Ironman Triathlon Training: Hyponatremia and Hydration

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It wasn't too long ago when athletes in the Ironman triathlon were told to take on board as much water as they could to prevent dehydration. They were told to get most of this during the bike as access to fluids in the swim isn't possible, and it's harder to swallow fluids whilst running.
'Drink before you are thirsty' was the usual mantra.

Well that advice just doesn't cut it these days, and athletes need to take a much more calculated approach with their rehydration strategies. Over-hydration (drinking too much water) can result in a serious condition known as Hyponatremia. This condition can result in serious consequences such as death.

Are you thinking that this doesn't apply to you? **THINK AGAIN**. A study by Speedy et al (1999) reported that 18% of the 330 race finishers at the 1997 New Zealand Ironman triathlon were hyponatremic. The authors concluded that fluid overload was responsible for 73% of those individuals with severe hyponatremia. It was also found that 29% of the athletes in the 1984 Hawaiian Ironman triathlon had developed the condition. In addition, Davis et al (2001) chronicled 26 cases of symptomatic hyponatremia from the 1998 and 1999 San Diego marathon events. The average finish time for the 26 runners was 5 hours, 38 minutes (range = 4:00 to 6:34), and many runners admitted drinking as much fluid as possible during and after the event. How much did they drink? That remains unclear, but plasma sodium values ranged from 117 to 134 mmol/litre, so excessive drinking is a strong possibility. Moreover, sweat sodium loss—although not measured in this study—likely contributed to the problem.

Hyponatremia: The Facts

Hyponatremia, or "water intoxication" (definition), is a disorder in fluid-electrolyte balance that results in abnormally low plasma sodium concentration (<135 mmol/L; normal = 138-142 mmol/L). A sustained decrease in plasma sodium concentration disrupts the osmotic balance across the blood-brain barrier, resulting in a rapid influx of water into the brain (Murray, R. 2003). This causes brain swelling and a cascade of increasingly severe neurological responses (confusion, seizure, coma) that can culminate in death from rupture of the brainstem.
The lower and faster blood sodium falls, the greater the risk of life-threatening consequences. A decrease in plasma sodium concentration to 125-135 mmol/L usually results in little more than gastrointestinal symptoms such as bloating and nausea. Below 125 mmol/L, the symptoms become more severe and include confusion, throbbing headache, wheezy breathing, swollen hands and feet, unusual fatigue, and incoordination. When plasma sodium concentration drops below 120 mmol/L, seizure, coma, and death become more likely. However, some athletes have survived hyponatremia of <115 mmol/L (Backer et al., 1993), while others have died at >120 mmol/L (Gardner, 2002a).

Severe cases, according to USATF (USA Track and Field), can cause grand malseizures, increased intra-cranial pressure, pulmonary edema (fluid in the lungs), respiratory arrest and even death. When exercising for a long time, triathletes lose sodium and other minerals in their sweat. Drinking too much water while at the same time losing sodium can result in a too-low sodium level, or hyponatremia.

Hyponatremia can be caused by dozens of different factors, but in triathletes excessive drinking is often, but not always, the common denominator. Even in the absence of other physiological provocations, excessive drinking alone can result in hyponatremia, as has occurred in people who have ingested large volumes of fluid (e.g., 3 litres of fluid in an hour) in attempts to produce a dilute urine to escape detection of banned drugs during drug tests (Zehlinger et al., 1996; Gardner, 2002b). Although hyponatremia is often associated with prolonged exercise, it can also occur at rest when too much fluid is ingested too quickly.

Hyponatremia can also occur with severe hyperglycemia or with glycerol loading (Freund et al., 1995) when water retained in the vascular space is sufficient to temporarily reduce blood sodium concentration.

