration. Together, these studies show a clear impairment of physiological function when everything else, except for dehydration, is the same.

Unfortunately, these studies were not designed to look at the effect of dehydration on actual sports performance. The one study that addressed sports performance was published by Larry Armstrong et al. in 1985⁽⁴⁾. In that study, the subjects ran simulated track races, in a euhydrated or a hypohydrated condition. To produce dehydration without fatigue being part of the equation, the researchers used a diuretic to achieve 2% BM dehydration. Times were 9s, 78s and 165s slower in the hypohydrated state for the 1500, 5000 and 10000 meter races, respectively.

Poor initial hydration status. The study by Armstrong and colleagues cited above points to a particular issue which is difficult to argue against: starting a competition or workout session already in a state of hypohydration is not a good strategy, particularly if sweat rates are going to be so high that it will be impossible to drink at a similar rate. It is puzzling, therefore, that many athletes and recreational exercisers would show up for their competition or workout with indications of moderate to serious hypohydration.

One commonly used measure of hydration status is the urine specific gravity (USG)⁽⁶⁾: when humans are dehydrated, the renal system helps retain fluid by concentrating the urine, which translates in higher urine osmolality and specific gravity, and a darker urine color. Using this measure, Aragón-Vargas et al.⁽²⁾ showed that 7 out of 17 football players tested before a professional game in the heat arrived at the stadium with USG values higher than 1.020, that is, significantly hypohydrated. But perhaps more alarming are the results obtained from the tests carried out with Boca Juniors, a famous professional team in Argentina, in 2005 (unpublished data). The same players were tested in the morning and afternoon, as the team had two-a-day practice. All the players were familiar with hydration advice, and they were aware of the fact that the tests were being performed by the Gatorade Sports Science Institute[®]; one would have thought they would pay special attention to hydration. Figure 2 shows the USG values for all the players tested before their practice sessions: 19 out of 23 players arrived hypohydrated for the morning session, and even worse, 18 out of 22 did so for the afternoon session, after having ample time to correct the problem. Perhaps they were not concerned about the prevailing heat on that day, a moderate-risk WBGT of 20.9°C . Nevertheless, tests with different professional football teams have showed that there is always an important number of players who will start their practice or competition in a hypohydrated state.

