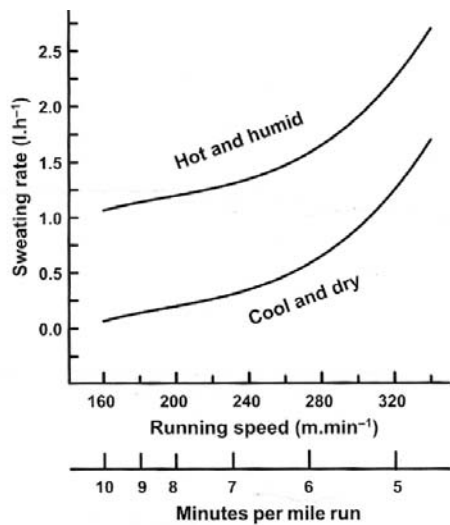


Dehydration and the Endurance athlete Constance Mier

Why do we sweat during exercise?

The body's attempt to maintain a normal temperature is called *thermoregulation*. Exercise increases heat production which challenges the body's thermoregulatory system. Intense exercise can increase heat production 20 times above rest. If the body did not have the means of removing heat, it would take only a few minutes for body temperature to reach dangerous levels. Thus, heat loss is essential to maintenance of body temperature and athletic performance, especially in warm environmental conditions. Sweating is the primary means of heat loss during exercise. Approximately 580 Calories are lost with every liter of sweat that is evaporated from the body's surface. The higher the intensity of exercise, the greater the sweat rate. In addition to the heat load imposed by exercise, the environment can add heat stress. Depending on the exercise intensity and the environment, some athletes can lose as much as three liters of sweat every hour during intense exercise. This is equivalent to more than 12 cups of fluid each hour.



This graph is from: Sawka M. N. & T. D. Noakes. Does dehydration impair exercise performance? *Med. Sci. Sports Exerc.* 39: 1209-1217, 2007.

Besides exercise intensity, what determines my sweat rate?

Several factors affect sweat rate including exercise intensity, hydration state, clothing, age, gender, training status, acclimation state and environmental conditions. During exercise, it is not unusual for metabolic heat production to exceed heat loss resulting in a higher than normal body temperature. However, under most conditions the increase in body temperature is maintained within a safe range and the hyperthermia experienced is mild. The ability to keep body temperatures within a safe range during exercise depends on the ability to match the heat production plus environmental heat load with heat loss. This ability varies greatly from one individual to the next.

How can I measure my sweat rate?

Simply measure nude body weight before and after exercise (convert to kilograms by dividing pounds by 2.2). Do this on a day that you do not consume anything during exercise or you consume only fluids. Keep track of the fluids you consume and note the quantity at the end of exercise. It is easier to measure your fluid intake in liters (1 liter is about 34 ounces or 4 cups). Assuming you do not urinate between weigh-ins, subtract your post-exercise weight from your pre-exercise weight and add the amount of fluid you drank during exercise. Your final calculation is the total amount of fluid you lost during exercise (remember, kilogram is equivalent to a liter). Determine your sweat rate by dividing the quantity by the number of hours you exercised (i.e., 75 minutes would be 1.25 hrs). For

example, say you exercised 2 hours and drank 1 liter of water during that time. Your pre-weight was 75 kg and your post weight was 74 kg. You lost 1 kg of body weight which is equivalent to 1 liter. Add that to the liter of water you drank and you have a total of 2 liters. Since you exercised for 2 hours, your sweat rate was 1 liter per hour.

How does my body adapt to a hot environment?

The human body is quite capable of adapting to extreme environmental conditions with proper hydration and repeated exposures (acclimation). One of the primary adaptations to chronic exposure to a hot environment is increased ability to sweat. This includes being able to sweat sooner, over a greater surface area of the body and at a much higher rate. In addition, the acclimated athlete can transfer more blood to his or her skin without compromising blood flow to the muscles. This allows heat to be removed from the body more effectively. At a given intensity, an acclimated athlete will have a lower body temperature as a result of his or her ability to lose heat at a higher rate. There is a catch to this, however. Because the acclimated athlete is capable of a higher sweat rate, risk of dehydration is higher. In other words, the acclimated athlete will require more fluids during exercise than an unacclimated athlete in order to avoid dehydration.