During exercise, and particularly during exercise in the heat, urine production declines 20—60% from resting values due to a decrease in kidney blood flow, which results in a decreased rate of urine production (Zambraski, 1990). At the same time, the kidneys are reabsorbing both sodium and water in response to sympathetic nerve stimuli and to exercise-induced increases in aldosterone (Zambraski, 1990). As a result, exercising humans have a reduced capacity to excrete water; a normal physiological response that nevertheless increases the risk that excessive drinking will lead to hyponatremia. The capacity of the kidneys to process excess fluid can also be overwhelmed at rest. Whenever fluid intake exceeds the maximal rate of urine production, plasma sodium will unavoidably fall. Speedy et al. (2001) and Noakes et al. (2001) showed that plasma sodium levels can quickly plummet when resting subjects overdrink water. The volumes of water ingested in these studies (~1.5 litres/hour over 2-3 hours) could easily be consumed by an overzealous drinker either the evening before or the morning of a race. Most adults can drink 1.5 litres (1.6 quarts) or more per hour, exceeding maximal urine production of about 1,000 ml/hour (Zambraski, 1990). Under most circumstances, modest overdrinking presents little threat of hyponatremia. In fact, most people overdrink periodically throughout the day, with the excess water soon lost as urine. However, some athletes may drink large volumes of fluid in the days preceding the race in a misguided attempt to stay well hydrated or may inadvertently overdrink because their daily fluid intake remains high even though their training load has decreased. For example, Eichner (2002) noted that a woman who experienced hyponatremia in a marathon race drank 10 litres (10.6 quarts) of fluid the night before. Regardless of the reason, excessive drinking before, during, and after exercise dramatically raises the risk of hyponatremia.

Although dehydration remains the primary challenge for the vast majority of athletes, hyponatremia should be recognized as a possible threat to those athletes who go overboard in their hydration practices. With prolonged exercise in the heat, sweat loss may deplete the body of 13 to 17g of salt per day. This is approx. 8g more than is normally provided in the daily diet, therefore it is imperative that lost sodium is replaced (Mcardle et al, 1996).

Who is at Risk of Hyponatremia?

Hyponatremia is very rare in races lasting less than four hours in length and becomes more frequently evident in races up to and longer than eight hours (i.e. half ironman and ironman triathlon). It seems most common in female and beginning marathon runners and triathletes for two reasons:

1) They are on the race course for many hours more than the elites, losing lots of sodium in sweat. Slower triathletes tend to be at a greater risk as they have more time and easier opportunities to drink excessively.

2) They are hyper-vigilant about staying hydrated. They drink lots of water in the days before the race, and then stop at every fluid station along the course (Eichner, R)

Hyponatremia was three times more common in women than in men in a study of finishers at the 1997 New Zealand Ironman triathlon (Speedy, 1999). Backer et al. (1999) found that six of seven hikers who suffered from hyponatremia in the Grand Canyon were female. These findings led to the hypothesis that females are somehow more susceptible to hyponatremia (Eichner, 2002). This gender trend, however, may be more behavioural than biological. Anecdotes suggest that females are more vigilant drinkers (witness the propensity for women to carry bottled water with them throughout the day) and female athletes may be more likely to heed, and sometimes exceed, advice from coaches and experts. So women, more than men, may overdo the advice that "staying well hydrated is good for health and performance."

Even if the risk of hyponatremia is not greater in females, the clinical outcome for females is worse than for males (Ayus et al., 1992). This may be because estrogen inhibits the enzyme responsible for moving potassium out of brain cells (Arieff, 1986). The response to the swelling caused by hyponatremia is to transport potassium out of the cell, thereby reducing intracellular osmolality and offsetting the influx of more water into the cell (Adrogué & Madias, 2000). Accordingly, if the sodium-potassium ATPase enzyme is inhibited by estrogen, the clinical outcome of hyponatremia may be graver. According to Ayus and Arieff (1992), young women, who have relatively high levels of estrogen, are 25 times more likely to die or have permanent brain damage as a result of postoperative hyponatremic brain swelling compared to men or postmenopausal women, who have relatively low levels of estrogen.

