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Considerations for ultra-endurance activities: part 2 – hydration

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ABSTRACT

It is not unusual for those participating in ultra-endurance (> 4 hr) events to develop varying degrees of either hypohydration or hyperhydration. Yet, it is important for ultra-endurance athletes to avoid the performance limiting and potentially fatal consequences of these conditions. During short periods of exercise (< 1 hr), trivial effects on the relationship between body mass change and hydration status result from body mass loss due to oxidation of endogenous fuel stores, and water supporting the intravascular volume being generated from endogenous fuel oxidation and released with glycogen oxidation. However, these effects have meaningful implications during prolonged exercise. In fact, body mass losses well over 2% may be required during some ultra-endurance activities to avoid hyperhydration. Therefore, the typical hydration guidelines to avoid more than 2% body mass loss do not apply in ultra-endurance activities and can potentially result in hyperhydration. Fortunately, achieving the balance of proper hydration during ultra-endurance activities need not be complicated and has been well demonstrated to generally be achieved by simply drinking to thirst and avoiding excessive sodium supplementation with intention of replacing all sodium losses during the exercise.

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Introduction

With the recent explosion in participation in ultra-endurance (> 4 hr) activities (Deutsche Ultramarathon Vereinigung e.V., [n.d.](#); Hoffman, Ong, & Wang, [2010](#)), attention to the unique needs of this population becomes increasingly important. Nutritional issues specific to ultra-endurance activities have been addressed in our preceding paper on the topic (Costa, Hoffman, & Stellingwerff, [2018](#)). The present work will focus on hydration needs during ultra-endurance activities. This topic is particularly important in that hydration guidelines suitable for short periods of exercise are not appropriate for ultra-endurance activities and may even cause harm. Herewith, we will review basic principles

on proper hydration in ultra-endurance activities, discuss the prevalence and adverse effects of hypohydration and hyperhydration (also referred to as overhydration) in these activities, and provide guidance on how to maintain proper hydration during ultra-endurance activities.

Clarifying “proper hydration”

Proper hydration during exercise requires body mass loss since water is generated with fuel oxidation, water bound to glycogen is released during glycogenolysis, and mass is lost from oxidation of endogenous fuel stores (Hoffman, Goulet, & Maughan, 2018; Maughan, Shirreffs, & Leiper, 2007). Though trivial during short periods of exercise (< 1 hr), disregard of these factors during prolonged exercise can result in a meaningful magnitude of hyperhydration. For instance, Hoffman et al. (2018) calculated that the required mass loss to maintain euhydration during a 161-km mountain ultramarathon is likely over 2% of body mass even if considering recent suggestion that most of the water associated with glycogen may be osmotically active (King, Jones, & O'Hara, 2018). Thus, following the typical hydration recommendations to avoid body mass losses of 2% during exercise (Armstrong et al., 2007; Kreider et al., 2010; McDermott et al., 2017; Rodriguez, Di Marco, & Langley, 2009; Thomas, Erdman, & Burke, 2016) could result in hyperhydration during ultra-endurance activities.

Prevalence of inappropriate hydration

Change in body mass is a commonly measured variable during studies at endurance and ultra-endurance competitions. In separate publications that compiled body mass change data from multiple events ranging in completion times from ~ 3 to ~ 30 hr, an average of 11% (Noakes et al., 2005) and 36% (Hoffman, Hew-Butler, & Stuenkel, 2013) of the cases had no loss or a gain in body mass during the event while a sizable proportion of the participants had lost over 5–6% of body mass (Figure 1). Considering that there should be some body mass loss of up to a few percent, it is evident that mismanagement of hydration needs is quite common during endurance and ultra-endurance competitions.