What happens if I don't replace the fluids lost during exercise?

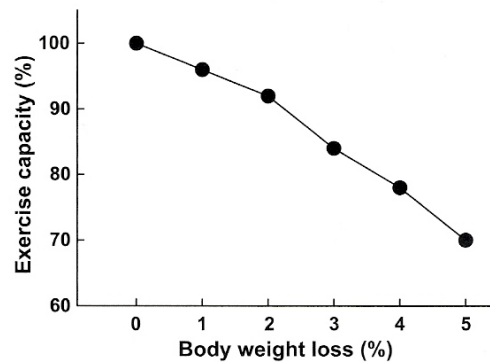
Because sweating is the primary means of heat loss during exercise, body fluid levels will be greatly affected. Compared to a sedentary person who begins an exercise program, an athlete is acclimated from repeated exposures and has a much higher sweat rate. In addition, athletes can work at a much higher metabolic heat load which is a function of exercise intensity. During a long race, training session or game, it would not be difficult for some athletes to lose as much as 8-10 liters of fluid from sweating. Imagine the difficulty of trying to maintain hydration during that period.

In addition, the athlete loses sodium and other electrolytes through sweat. Sweat is mostly water and is typically more dilute than plasma volume. As the body acclimates from repeated exposures to heat, it becomes more efficient at conserving electrolytes and sweat typically becomes more dilute. Regardless, sweat contains several minerals, mostly chloride and sodium. In well-acclimated athletes, sodium loss can range from 115-700 mg each hour. Greater amounts of sodium can be lost in less acclimated athletes who sweat heavily (2500-5000 mg per hour). Of course the amount lost can vary from day to day and according to the type of training or competition the athlete engages in.

Fluid and electrolyte loss, especially during prolonged exercise (greater than 1 hour) in the heat can lead to serious medical disorders such as heat exhaustion and heat stroke. The greater the amount of dehydration relative to body weight, the greater the strain on the thermoregulatory and cardiovascular systems. As little as 1% loss of body weight may result in undue stress on the cardiovascular system associated with an increase in heart rate and reduced sweat rate. Dehydration in excess of 2-3% of body weight (about 1.5-2 liters for a 70-kg person) can impair aerobic performance. Under conditions of dehydration the body cannot thermoregulate as efficiently and a dehydrated athlete's body temperature will increase as a result. From severe dehydration, body temperatures can reach dangerous levels placing the athlete at risk of heat exhaustion and heat stroke.

How will performance be affected by dehydration?

During prolonged, continuous exercise such as running or cycling performed in a warm environment, a loss of 2% body weight can impair performance significantly. The greater the environmental heat load, the greater will be the impairment. Other possible effects of dehydration (2-3% of body weight) on athletic performance include impairments in cognition such as short-term memory, visual-motor tracking, and attention.



What is the best way to stay hydrated during exercise?

For adequate hydration, 3 strategies should be considered:

Pre-exercise - The goal of fluid intake prior to exercise is to begin exercise in a normal hydrated state. Typically, if 8-12 hours has past since the last exercise session and if normal meals have been consumed, the athlete should be in a normal state of hydration upon beginning exercise. However, if the previous exercise session elicited a substantial loss of fluid and/or recovery time was inadequate, a more aggressive prehydration strategy may be warranted. About four hours prior to exercise, the athlete should try to slowly drink beverages in an amount of about 5-7 ml per kg body weight. This is approximately 400-500 ml (about 2 cups) for a 75-kg individual. If no urine is produced or the urine appears dark or concentrated, additional fluids (3-5 ml/kg or 200-400 ml for a 75-kg individual) should be consumed about two hours prior to exercise. Hydrating several hours prior to exercise provides adequate time for urine output to return to normal before beginning exercise. Beverages should contain about 500-1100 mg sodium per liter or be consumed with salted snacks or foods in order to stimulate thirst and retain consumed fluids.