Athletes with ‘salty sweat’ are also more susceptible to hyponatremia. Highly fit athletes who are well acclimated to exercise in warm environments usually excrete sweat with sodium concentrations less than 40 mmol/litre of sodium, because the capacity of the sweat glands for sodium conservation is enhanced with heat acclimation and improved aerobic fitness. This reduction in sodium loss not only helps protect blood volume, but also reduces the risk of hyponatremia. However, relatively unfit and unacclimated individuals, and even some highly trained athletes, may excrete sweat containing sodium concentrations greater than 60 mmol/litre. These "salty sweaters", particularly those who have high sweat rates, can lose large amounts of sodium. For example, during an Ironman triathlon, an athlete with a normal sweat sodium concentration of 40 mmol/litre, losing a modest 1.0 litre of sweat each hour, would lose 11.0 grams of sodium (contained in 27.6 grams of sodium chloride) in 12 hours of racing. Of course, an athlete with saltier sweat would lose considerably more. The important consideration is that salt loss through sweating can be a contributing factor to the etiology of hyponatremia, with larger salt losses conferring greater risk.

In a review of exertional hyponatremia, Montain et al. (2001) provided estimates of the plasma sodium concentration changes that will occur during prolonged exercise when water intake is equal to sweat loss. Their calculations indicate that athletes who excrete sweat containing high levels of sodium are at greater risk of hyponatremia because it takes less water intake to induce dangerously low blood sodium levels. Using their calculations, it can also be estimated that high sweat sodium losses alone can result in hyponatremia during prolonged exercise (e.g., 9 hours or more) even in the absence of overdrinking. In addition, their calculations demonstrate that smaller athletes will be at a greater risk of hyponatremia because they have less ECF to dilute (smaller ECF volumes may be one reason why female athletes appear at greater risk of hyponatremia. For example, even if a male and female have the same body mass, the female has less total body water and less ECF, increasing the relative risk of hyponatremia.)

Hyponatremia is usually caused by a combination of sweat sodium loss and excessive water intake. As suggested by Hiller (1989), it is possible for dehydrated athletes to become hyponatremic during prolonged events if they lose a lot of sodium in sweat and drink water (and/or other salt-poor beverages) to replace most but not all of their sweat. For example, if in a long, hot race, an athlete loses 10 litres of salty sweat and drinks 8 litres of water, the athlete will become both dehydrated and hyponatremic. This is consistent with observations of physicians at the Hawaii Ironman triathlon, where some finishers arrive at the medical tent with signs and symptoms of dehydration (e.g., sunken eyes, tented skin—when skin on the back of the hand is pinched, it remains folded or "tented", ongoing low blood pressure when standing, etc.), yet are also hyponatremic. However, additional research is needed to confirm the likelihood of hyponatremia in dehydrated athletes.

How to Avoid Hyponatremia

DRINK TO STAY HYDRATED, DON'T OVERDRINK - Excessive drinking dramatically increases the risk of hyponatremia. It is vital not to overdrink before training or competition, because doing so can lower blood sodium before the event begins. Also, don't overdrink during or after exercise. Your fluid replacement plan should be designed to avoid or at least minimize dehydration. Weight gain during training or races is a sure sign of overdrinking. A simple way to gauge fluid needs is to weigh nude before and after a workout. A minimal weight loss indicates an effective fluid-replacement regimen. Weight loss of more than 1 - 2 pounds indicates dehydration and a need for drinking more during your next exercise session. Gaining weight during exercise is a sure warning sign of excessive drinking, so fluid intake should be reduced during subsequent bouts of exercise. Also, clear urine indicates good hydration status,

MAINTAIN A SALTY DIET to make certain you replace all of the salt lost during training - which can be considerable in some athletes. During a long race (e.g., more than four hours), consider eating salty snacks such as pretzels, especially if you are a salty sweater (skin and clothes caked in white residue). Also, eat a salty diet for the few days before the race (Eichner, 2002)

FAVOUR SPORTS DRINKS over water during training and competition, to keep your body hydrated, fueled and salted. The flavor of a sports drink will encourage you to drink enough to stay hydrated while providing the electrolytes to help replace what is lost in sweat during long periods of exercise.

RECOGNIZE THE WARNING SIGNS of hyponatremia. When in doubt, stop exercise, stop drinking, and seek medical help fast. In other words, don’t get to the stage where you require medical treatment.

What Should Athletes Drink?