These two compilation papers also demonstrated that exercise-associated hyponatremia (EAH) occurred in an average of 7% (Noakes et al., 2005) and 15% (Hoffman et al., 2013) of the cases, and can be present in association with hyperhydration, euhydration and hypovolemia. However, the symptomatic cases of EAH seem to occur virtually exclusively when there has been a gain in body mass or inadequate loss that is consistent with hyperhydration (Hoffman, Stuenkel, Sullivan, & Weiss, 2015a; Noakes et al., 2005). Indeed, hyperhydration is the primary risk for the development of symptomatic EAH and should be avoided in order to prevent potential health consequences from this condition (Hew-Butler et al., 2015).

Importance of proper hydration

As noted, maintaining body mass during an ultra-endurance event means that an athlete could be hyperhydrated and placing themselves at risk for developing symptomatic EAH (Hoffman et al., 2015a; Noakes et al., 2005) which can have severe

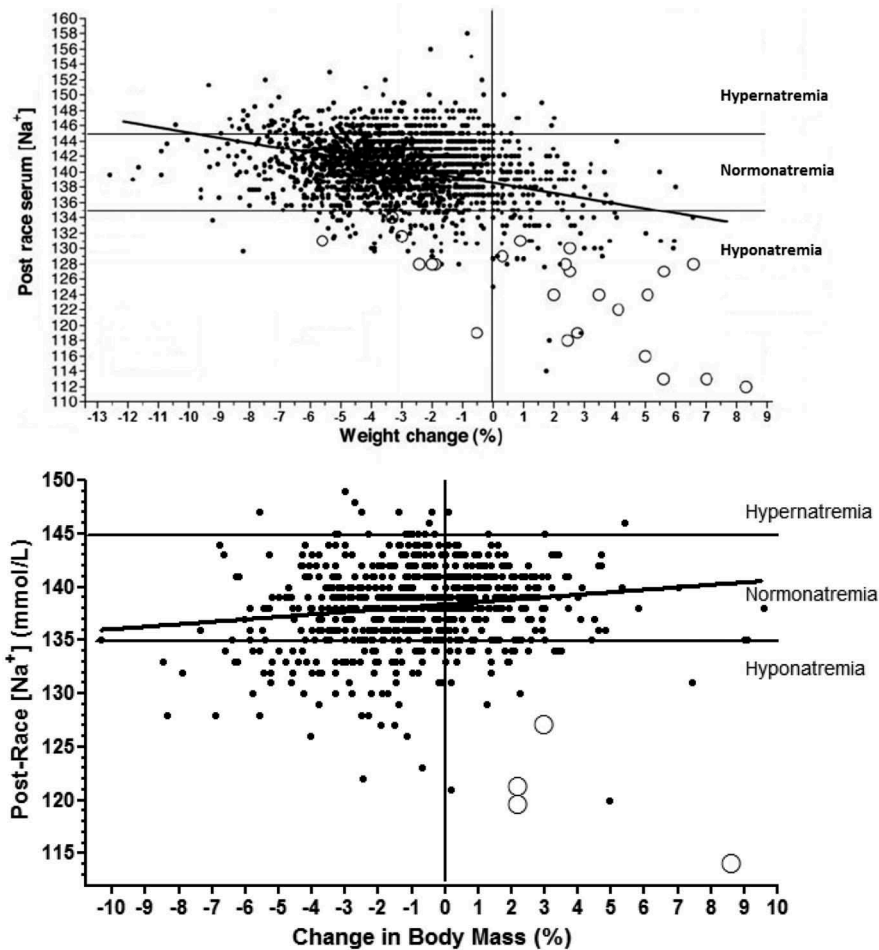


Figure 1. Relationship between post-event serum sodium concentration ($[Na^+]$) and change in body mass from 2135 observations at various endurance and ultra-endurance events (top) (Noakes et al., 2005) and 669 observations at 161-km ultramarathons (bottom) (Hoffman et al., 2013). Open circles are for cases of symptomatic EAH. Graphs have been adapted from Noakes et al. (2005) with permission (Copyright (2005) National Academy of Sciences, U.S.A) and Hoffman et al. (2015a) with permission of Dustri-Verlag. The top graph has been redrawn from the original so that the orientation of the horizontal axes are consistent for the two graphs.

