

Water and Salt Intake During Exercise

Hyponatremia: How to Recognize, Treat And Prevent It

Lulu Weschler is physical therapist, ultra cyclist and regular contributor to *UltraCycling*

As little as 2% dehydration adversely affects performance [1]. But, as little as 2% over hydration can cause life-threatening hyponatremia[2]. Clearly, you need to get your hydration needs just right. Hydration must be coupled with adequate sodium intake; sodium losses can be significant during prolonged exercise[3,4]. Barr et al[3] observed an average loss of 12 g salt in six hours of cycling at 86 degrees F and 30% relative humidity (2 g more than the average US daily intake of 10 g).

I. Water and Sodium Requirements

Since sodium requirements depend on water requirements, you must first figure out hydration needs. This you can do only by experiment, for which you must first have a reasonably good idea of your optimally hydrated weight.

Your optimally hydrated weight will vary. For day-to-day training and for multi-day tours, your pre-breakfast weight gives a reasonable estimate of what your weight should be at the end of the day's ride. But at the beginning of an event for which you have tapered, you may well weigh about 2.5% more than your optimally hydrated weight. This is because you start with a full load of stored glycogen plus the water molecules that "stick" on the glycogen. Burning glycogen both liberates this attached water and produces water as a metabolite[5,6]. Several hours after the start of an event, your weight should level out at roughly 2.5% less than what it was at the start. Keep track of various weights - morning, pre-ride, post-ride and evening, and put them in the context of what kind of riding you're doing, weather, and how you feel.

There is a simple test you can use to check optimal hydration weight. Bend your hand backwards, and pick up a fold of skin (lengthwise, using the thumb and forefinger of your other hand) on the back of your hand. A thin fold that stays raised (doesn't flatten out quickly) signals dehydration. A fold that you can't even pick up indicates bloating. A somewhat thin fold that disappears fairly quickly when you let it go represents optimal hydration. Skin elasticity decreases with age, making this a crude test (except in relative extremes of dehydration or over hydration) on people other than you.

Estimating Optimal Hydration

The goal is to find out how much water to ingest per hour, so that at ride's end you are at your optimally hydrated weight. In the examples in Table 1, this is assumed to be your morning weight.

Weigh yourself before and after a ride. Keep track of how much fluid you consume in fluid ounces. (You need to know the volume of your water bottles and CamelBack. Mark your bottle and CamelBack bladder in eight ounce gradations. Use a measuring cup to pour in eight ounces, mark the level with a magic marker, pour in another eight ounces, and mark again and so on.) Note the time for the ride. Then calculate fluid ounces per hour (see Table 1). The key equivalence: 1 lb = 15.2 fluid oz. water.

The longer the ride time, the more accurate your results. Bathroom scales are precise to no more than +/- 1 lb. Notice also that the less you weigh, the larger the impact of an error. Women's typically lower body weight is part of the reason they turn up hyponatremic more often than men [2,7].

Repeat the experiment at different temperatures. If you can't do this, then use Lon Haldeman's 75% for 10 degrees F rule as a guide: Haldeman needs 60 oz/hour at 100F, roughly 75% of that, or 45 oz/hour at 90F, and 32 oz/hour at 80F. At 70F and below, he needs about 15 oz/hr[8].

Table 1 Calculating Your Fluid Needs

Weigh yourself before and after a ride. Keep track of how many fluid ounces you ingest. 1 lb = 15.2 fluid ounces.

	A	B	C	D	E	F
	Time Riding, Hours (direct measure)	Fluid Ingested During Ride, Oz (direct measure)	Weight Change, Lb Wt after - wt before	Fluid Deficit or Excess, Oz 15.2 x C	Total Fluid You Need, Oz B-D	Fluid You Need Per Hour, Oz E/A
Example	10	400	+2	30 excess	370	37

Example 6 II	160	0	0	160	27
Example 8 III	310	-3	46 deficit	356	45

Estimating your sodium needs

Once you know your fluid intake under various conditions, then you can estimate your sodium requirements. Sodium intake is estimated proportionally to fluid intake, not to riding time. How much sodium you need depends on how much fluid (sweat and urine) you're losing and also on the sodium concentration in the fluid you've lost. During exercise, urine has approximately the same sodium concentration as sweat. A liter of sweat contains, on average, 50 meq sodium[3,9,10,11,12] which equals 1000 mg sodium/quart of sweat (see Table 2).