During exercise - In terms of thermoregulation, a high sweat rate is advantageous to an athlete because he or she can more efficiently lose heat and avoid hyperthermia. However, with increased sweat rates comes a greater risk of dehydration when fluids are not adequately replaced. Thus, fluid replacement becomes more critical for the athlete. However, attempting to replace a high volume of fluid loss during exercise can be quite difficult, especially during a game or race. The *American College of Sports Medicine's Position Stand on Exercise and Fluid Replacement (2007)* recommends that the goal of drinking during exercise should be to prevent excessive dehydration (> 2% body weight loss). The table below provides some estimates based on body weight and sweat rate.

Body weight is provided in the left column, sweat rates are given at the top of the remaining columns.

	<i>.5 l/hr</i>	<i>1.0 l/hr</i>	<i>1.5 l/hr</i>	<i>2.0 l/hr</i>
60 kg	100 ml	600 ml	1100 ml	1600 ml
70 kg	300 ml	800 ml	1300 ml	1800 ml
80 kg	500 ml	1000 ml	1500 ml	2000 ml
90 kg	700 ml	1200 ml	1700 ml	2200 ml

Athletes must not rely on the thirst mechanism to tell them when to drink. Typically, thirst is not perceived until as much as 2% of body weight is lost from sweat. It is recommended that athletes such as marathon runners consume frequently in an amount ranging from 0.4 to 0.8 liters per hour, the lower end for slower, lighter athletes exercising in cooler environments and the higher end for heavier, faster athletes exercising in a warm environment.

Post-exercise - The goal after exercise is to fully replace fluid and electrolytes lost during exercise. When and how much the athlete consumes will depend on how quickly rehydration must be accomplished and the amount of the fluid-electrolyte deficit. With sufficiently long enough recovery

periods, consuming normal meals and snacks with adequate volumes of plain water should restore the normal state of hydration, as long as the foods and snack contain sufficient sodium to replace sweat loss. But, if dehydration is significant and the athlete has a relatively short recovery time (less than 12 hours), rehydration strategy must be more aggressive. If sodium is not adequately replaced during recovery, obtaining normal hydration will be prevented and excess urine production will be stimulated. Sodium consumed during recovery will help retain ingested fluids and stimulate thirst.

What kind of sport drinks should I consume?

It is recommended that sport drinks contain about 460-700 mg sodium per liter, 80-200 mg potassium per liter, and about 5-10% (50-100 g per liter) carbohydrate. The need for the specific electrolytes and carbohydrate will depend on the type and duration of exercise being performed. The sodium and potassium in a sport drink help to replace what is lost through sweat and the sodium in the drink also stimulates thirst. The carbohydrate provides energy by helping to maintain blood glucose levels, especially important during prolonged exercise. Non-fluid sources such as energy bars, gels and other foods can supply electrolytes and carbohydrate as well.

Do I need to add salt to my diet?

Electrolytes such as sodium are important to maintaining fluid balance in the body. Sodium is very easy to obtain from a normal diet because it is a major additive in many packaged or processed foods. The most common source of sodium is table salt (*sodium chloride*), often added to foods. Only one teaspoon of table salt contains about 2300 mg of sodium. Thus, it can be very difficult for most Americans to avoid exceeding the recommended maximum of 2300 mg per day. In fact, Americans consume over 5000 mg per day. When sweating is profuse such as during intense physical activity or exposure to high environmental heat, daily sodium losses can be high, especially in those with very high sweat rates and sweat sodium concentrations. For example, an athlete whose sweat contains 40 mmol of sodium per liter (an average value), will lose approximately 1840 mg of sodium by sweating 2 liters per day. In some athletes, sodium loss can exceed 3000 mg per hour. The amount of sweat and sodium loss can vary greatly among athletes, ranging from 20 to 80 mmol per liter of sodium and sweat losses exceeding 2 liters per hour. This predisposes an athlete to a large sodium loss. In fact, in one documented case a triathlete lost 13000 mg of sodium during four hours of exercise. Dietary sodium intake should match daily sodium loss, thus athletes will typically exceed the adequate intake recommendation of 1500 mg. The amount of sodium loss will vary from day to day and sodium intake should reflect this as well. Thus, under conditions when an athlete is sweating large quantities on a daily basis, he or she would likely need to be liberal with the salt shaker.