consequences (Hew-Butler et al., 2015). Hyperhydration can also indirectly decrease performance through increasing body mass *via* unnecessary fluid carriage, delays for drinking and filling fluid containers, and pauses required for urination. Burdensome gastric load and unabsorbed fluid in the upper gastrointestinal tract from excessive fluid intake can also induce adverse gastrointestinal symptoms that commonly interfere with exercise performance and account for withdrawal from ultra-endurance events (Costa et al., 2018; Hoffman & Stuempfle, 2016a; Hoffman, Stuempfle, & Valentino, 2015b; Stuempfle & Hoffman, 2015; Stuempfle, Hoffman, & Hew-Butler, 2013; Stuempfle, Valentino, Hew-Butler, Hecht, & Hoffman, 2016).

While hyperhydration can have potential health and performance consequences, significant hypohydration may also result in impaired exercise performance, and increases the risk of developing heat illness such as heat exhaustion, since hypohydration can impair evaporative cooling by reducing sweating rate for a given core temperature (Sawka, Montain, & Latzka, 2001). As little as 1–2% loss in total body water has been reported to impair endurance performance in controlled laboratory conditions (Sawka et al., 2001), though generally not under ecologically valid conditions so translation into field based competition warrants caution (Wall et al., 2015). It is important to also recall that a greater body mass loss is required to cause a given percentage of hypohydration during ultra-endurance activities. Furthermore, it is now recognized that high intensity exercise, rather than the moderate intensities associated with ultra-endurance activities, is where heat exhaustion is most likely to occur (Armstrong et al., 2007). Serious elevations in core temperature are not typical during ultra-endurance events, even under hot conditions (Valentino, Stuempfle, Kern, & Hoffman, 2016). There is also no reason to believe that excessive fluid intake offers protection from serious heat stroke and associated septicaemia and systemic immune response (Gill et al., 2015a, 2015b; Nolte, Hew-Butler, Noakes, & Duvenage, 2015). Previous exploratory field research has reported a substantial magnitude of bacterial endotoxemia and responsive cytokinemia in euhydrated and hyperhydrated ultramarathon runners in response to 230-km multi-stage and 24-h ultramarathons (Gill et al., 2015a, 2015b). Thus, avoiding hyperhydration or hypohydration is recommended for health and performance.

Exercise-associated muscle cramping is another condition commonly purported to be due to a fluid and sodium imbalance (Hoffman, Bross, & Hamilton, 2016a). However, growing evidence from experimental (Braulick, Miller, Albrecht, Tucker, & Deal, 2013; Miller et al., 2010) and observational (Hoffman & Stuempfle, 2015a; Maughan, 1986; Schwellnus, Allie, Derman, & Collins, 2011; Schwellnus, Drew, & Collins, 2011; Schwellnus, Nicol, Laubscher, & Noakes, 2004; Sulzer, Schwellnus, & Noakes, 2005) studies suggests that muscle cramping associated with endurance exercise is most likely due to altered neuromuscular control rather than uncompensated water and sodium losses incurred during exercise. Findings of higher plasma creatine kinase concentrations after a 161-km ultramarathon among runners with muscle cramping than those without cramping provides evidence that those developing cramping are placing greater demands on their muscles relative to their current state of training (Hoffman & Stuempfle, 2015a). Further evidence that exercise-associated muscle cramping is not generally related to fluid and sodium imbalances in ultra-endurance activities comes from findings of no difference between those with and without cramping during a 161-km ultramarathon in terms of body mass change, post-race plasma sodium concentration, sodium supplement intake, and total sodium intake (Hoffman & Stuempfle, 2015a; Hoffman et al., 2015b). Thus, exercise-associated muscle cramping in ultra-endurance activities are not likely to respond to fluid and electrolyte intake beyond that appropriate for maintaining euhydration. Proper training, inclusive of periodically simulating the demands of racing (e.g., relative concentric and eccentric muscle contractile stimulation) in specific long training bouts featuring race terrain and temperatures, is likely the best prevention for muscle cramping.