Athletes should choose a sports drink containing adequate sodium to help offset hyponatremia. Research shows that fluid intake is enhanced when beverages are cool (~150C), flavoured and contain sodium. This makes sports drinks an ideal choice during exercise. Sports drinks are not gimmicks. They are legitimate products that are well researched and proven to improve fluid intake and performance. A lot of science has gone into developing the flavour profile of sports drinks so that they encourage fluid intake during exercise. In addition, sports drinks contain carbohydrate at a concentration (6-8%), which allows refuelling to take place during exercise. Several studies demonstrate that use of sports drinks will improve fluid intake. A study conducted with AIS netball and basketball players in 1999 demonstrated better fluid balance with a sports drink compared to water.

This is consistently observed across AIS sporting programs. Even athletes who prefer to drink water during exercise, demonstrate better fluid intake when forced to drink sports drink.

In the past, it was believed that sports drinks only benefited the performance of exercise greater than 90 minutes. However, in recent years, the intake of carbohydrate and fluid has been shown to be beneficial for high intensity exercise of approximately 60 minutes. This makes sports drinks a good option for many types of sporting activity.

Water is still a suitable option during exercise. However, water drinkers need to be aware that water does not stimulate fluid intake to the same extent as sports drinks. Drinking to a plan is therefore crucial when drinking water. Don't rely on thirst.

Cordial, soft drinks and juice generally contain greater than 10% carbohydrate and are low in sodium. This can slow down gastric emptying and makes these drinks a less suitable choice, especially for high intensity activity.

Some athletes exercising at low intensities may tolerate juice, soft drink and cordial but in most situations, sports drinks are the better option (Minehan, 2001).

Which Sports Drink is the Best?

Food standards in Australia place restrictions on the formulation of sports drinks. As a result, sports drinks sold in Australia are very similar in composition. See the table below. Choose a sports drink that has 6-8% carbohydrate, ~20mmol/L sodium, is affordable, comes in a convenient package and tastes good.

Drink	CHO (%)	Sodium (mmol/L)	Cost per Unit	Cost per Litre
Isosport	6.7	18	$8.00 per 600 g powder $1.56 per 600 ml RM	$1.00 (powder) $2.60 (RM)
Gatorade	6.0	18	$9.84 per 500 g powder $1.62 per 600 ml RM	$1.23 (powder) $2.70 (RM)
Powerade	8.0	10	$1.72 per 600 ml RM	$2.87 (RM)
PB Electrolyte Drink	6.8	25	$19.80 per 500 g powder*	$3.17 (powder)
Energiser	6.0	18	$1.12 per 600 ml RM	$1.87 (RM)
Staminade	5.0	10	$5.79 per 275 g powder	$1.05 (powder)

Fluid Replacement Guidelines

Drink one litre of fluid for every litre lost during a race, in a one-to-one ratio. Fortunately, athletes can easily estimate their own fluid requirements by weighing themselves before and after exercise sessions. Each kilogram of weight lost is equivalent to one litre of fluid. Adding on the weight of any fluid or food consumed during the exercise session will provide an estimate of total fluid loss for the session.

For example, an athlete who finishes an exercise session 1 kg lighter and has consumed 1 litre of fluid during the session has a total fluid loss of 2 litres.

Example:

Pre-exercise weight	55 kg
Post-exercise weight	53.5 kg
Volume of fluid consumed during exercise (1 litre)	1 kg
Exercise duration	2 h

Calculations:

Fluid deficit (L) = 55 kg - 53.5 kg = 1.5 kg
Total sweat loss (L) = 1.5 kg + 1 kg = 2.5 kg
Sweat rate (L/h) = 2.5 kg/2 h = 1.25 L/h

Once an athlete's individual sweat losses are known, a plan can be prepared to help the athlete achieve better fluid replacement in subsequent exercise sessions. Fluid replacement plans will differ according to the athlete and the opportunities for drinking during the sport. However, where possible it is better to begin drinking early in exercise and adopt a pattern of drinking small volumes regularly rather than trying to tolerate large volumes in one hit. Most athletes can tolerate 200-300 ml every 15-20 minutes but tolerance will vary according to the exercise intensity

It has been suggested that athletes restrict fluid intake to no more than 400—800 ml per hour during exercise to reduce the risk of hyponatremia (Noakes, 2002). This is sound advice for those athletes who sweat at such low rates, but faulty advice for those who sweat substantially more. Those athletes can benefit from rates of fluid intake that more closely match their sweat losses, without increasing their risk of hyponatremia, provided that sodium is also ingested during exercise. Noakes (2002) argues that athletes have been told that they should "drink as much as possible during exercise," advice that might predispose some to excessive drinking and hyponatremia. There are several recent scientific position stands (see below) that provide guidelines for fluid replacement before, during, and following exercise, none of which suggest that athletes should "drink as much as possible during exercise." As would be expected, the language of the position stands is not uniform, but the recommendations are similar in both intent and content.