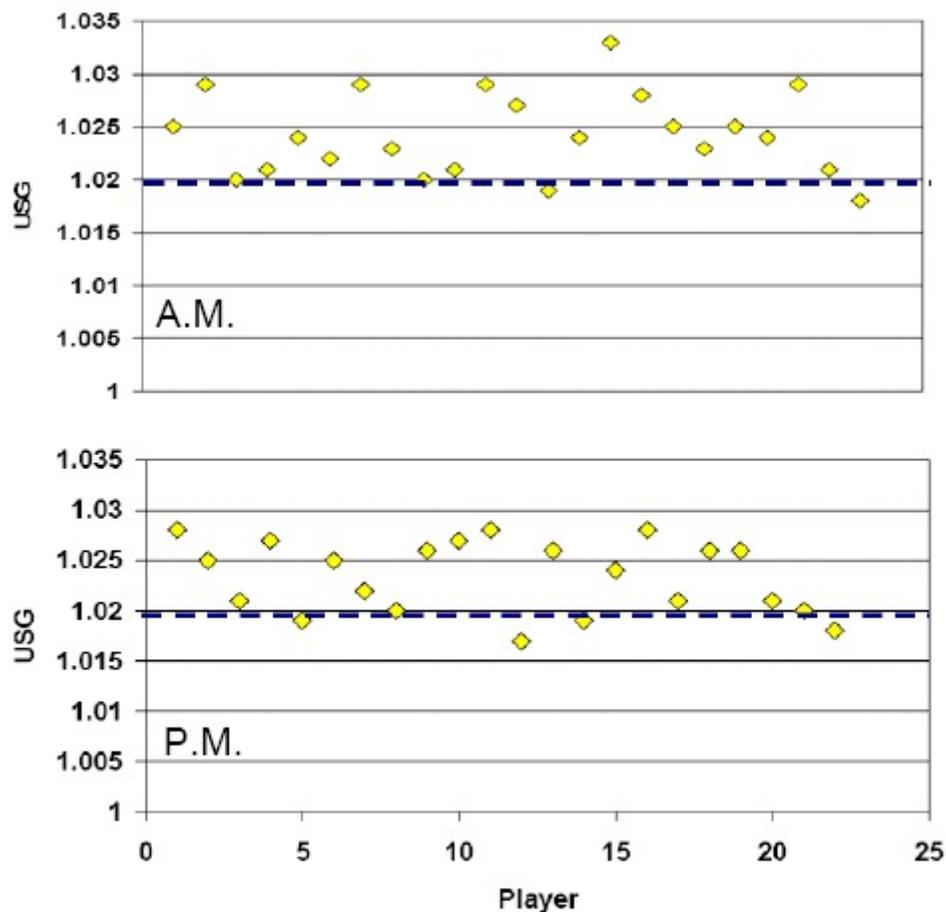


Figure 2

Figure 2. Initial hydration status of professional players from Club Atlético Boca Juniors, Argentina, before their morning and afternoon practice. Urine specific gravity was measured using an Atago urine specific gravity refractometer (Atago, Tokyo, Japan).

Measuring urine specific gravity is not accessible to all athletes, because it requires the utilization of an expensive refractometer. Urine color charts have been used as a practical alternative⁽⁵⁾, but more recently another method based on the urine volume response to a standard water load was published⁽⁷⁾. This and other practical methods are bringing initial hydration status assessment closer to the athlete; it is expected that better and more practical assessment will allow more athletes to start their training or competition in a euhydrated state.

Is complete rehydration desirable? Is it even possible? There are many situations when complete rehydration (drinking to match sweat rates) during exercise may not make sense, such as events where the time lost because of drinking is greater than the possible time gain from maintaining euhydration. The event may be short enough to cause only minimal dehydration, or the environment may be cold enough that any dehydration will have little, if any, negative effect on performance. But as already mentioned, when athletes exercise in the heat they should avoid dehydration.

Sometimes, environmental heat stress is so high or the effort is so intense, that the sweat rate exceeds maximum ingestion, gastric emptying, and intestinal absorption rates by far. Under those conditions, complete rehydration is not possible. There are data, however, suggesting that some athletes could be drinking more and maintaining euhydration. Figure 3 shows the results from the Liberia game mentioned above. This is a clear case where most players would not be able to drink to match sweat losses, unless they had practiced drinking large volumes and had access to fluids during the game: only four players had sweat rates of 1 liter per hour or less. All of these players, however, were drinking at a rate below $650 \text{ mL}\cdot\text{h}^{-1}$, while other players were ingesting fluids at higher rates. Two players had fluid ingestion rates close to $1000 \text{ mL}\cdot\text{h}^{-1}$. The data support the fact that some players could be drinking far more fluid during their competitions or training sessions, to better match their sweat losses.