Maintaining proper hydration

Maintaining proper hydration is generally not a complicated process. It is simply a matter of balancing water losses with the combination of water intake and water that becomes available to support the circulatory system through fuel oxidation. Fortunately, the human body is well adapted with internal cues that adequately support this process during prolonged low to moderate intensity exercise.

How much fluid?

Thirst is an evolutionarily developed stimulus that serves to regulate plasma osmolality and blood volume (Fitzsimons, 1998). While the concept that thirst provides an adequate stimulus to maintain proper hydration during exercise is still challenged (Armstrong, Johnson, & Bergeron, 2016), past recommendations emphasizing that thirst is an inadequate stimulus for maintaining proper hydration were largely intended for situations in which hypohydration might develop rapidly from high sweat rates associated with high exercise intensities (Hew-Butler et al., 2015), which is irrelevant during prolonged lower-intensity ultra-endurance activities. Ample evidence now demonstrates that “*drinking to thirst*” during ultra-endurance activities, even under hot ambient conditions, will allow maintenance of proper hydration (Costa, Gill, Hankey, Wright, & Marczak, 2014; Costa et al., 2013b; Dempster, Britton, Murray, & Costa, 2013; Hoffman & Stuenkel, 2014, 2016b; Nolte, Noakes, & Van Vuuren, 2011; Tam, Nolte, & Noakes, 2011) and attenuate thermal and circulatory strain (Armstrong et al., 1997). Other studies have also demonstrated that drinking to thirst during prolonged exercise does not impair performance compared with a higher volume of fluid intake (Backes & Fitzgerald, 2016; Backx, Van Someren, & Palmer, 2003; Dion, Savoie, Asselin, Garipey, & Goulet, 2013; Dugas, Oosthuizen, Tucker, & Noakes, 2009; Holland, Skinner, Irwin, Leveritt, & Goulet, 2017; Lee et al., 2014; Lopez et al., 2016). In other words, proper fluid intake during prolonged exercise can generally be achieved by simply drinking water or other hypotonic fluids based on the dictates of thirst assuming there is access to fluids when thirst is present.

As opposed to drinking to thirst, “*programmed drinking*” or “*drinking to a specific schedule*” is another strategy commonly used by ultra-endurance athletes (Hoffman & Stuenkel, 2014; Winger et al., 2013). Programmed drinking typically involves consuming fluid at a specific rate determined through estimates of individual sweat rates. However, this approach is fraught with problems. Besides the fact that all sweat loss should not be replaced with fluid intake, it is difficult to estimate an accurate sweat rate for prolonged exercise because it is affected by many factors (Armstrong & Maresh, 1998). Variations in test conditions from those during competition resulting in relatively minor discrepancies between the calculated and actual sweating rate could cause fluid intakes resulting in meaningful levels of hyperhydration or hypohydration during prolonged exercise. Programmed caloric intake when the calories are largely or exclusively in liquid form adds another dimension to proper hydration that might be optimally addressed through the use of separate concentrated caloric solutions and water.

If proper hydration can be maintained by simply responding to the signals of thirst, it is legitimate to wonder why athletes mismanage their hydration needs so frequently

during endurance and ultra-endurance events (Costa et al., 2014, 2013b; Hoffman et al., 2013; Noakes et al., 2005). As previously noted (Hoffman, Cotter, Goulet, & Laursen, 2016b), we believe that behaviours resulting in hyperhydration are often driven by excessive concerns about hypohydration, muscle cramping, and heat illness, likely resulting from professional organization guidelines and marketing efforts emphasizing the importance of avoiding hypohydration. Organizational guidelines are known to diffuse beyond the scientific and medical literature (Hoffman et al., 2016a) and to influence the hydration strategies of ultra-endurance athletes (Winger et al., 2013). In terms of an explanation for why hypohydration frequently occurs, it may often be due to gastrointestinal symptoms interfering with proper nutrition and fluid intake (Costa, Snipe, Camões-Costa, Scheer, & Murray, 2016; Stuenkel & Hoffman, 2015). We have addressed potential measures to prevent and control such symptoms in our preceding paper (Costa et al., 2018).