American College of Sports Medicine (1996): "It is recommended that individuals drink about 500 ml (about 17 ounces) of fluid about 2 hrs before exercise to promote adequate hydration and allow time for the excretion of excess ingested water. During exercise, athletes should start drinking early and at regular intervals in an attempt to consume fluids at a rate sufficient to replace all the water lost through sweating (i.e., body weight loss), or consume the maximal amount that can be tolerated."

American Dietetics Association, Dietitians of Canada, and American College of Sports Medicine (2000): "Athletes should drink enough fluid to balance their fluid losses. Two hours before exercise, 400 to 600 ml (14 to 22 oz) of fluid should be consumed, and during exercise, 150 to 350 ml (6 to 12 oz) of fluid should be consumed every 15 to 20 minutes depending on tolerance."

National Athletic Training Association (2000): "To ensure proper pre-exercise hydration, the athletes should consume approximately 500 to 600 ml (17 to 20 oz) of water or a sports drink 2 to 3 hours before exercise and 200 to 300 ml (7 to 10 oz) of water or a sports drink 10 to 20 minutes before exercise. Fluid replacement should approximate sweat and urine losses and at least maintain hydration at less than 2% bodyweight reduction. This generally requires 200 to 300 ml (7 to 10 oz) every 10 to 20 minutes."

These guidelines recognize that drinking adequately during exercise improves performance and reduces the risk of heat-related illness, but none suggests that athletes "drink as much fluid as possible during exercise." In triathlon, athletes should try to consume fluid on the bike as a priority, particularly in hot, humid conditions. Your fluid intake plan should be determined prior to and during the race, according to:

- Your individual tolerance
- Environmental conditions
- Race you are competing in

The examples used in each paper to characterize fluid intake during exercise contain values for fluid consumption that accurately portray "average" sweat losses. Obviously, athletes who lose more than the average amount of sweat will require more than the average amount of fluid intake to prevent significant dehydration. Those athletes who sweat at lower-than-average rates should drink less. On those occasions when it is not possible to closely match fluid intake with sweat rate, the guidelines suggest that athletes ingest as much fluid as they can comfortably tolerate. This advice recognizes that drinking to minimize dehydration is a good thing, even when athletes can't drink enough to keep pace with large sweat losses. The various guidelines on fluid replacement during exercise are just that - guidelines to help athletes meet their individual needs.

This common-sense logic underscores the value of athletes recording their body weights before and after training sessions to determine if their fluid intakes match their sweat losses. For example, if a 130-lb (60-kg) distance runner weighs 5 lbs (2.3 kg) less after a 10-mile (16-km) run, this is a clear indication that fluid intake should have been greater. In contrast, a 260-lb (118-kg) football player who weighs only 2 lbs (0.9 kg) less after a tough practice has done a fairly good job of drinking during practice. And a female triathlete who weighs 1-lb (0.45 kg) more after a long training session on her bike should cut back on drinking during her next ride.

Lastly, and an even more controversial, is replacing electrolytes, specifically sodium while racing. It is popular amongst long course triathletes to consume sodium during a race to avoid the likelihood of developing hyponatremia (low plasma sodium levels). It is likely that hyponatremia occurs by over consuming low sodium fluids, above and beyond your fluid requirements. We don't have any definitive answers regarding optimal sodium intakes, although the American College of Sports Medicine (1996) suggests that you aim to consume 0.5-0.7grams of sodium (or 30mmol) per hour during prolonged exercise.