I've heard of something called hyponatremia. What is that?

Hyponatremia is a condition of excessively low sodium levels in the body. It is a risk among some endurance athletes who engage in very prolonged periods of exercise (greater than 4 hours) while consuming large amounts of water, especially in a hot and humid environment. Under these conditions, the athlete attempts to replace sweat loss with plain water. At the same time, electrolytes are being lost through sweat and are not being replaced. As a result of the overconsumption of water, sodium concentration in plasma volume decreases, possibly reaching dangerous levels. A sustained decrease in sodium concentrations can result in a rapid influx of water into the brain which can lead to brain swelling and severe neurological responses that can cause death, reported to have occurred in a few athletes. Non-fatal hyponatremia is common among ultra-endurance athletes and individuals who engage in prolonged intense exercise (e.g., marathons, triathlons, backpacking, military training).

How do I avoid hyponatremia?

Practically speaking, the two key risk factors for hyponatremia are excessive drinking or dehydration with large sodium loss from sweat. An athlete can suffer from hyponatremia by simply not replacing water and salt during prolonged exercise. In this case, the athlete can suffer from symptoms associated with dehydration, including hypotension, high heart rate, reduced sweat rate and increased body temperature. On the other hand, an athlete can adequately replace lost water by consuming water without sodium. In such a case, the athlete stays hydrated. But because of the loss of sodium from sweat, there is a decrease in sodium in the body and the water consumed helps to dilute the sodium concentration in plasma. Thus, hyponatremia can be associated with too much water consumption. Under these conditions, the athlete will not suffer from dehydration and will likely have normal heart rate, blood pressure and body temperature. Yet, some of the symptoms for hyponatremia are similar to dehydration. These symptoms include confusion, disorientation, headache, nausea, vomiting and muscle weakness. As a result, an athlete suffering from these symptoms upon crossing the finish line will often times be given water to help alleviate dehydration. But if the athlete is not dehydrated and has hyponatremia, consuming the water will only serve to worsen the condition. Factors associated with increased risk of hyponatremia include the following:

- Overdrinking
- Fluid retention (e.g., inappropriate hormonal response)
- Exercise duration (> 4 hr continuous)
- Low body weight
- Women (small stature)
- Pre-exercise overhydration
- Excessive Na⁺ losses (unacclimated, less fit)
- Insufficient Na⁺ in food consumption

Summary of the guidelines for fluid and electrolyte replacement (based on the 2007 recommendations from the *American College of Sports Medicine Position Stand on Exercise and Fluid Replacement*)

- Consume normal meals and fluids during recovery, adding salt to meals may be warranted when there is significant sweat loss during activity.
- During short recovery periods or when previous activity results in significant dehydration, consume 200-500 ml fluid containing sodium 4 hr and again 2 hr before exercise to promote hydration and allow time to excrete excess fluid.
- During exercise, start drinking early (don't wait for thirst) at regular intervals at a rate sufficient to replace water lost from sweat. Drink fluids that contains sodium, and for exercise performed more than an hour, fluids should also contain carbohydrates.
- Fluid loss should not exceed 2% of body weight. This usually requires about 200-300 ml every 10-20 min.
- Do not drink fluids in excess of fluid loss during exercise.
- Replace about 150% of water loss following exercise. Drink smaller amounts frequently and consume sodium with beverages.
- An athlete can determine whether they are sufficiently replacing fluids lost during exercise by weighing themselves before and after exercise.
- Avoid restricting salt in the diet.
- Don't use dehydration as a means to lose weight.

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