Example: You consume a 20 oz. water bottle of a sports drink. Since one quart equals 32 oz., you need $20/32 \times 1000 = 625$ mg sodium. The sports drink gives you 440 mg/quart, or 275 mg. To complement the fluid intake you still need about 350 mg sodium, which you can get from food or a salt capsule.

The volume of blood plasma increases by about 10% on the first day of hot weather riding[13], even if you are already fit. You need more sodium when you are acclimating to heat. For a 154 lb athlete, that extra plasma requires about 2.5 g salt (~ 1000 mg sodium) to be brought up to normal sodium concentration. Do this by increasing the ratio of salt capsules to fluid intake, by eating more salty snacks and/or adding more table salt to food.

Withholding sodium won't "teach" your body to conserve sodium. The trigger for sodium conservation appears to be core temperature, not sodium concentration[14]. You produce as much of the sodium-conserving hormones on your first day of heat acclimatization as on the last day; what changes is theorized to be the sensitivity of the kidneys and sweat glands to those hormones.

Competing in hot weather after you've trained in cool weather should be treated like the first few days of heat acclimatizing: increase your sodium intake.

Acclimatization decreases the sodium-in-sweat concentration. Studies of unfit subjects have shown as much as a 60% reduction of sodium-in-sweat as a consequence of acclimatization. So, you need somewhat less sodium when you are acclimatized to heat.

Sodium, sodium chloride and table salt

Sodium chloride is table salt. Table salt dissolves in water to give sodium and chloride ions. Dissolved salt is invisible, but a taste of its solution will confirm its presence!

Sodium is 0.39 the weight of sodium chloride, so table salt is approximately 2/5 sodium. A gram of salt (or salt tablets) contains 400 mg of sodium. USDA regulations require that "mg sodium" be printed on food labels (but not supplements). Since table salt is the stuff you can see and measure, it is useful to know that one teaspoon of table salt weighs about 6 g, or 6,000 mg. There are about 2.4 g sodium in one teaspoon salt. The average American daily intake of salt is estimated to be 10 g, or about one and two-thirds teaspoons salt.

Table 2 Sodium Concentration Of Various Fluids

Since one teaspoon of table salt has about 2400 mg sodium, normal blood plasma has about one and one-third teaspoons of salt per quart. 1 g = 1000 mg.

To convert from meq/liter to mg/quart, multiply by 21.8

To convert from mg/quart to mg/fluid ounce, divide by 32

Fluid	Sodium Concentration (Meq/Liter)	Sodium Concentration (Mg/Quart)	Sodium Concentration (Mg/Fluid Ounce)
Blood plasma, normal	135-145	2940-3160	91.9-98.8
Blood plasma, Hypo-natremic	<135	<2940	<91.9
Blood plasma, Hyper-natremic	>145	>3160	>98.8

Fluid outside cells	135-145	2940-3160	91.9-98.8
Fluid inside cells	14	305	9.53
Sweat	Average 50; (range, 20-80)	1090 (440 - 1740)	34.1 (13.8-54.4)
Urine	1-500	22 - 10,900	1.5-341
Normal (0.9% sodium chloride) IV	154	3360	105
3% sodium chloride IV	513	11,200	350
Campbell's chicken broth	263	5730	179
V-8 juice	114	2490	77.8
Sports drinks	Average 20; (range, ~18-23)	440 (390 - 500)	13.8 (12.2-15.6)

II. Hyponatremia

"Hypo-" means "too little." "Natrema" comes from the Latin word for sodium, and means "sodium status." Be careful to keep "hypo-" distinguished from "hyper-." Hyper means "too much."

Concentration is the key to understanding hyponatremia: concentration is the amount of sodium divided by the volume of blood plasma (typically expressed in milliequivalents, or meq, per liter). The body doesn't care about the total amount of sodium. It cares how much sodium you have for a given volume of blood plasma. Increase the amount of blood plasma by drinking too much water too fast, and you may not have enough sodium for that increased amount. You're dividing sodium by a larger number, and hence the concentration becomes smaller. If the volume of blood plasma is large enough, you've got hyponatremia, even if the total amount of sodium hasn't changed.