What kind of fluids?

A wide variety of “sports drinks” are marketed for consumption during exercise. In general, these are hypotonic drinks containing water, various concentrations and forms of carbohydrates, sodium and other electrolytes in varying concentrations, and flavouring. Such drinks are typically provided at aid stations in ultra-endurance events, and many are available in power form which offers the convenience of a relatively low mass caloric source to be transported and prepared by the athlete as needed, as long as water is available. However, ultra-endurance athletes do not typically rely exclusively on sports drinks for their source of water or calories, but rather choose a variety of foods and fluids, in solid, gel or liquid forms, including energy-rich caloric sources specifically marketed for use during exercise, fruit, candy, soup, carbonated beverages, fruit juices, and water (Costa et al., 2013a, 2013b; Martinez et al., 2018; Pfeiffer et al., 2012; Stuenkel, Hoffman, Weschler, Rogers, & Hew-Butler, 2011). This is likely done to avoid the monotony from a single nutrition and water source (i.e., taste and flavour fatigue). It is also important to note that sports drinks are a source for both hydration and fuelling, which have unique requirements. Consuming real food in conjunction with water allows for matching the water and caloric intake with the needs in such a way that would otherwise be challenging to accomplish through a sports drink which combines the water and calories in a fixed ratio. Consumption of water is also a satisfying method to cleanse the mouth of flavours that can become unpleasant after prolonged consumption. Furthermore, there is no unique value from obtaining calories and electrolytes from a sports drink. Thus, it is best for the ultra-endurance athlete to assess individual fluid requirements and plan on meeting those requirements through various sources, including water, and that their plan should be tested during training.

Is sodium supplementation necessary?

It is typical for hydration guidelines to recommend ingestion of sodium during exercise for maintenance of hydration and prevention of muscle cramping (Hoffman et al., 2016a), and use of sodium supplementation has been common practice among ultra-endurance athletes (Hoffman & Stuenkel, 2014, 2015b; Stuenkel et al., 2011). Indeed,

sodium intake during exercise will drive thirst (Hoffman & Myers, 2015a; Hoffman et al., 2015a), but it has been demonstrated that supplemental sodium is not necessary to maintain proper hydration during prolonged exercise up to 30 hr even under hot conditions (Hoffman & Stuempfle, 2014, 2015b, 2016b). It is thought that the sodium consumed during meals should be adequate to replace losses during routine exercise (Casa et al., 2015) and the sodium consumed with the typical race diet during an ultra-endurance event appears adequate for avoidance of salt-depletion hypohydration (Hoffman & Stuempfle, 2015b, 2016b). Sodium intake during exercise will also not prevent EAH in the presence of hyperhydration (Hoffman & Myers, 2015a; Hoffman et al., 2015a), but excessive sodium intake may actually increase the risk of developing EAH (Hoffman & Myers, 2015a; Hoffman et al., 2015a) or pulmonary edema (Luks, Robertson, & Swenson, 2007). Thus, excessive sodium supplementation should be avoided during ultra-endurance activities (Hew-Butler et al., 2015) and should not be used with the intention to replace all losses during the exercise. Interestingly, a recent systematic review has highlighted that the amount of dietary sodium intake leading into an exercise bout may determine sweat sodium losses during exertional-heat stress such that greater sodium intakes result in greater losses and vice-verse (McCubbin & Costa, 2018). Thus, highly visible losses (e.g., salt crusting on race clothing and/or equipment) of sodium during ultra-endurance events does not necessarily indicate the need for increased requirements, but might simply reflect recent dietary intake.