Sports drinks contain between 0.2-0.58 grams of sodium per litre, so it's likely you will need to consume sodium from sources other than sports drink during the race. Interestingly, other race day favourites such as water, cola flavoured soft drinks, sports bars and sports gels are even lower in sodium. So you need to include other higher sodium containing options in order to meet your sodium goals such as a vegemite sandwich (Cox, G, 2005).

Alternative options for increasing sodium intake include Gatorlyte (which contains 33 mmol of sodium) or Gastrolyte (which contains 60 mmol/L when made at full strength). Salt tablets (such as Saltadex) can also be used. They are a great option during the run as they are easy to consume. One tablet contains 7 mmol of sodium (Cox, G. 2005)

Outlined in the table below is a sample hourly plan for an athlete competing in a long course triathlon for both the cycle and run. These guidelines are based on the assumption that the athlete weighs roughly 70kg, is fed and well hydrated before the race start, with the race held in moderate conditions.

Discipline	**Hourly suggestions**	**Expert comment**
Cycle	750ml of 7% sports drink, a vegemite sandwich and additional sips on water	The sports drink provides 50g of carbohydrate, with an additional 25g from the vegemite sandwich. The sandwich offers a great source of sodium and a savoury option compared with the sports drink. You can manipulate the amount of water you drink to increase your fluid intake.
Run	Power Gel, two cups of sports drink and two cups of cola soft drink	The gel provides 28g of carbohydrate. Assuming you drink 100ml from each cup, that's 400ml total and an additional 36g of carbohydrate – total carbohydrate 64g. As you can see it is pretty difficult to meet your minimum fluid needs while on the run.

References

Adrogué, H.J., and N.E. Madias (2000). Hyponatremia. New Engl. J. Med. 342:1581-1589.

American Academy of Pediatrics (2000). Climatic heat stress and the exercising child and adolescent. Pediatrics 106:158-159.

American Dietetic Association, Dietitians of Canada, and American College of Sports Medicine (2000). Nutrition and athletic performance. J. Amer. Diet. Assoc. 100:1543-1556.

American College of Sports Medicine (1996). Position stand on exercise and fluid replacement. Med. Sci. Sports Exerc. 28:i-vii.

Arieff, A.I. (1986). Hyponatremia, convulsions, respiratory arrest, and permanent brain damage in healthy women. N. Engl. J. Med. 314:1529-1535.

Armstrong, L.E., W.C. Curtis, R.W. Hubbard, R.P. Francesconi, R. Moore, and E.W. Askew (1993). Symptomatic hyponatremia during prolonged exercise in the heat. Med. Sci. Sports Exerc. 25:543-549.

Ayus, J.C., J.M. Wheeler, and A.I. Arieff (1992). Postoperative hyponatremic encephalopathy in menstruant women. Ann. Intern. Med. 117:891-897.

Ayus, J.C., J. Varon, and A.I. Arieff (2000). Hyponatremia, cerebral edema, and noncardiogenic pulmonary edema in marathon runners. Ann. Intern. Med. 132:711-714.

Backer, H.D., E. Shopes, and S.L. Collins (1993). Hyponatremia in recreational hikers in Grand Canyon National Park J. Wilderness Med. 4:391-406.

Cox, G. (2005). Nutrition Issues in Ironman Triathlon Events. Australian Institute of Sport.

Craig, S.C. (1999). Hyponatremia associated with heat stress and excessive water consumption: The impact of education and a new Army fluid replacement policy. MSMR 5:1-9.

Davis, D.P., J.S. Videen, A. Marino, G.M. Vike, J.V. Dunford, S.P. Van Camp, and L.G. Maharam (2001). Exercise-associated hyponatremia in marathon runners: a two-year experience. J Emerg. Med. 21:47-57.

D.R. Lamb (eds.) Perspectives in Exercise Science and Sports Medicine. Vol. 3, Fluid Homeostasis During Exercise. Indianapolis: Benchmark Press, pp. 247-280.

Eichner, E.R. (2002). Exertional hyponatremia: why so many women? Sports Med. Digest 24:54-56.

Freund, B.J., S.J. Montain, A.J. Young, M.N. Sawka, J.P. DeLuca, K.B. Pandolf, and C.R. Valeri (1995). Glycerol hyperhydration: hormonal, renal, and vascular fluid responses. J. Appl. Physiol. 79:2069-2077.