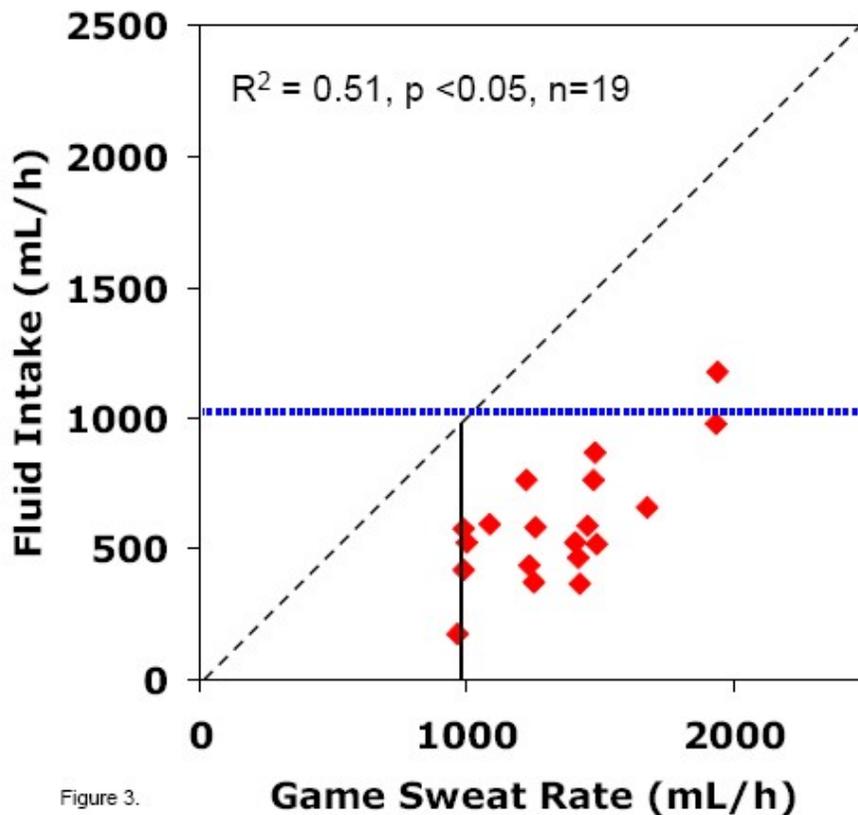


Figure 3. Individual fluid intake vs. sweat loss during a professional tournament football game between Liberia and ADR. WBGT = 26.8°C. Values are expressed as rates per hour. The dashed line indicates theoretical euhydration. The blue dotted line shows a tolerable fluid intake of 1 liter per hour. Individuals to the right of the vertical black line would have to push themselves too hard to maintain euhydration.

Quick post-exercise rehydration remains a challenge. Because in many cases athletes are not drinking enough to avoid dehydration, and sometimes they are expected to

perform again within a short period of time, it may be necessary to apply aggressive rehydration protocols to try to start the next effort in a euhydrated state. The task, however, is not easy, as the renal system will normally respond quickly to these hydration protocols by eliminating not only excess fluid, but even an important amount of the “fluid deficit”, returning the body to a hypohydrated state within a few hours; the problem is more severe when drinking plain water than with sports drinks⁽¹³⁾. New formulations, such as the utilization of milk, may be more effective at promoting fluid retention.⁽¹⁴⁾

A few recent papers should be mentioned. First, a paper by Shirreffs and colleagues⁽¹³⁾ evaluated the rehydration effectiveness of four commonly used drinks: pure water, mineral water, Apfelschörle (a mixture of apple juice and mineral water), and a conventional sports drink; the latter three are perceived to result in better fluid retention due to their electrolyte content. The study showed that only the sports drink was able to maintain euhydration four hours post-rehydration with a volume equivalent to 150% of sweat loss. Another paper from the same laboratory studied the effectiveness of milk for post-exercise rehydration⁽¹⁴⁾, using a similar protocol. In that particular study, the two milk beverages resulted in much better fluid retention than water and a sports drink, even though the sodium content of the milk+sodium drink was not more effective than regular milk. The results are promising even though lactose intolerance remains an issue for a large number of athletes.

Beverage temperature, in addition to its composition, may have an impact on fluid retention after post-exercise rehydration. Pérez-Idárraga & Aragón-Vargas evaluated urine elimination after water ingestion at cold (4-6°C), ambient (23-25°C), and warm (38-40°C) temperatures. No differences were found in urine volume or any of the other measures of rehydration effectiveness⁽¹²⁾.

There is an issue regarding rehydration after exercise in the heat which has received little attention: the contribution to fluid balance of continued sweating after the cessation of exercise. Figure 4 shows the results from a field study in the Costa Rican Caribbean city of Limón.⁽¹⁾ Nineteen male teenage athletes exercised outdoors at a heat stress index of WBGT = 26.5±0.6°C until they reached an average dehydration of 2.3% BM, on three separate occasions. They rehydrated with a volume of plain water, a conventional sports drink, or coconut water, equivalent to 125% of sweat loss. After 3 hours of monitoring, water was less effective at fluid retention than either coconut water or the sports drink. But the particularly interesting point is that urine loss during monitoring was considerably less than the loss from continued sweating. This makes sense since all the athletes recovered in the heat, as is often the case in real-life situations. Most post-exercise rehydration studies have followed protocols where the participants exercise in an environmental chamber but proceed to recover in an air conditioned room. The take-home message is that for exercise in the heat, it may be necessary to use even larger rehydration volumes over longer periods to offset continued sweat losses in addition to urine losses.