Popular press accounts of exercise-associated hyponatremia have emphasized hyponatremia associated with too much ingested water leading to water retention or bloating. All deaths from hyponatremia, and all serious cases reported in the literature have involved bloating[2,15,16,17,18]. The reason is brain swelling[19]. Extra fluid goes first from the gut into the bloodstream. Then it seeps out through the capillary membranes (the smallest blood vessels) into the extracellular space[5], mostly between muscle and skin, where because of the skin's stretchiness, there is plenty of room for expansion. But the brain is encased in a bony vault (the skull) that allows no room for expansion, and the result is an intolerable pressure, symptoms of which can be any or all of the following: change in mental status, confusion, incoordination, seizures (convulsions), coma, death.

A dehydrated athlete (dehydration is the exact opposite of bloating) can be hyponatremic. In a study of Ironman triathletes (9-15 hour events), there were more dehydrated, hyponatremic athletes at the finish than bloated, hyponatremic athletes[20]. But the dehydrated, hyponatremic athlete does not have enough fluid with which to develop brain swelling, and is not in imminent danger. However, a dehydrated, hyponatremic athlete who re-hydrates too quickly and without adequate sodium, could develop brain swelling.

Compounding the danger of bloating hyponatremia is that it can be misdiagnosed and treated as dehydration[17]. The reason for this is that bloating hyponatremia has two counter-intuitive features: the bloating itself and urination shutdown.

The Bloating Paradox

We tend to associate water retention with excess sodium, but studies point to bloating as a red flag warning of hyponatremia in exercising athletes. In these studies, athletes are weighed pre- and post event, and their post-event plasma sodium levels are measured. The universal finding is that the more an athlete weighs at the finish compared to the start, the lower the plasma sodium is likely to be. Athletes whose weight has increased (the "bloaters") have a high probability of being hyponatremic. Not one bloated athlete, nor even any athlete who has maintained weight, has been found to have plasma sodium concentrations that are too high[20,21,22,23,24,25,26,27,28].

Nor is it necessarily excess sodium that causes a bloating athlete to have retained water in the first place. In a heat acclimation experiment[29] one subject (of 10) bloated and became hyponatremic within four hours of beginning the experiment. During this time, the subject was consuming water at twice the rate of his fellow subjects. He was also urinating more as well, but not enough, and he developed bloating and hyponatremia. His bloating was not due to excess sodium: he started the experiment with a blood plasma sodium concentration of 134 meq/liter compared to the other subjects' 140+/-1 meq/liter (normal is 135-145 meq/liter).

Nor is the generalization that excess sodium always causes water retention true: water retention was not observed in an experiment³⁰ with 20-24 year old healthy males whose sodium chloride intake was ramped up from their daily average of ~12 g to 31 g.

The Urination Shutdown Mystery

It is possible to grossly overdrink[17,31] and overwhelm even the best of kidneys. Maximal urination rates are in the neighborhood of

one quart/hour [29,32]. If you're taking in fluid at a rate that exceeds what you're putting out via sweat plus urine, then you will bloat. Overdrinking has been the cause of many cases of hyponatremia[2,18,31].

It is also possible for urination to shut down in the presence of a moderate fluid overload, one that the kidneys at rest will excrete[33]. Why the urinary overflow valve jams shut for some people during exercise is not understood[5], but the result is bloating.

Urination shutdown can be dangerously misleading. If an athlete is not urinating, we think dehydration - but here is the exact opposite, an overhydrated athlete who has stopped urinating! To avoid making a mistake, consider the context: is the non-urinating athlete bloated? Has his/her weight increased? What has been his/her fluid intake over the last few hours?