Gardner, J.W. (2002a). Death by water intoxication. Military Med. 5:432-434.

Gardner, J.W. (2002b). Fatal water intoxication of an Army trainee during urine drug testing. Military Med 5:435-437.

Hew, T.D., J.N. Chorley, J.C. Cianca, and J.G. Divine (2003). The incidence, risk factors, and clinical manifestations of hyponatremia in marathon runners. Clin, J. Sports Med. 13:41-47.

Hiller, W.B.D. (1989). Dehydration and hyponatremia during triathlons. Med. Sci. Sports Exerc. 21:5219-5221.

Minehan, M (2001). AIS Sports Nutrition Fact Sheet: Fluid.

Mcardle, W et al (1996). Exercise Physiology. 4th Edition. Williams and Wilkins.

Montain, S.J., M.N. Sawka, and C.B. Wenger (2001). Hyponatremia associated with exercise: risk factors and pathogenesis. Exerc. Sports Sci. Rev. 3:113-117.

Murray, R (2003). Hyponatremia in Athletes. Sports Science Exchange 88: 16 (1).

Murray, R. (2000). Regulation of fluid balance and temperature during exercise in the heat—scientific and practical considerations. In: H. Nose, C.V. Gisolfi, and K. Imaizumi, (eds.) Exercise, Nutrition, and Environmental Stress. Carmel, IN: Cooper Publishing, pp. 1-20.

National Athletic Training Association (2000). Fluid replacement for athletes. J. Ath. Training 35:212-224.

Noakes, T.D., R.J. Norman, R.H. Buck, J. Godlonton, K. Stevenson, and D. Pittaway (1990). The incidence of hyponatremia during prolonged ultraendurance exercise. Med. Sci. Sports Exerc. 22:165-170.

Noakes, T.D., G. Wilson, D.A. Gray, M.I. Lambert, and S.C. Dennis (2001). Peak rates of diuresis in healthy humans during oral fluid overload. S. African Med. J. 91:852-857.

Noakes, T.D. (2002). Hyponatremia in distance runners: fluid and sodium balance during exercise. Curr. Sports Med. Reports 4:197- 207.

Olsson, K.E. and B. Saltin (1970). Variation in total body water with muscle glycogen changes in man. Acta Physiol. Scand. 80:11- 18, 1970.

O'Toole, M. L., P. S. Douglas, R. H. Laird, and W. D. B. Hiller (1995). Fluid and electrolyte status in athletes receiving medical care at an ultradistance triathlon. Clin. J. Sport Med. 5:116-122.

Pivarnik, J.M., E.M. Leeds, and J.E. Wilkerson (1984). Effects of endurance exercise on metabolic water production and plasma volume. J. Appl. Physiol. 56:613-618.

Quinton, P.M. (1999). Physiological basis of cystic fibrosis: a historical perspective. Physiol. Rev. 79:S3-S22.

Smith, H.R., G.S. Dhatt, W.M. Melia, and J.G. Dickinson (1995). Cystic fibrosis presenting as hyponatraemic heat exhaustion. Br. Med. J. 310:579-580.

Speedy, D.B., T.D. Noakes, T. Boswell, J.M.D. Thompson, N.Rehrer, and D.R. Boswell (2001). Response to a fluid load in athletes with a history of exercise induced hyponatremia. Med. Sci Sports Exerc. 33:1434-1442.

Speedy, D.B., T.D. Noakes, I.R. Rogers, J.M.D. Thompson, R.G.D. Campbell, J.A. Kuttner, D.R. Boswell, S. Wright, and M. Hamlin (1999). Hyponatremia in ultradistance triathletes. Med. Sci. Sports Exerc. 31:809-815.

Zambraski, E.J. (1990). Renal regulation of fluid homeostasis during exercise. In: C.V. Gisolfi and

Zehlinger, J., C. Putterman, Y. Ilan, E.J. Dann, F. Zveibel, Y. Shvil, and E. Galun (1996). Case series: hyponatremia associated with moderate exercise. Am. J. Med. Sci. 311:86-91.