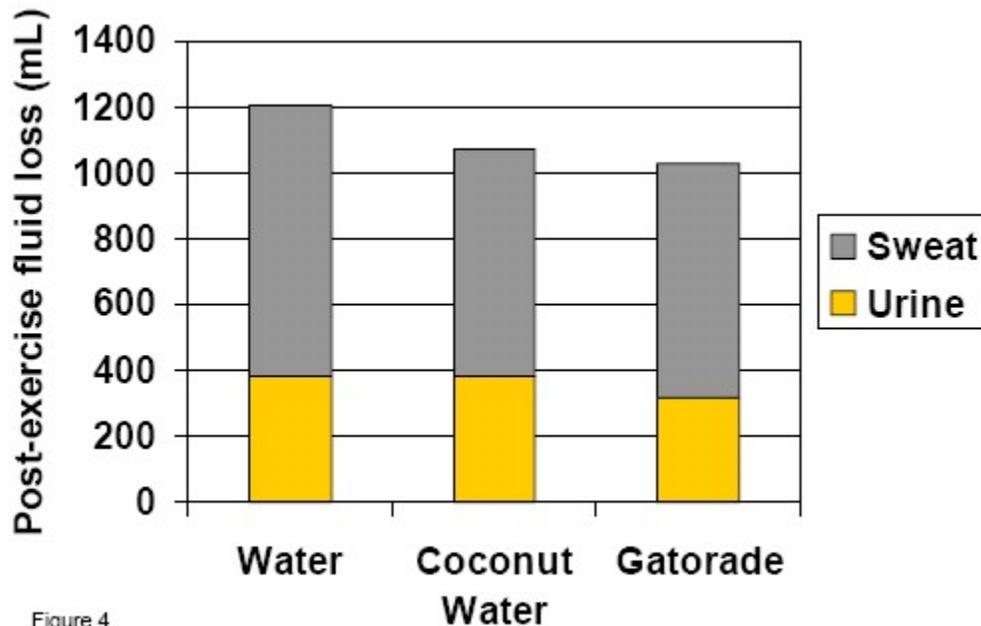


Figure 4

Figure 4. Additional fluid loss during recovery after exercise and rehydration in the heat. Monitoring time = 3 hours, $n = 19$. Adapted from Aragón & Madriz, 2000.

The risk of hyponatremia while exercising in the heat is low. A key consensus statement from 2005⁽¹⁰⁾ established excess drinking as the major cause of exercise-associated hyponatremia. Athletes overhydrate when their sweat losses are low and their fluid intake is high, such as when slow runners or cyclists compete in a cool environment. But when exercising in the heat, sweat rates are often higher than 1.5 L per hour; it is very difficult to drink too much under those circumstances. Professional football players, in particular, have repeatedly shown not to overhydrate during match play in the heat, not only because of the high sweat rates but also because of limited opportunities to drink due to sport regulations. Figure 5 plots fluid intake against sweat loss during a simulated match played at WBGT = 24.3 °C (unpublished data); none of the players got close to overdrinking. The message cautioning athletes not to overdrink should be restricted to the right sports and environmental conditions. In addition, it is necessary to repeat that relying solely on thirst is not safe.⁽¹⁵⁾

Conclusions. Exercise in the heat is a very specific challenge which requires particular attention. A number of recent studies focusing on important events taking place in moderate to cool conditions have downplayed the importance of hydration during exercise. Data were presented supporting the need to drink enough when exercising in the heat.

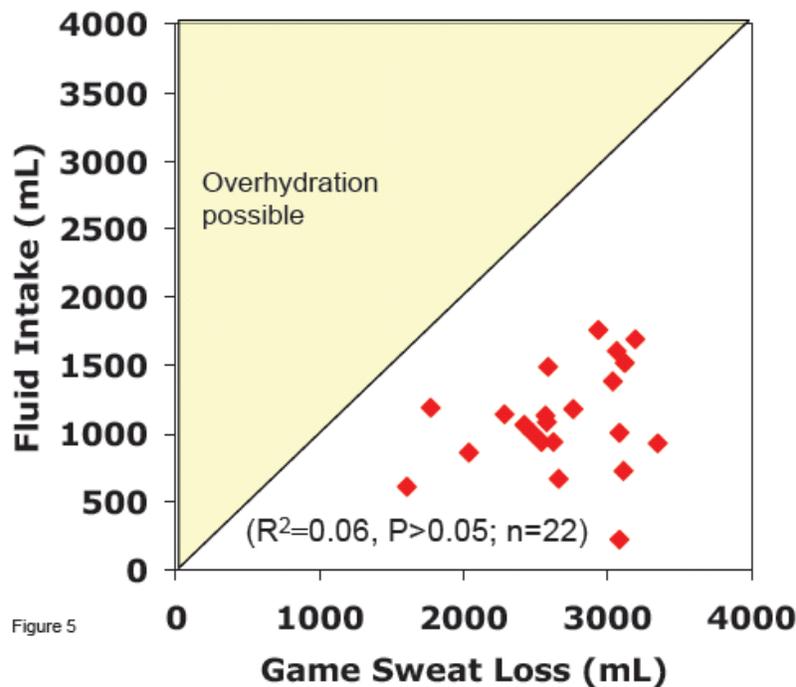


Figure 5. Individual fluid intake vs. sweat loss during a simulated game, Club Deportivo Saprissa, Costa Rica, at WBGT = 24.3°C.

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