Recognizing bloating hyponatremia

The only way to definitively diagnose hyponatremia is to take a blood sample and analyze it for plasma sodium. Fortunately bloating hyponatremia has its own set of symptoms, first of which is the bloating itself:

- Bloating: puffiness around the sock line and shorts band, at the wrists and hands around a watch and ring. The rider begins to feel and/or resemble the Michelin Man. The rider may experience a forehead headache which is accentuated by riding on a bumpy road.
- Weight increase: a bathroom scale is essential for crewed events. The 2003 Boston Marathon placed scales along the course and advised anyone who gained weight during the run to stop drinking[34].
- Nausea and vomiting: common in bloating hyponatremia, possibly more so than in other "exertional maladies"[31].
- Altered mental status in a bloated athlete: indicates brain swelling and represents a dire medical emergency as do convulsions (or seizures) and coma.

A bloated, hyponatremic athlete will typically not have an elevated core temperature[16]. The only definitive measure of core temperature is rectal temperature[35], but you can make an educated guess by checking skin temperatures at several different locations. Core temperature reaching ~104 degrees F is what signals the fatigue or malaise that forces an exercising athlete to stop[36]. Higher core temperatures are more likely in short events (for example, a 40 km time trial) than endurance events[37], but also represent a medical emergency for which the proper treatment is cooling.

Treating bloating hyponatremia

First, stop drinking (except as a means for salt ingestion)! Second, ingest salt! How much? Follow the emergency room treatment[2,38,39,40]: aim for a rapid but incomplete correction of hyponatremia. If you have salt tablets/capsules, take 300-500 mg sodium followed by the same amount 10-15 minutes later. The 2003 Boston Marathon medical team used "a hot salty broth" with concentration approaching that of the 3% sodium chloride IV to successfully treat hyponatremia[34]. Anecdotal reports (including my personal experience) suggest quick recovery, within 5-20 minutes. Slow down on sodium ingestion as soon as symptoms abate.

Do not start a normal (0.9% sodium chloride) IV and do not give a sport drink, both of which will only increase the fluid overload[2]. Do not resume drinking until you have urinated the overload[34].

Dehydrated and HYPERnatremic

If you replace nothing while exercising, neither water nor sodium, you will initially become dehydrated and eventually have a too high sodium plasma concentration (hypernatremic). Sweat is a filtrate of blood plasma, filtered by the remarkably sophisticated sweat glands. Sweat is more dilute than blood plasma (see Table 2). You lose relatively less sodium than water in sweat, so relatively more sodium than water stays in the blood plasma. Hence, sodium concentration in blood plasma increases (you are dividing a somewhat smaller number, amount of sodium, by a much smaller number, volume of plasma.)

Non-bloating HYPOnatremia

You can make yourself dehydrated and hyponatremic by replacing water somewhat inadequately and sodium way too inadequately. What water you are ingesting is not enough to keep you properly hydrated, but enough to dilute the plasma sodium concentration to where you will become hyponatremic.

If you get in this state, you may know that you are dehydrated (your weight will have decreased). But there may be no specific symptoms to tell you that you are hyponatremic. It makes sense to re-hydrate with sodium; ingest salty snacks and/or sodium capsules or tablets as you re-hydrate.

Summary

The key is prevention. Determine your fluid and sodium requirements and follow them. Remember

- A bloated athlete is overhydrated, the exact opposite of dehydrated.
- Bloating is a red flag for hyponatremia.
- Mental changes plus bloating in an athlete indicate hyponatremia with brain swelling, and represent a dire medical emergency.

- Don't be fooled by a bloated athlete who is not urinating: he/she is overhydrated and on the way to hyponatremia if not already there.
- Don't be fooled into thinking that an athlete who is throwing up is becoming dehydrated. Vomiting is frequently a symptom of hyponatremia.
- Do not give a bloated athlete any fluid (except as a vehicle for salt).
- Give a bloated athlete salt.
- When it is hot and an athlete is distressed, do not automatically conclude that the cause is dehydration and the remedy is fluid ingestion.
- Sweat typically has 1000 mg sodium/quart; a typical sports drink has 440 mg sodium/quart. If during a sufficiently long ride, you ingest nothing but sports drinks, you will become hyponatremic at some point.

Be wary of generalized prescriptions, especially those that begin with "an athlete should consume no more than . . ." or "at least . . ." Let careful observations be the touchstone for your needs. If you find you require more/less water, or more/less salt than you expected after reading some treatise on the topic, then so be it.

More on [electrolyte and fluid](#) requirements in endurance athletes.



Triathlon