Assessing hydration status

Assessing hydration status can be challenging, even when altered to the degree of being clinically important (Hoffman, Joslin, & Rogers, 2017). Typical clinical signs of hypohydration have been shown to be unreliable after endurance competitions (McGarvey et al., 2010; Sharwood, Collins, Goedecke, Wilson, & Noakes, 2004), and athletes with central nervous system symptoms including dizziness, altered mental status, seizure and coma should not be automatically assumed to be severely hypohydrated since these symptoms can also be present with EAH (Hew-Butler et al., 2015). Oliguria (limited urine production) is also not generally a useful sign since it is a normal physiological response for urine to be concentrated and reduced in volume during exercise. Urine production is also reduced when EAH is developing because this condition is associated with the non-osmotically stimulated secretion of arginine vasopressin (Hew-Butler et al., 2015). As such, oliguria due to developing EAH could be confused with a sign of hypohydration (Hoffman & Myers, 2015b), and more fluid intake to address presumed hypohydration will increase the extent of dilutional hyponatremia. Monitoring body mass change can help distinguish hypohydration from hyperhydration, but it is important to use accurate scales and to recognize the appropriate mass loss for proper interpretation. Unfortunately, accurate body mass scales are typically not available during ultra-endurance events. Of course, blood analysis (e.g. blood osmolality and serum sodium concentration) is the optimal approach for clinical assessment of hydration status, but this too is rarely available during ultra-endurance events. Thus, assessing the amount of fluid consumed relative to the demands and needs based on experience might be the best consideration in assessing hydration status during prolonged exercise.

Table 1. Practical considerations for individualized hydration during ultra-endurance activities.

- Initiate exercise in an euhydrated state. Avoid hyperhydration.
- Drink to the dictates of thirst during exercise.
- Avoid excessive sodium supplementation during exercise. Consume sodium based on food cravings. Do not use highly visible salt losses as a signal for the need for more sodium intake.
- When fluid access is limited and must be carried by the athlete between sources, estimating fluid needs is best done through experience, or through training or laboratory conditions to assess the range of potential requirements, while recognizing that the appropriate fluid intake will vary with exercise intensity and ambient temperature and humidity.
- Determining hydration status is best achieved through history of fluid intake and monitoring body mass, recognizing that some body mass should be lost during prolonged exercise as a result of oxidation of endogenous fuel stores, water generation with fuel oxidation, and the release of water bound to glycogen during glycogenolysis. Oliguria (limited urine output) is not necessarily a signal of dehydration.

Practical recommendations

Key hydration recommendations for ultra-endurance activities are summarized in [Table 1](#). An initial consideration is that exercise should be initiated in an euhydrated state, which is best achieved through appropriate rehydration following each exercise session, and avoiding evidence of an acute loss in body mass of over 1% and the presence of dark colored urine and thirst when assessed in the morning (Cheuvront & Kenefick, 2014). While hyperhydration prior to exercise with sodium or glycerol may offer a small performance advantage under some circumstances (Mora-Rodriguez & Hamouti, 2012; Van Rosendal & Coombes, 2012), the benefit is likely only when fluid cannot be adequately taken in during exercise (Van Rosendal & Coombes, 2012), which is not usually the case in ultra-endurance events. Thus, hyperhydration is not recommended prior to ultra-endurance activities.

Owing to our internal cues that serve to regulate plasma osmolality and blood volume, drinking to thirst has now been demonstrated to be the optimal approach to proper hydration during prolonged exercise. Excessive sodium intake is not necessary and may be harmful. Under conditions in which there is limited access to fluids, the ultra-endurance athlete must estimate the fluid volume they need to carry between water sources to support their thirst, and to balance their access to water with the avoidance of carrying unnecessary water. Estimating fluid needs during periods of limited access is best done through experience while recognizing that the appropriate fluid intake will vary with exercise intensity and ambient temperature and humidity.

Conclusions

Proper hydration during prolonged exercise need not be complicated and has been well demonstrated to be achieved by simply drinking water or other hypotonic fluids to thirst and avoiding excessive sodium supplementation with intention of replacing all sodium losses during the exercise. Since body mass should be lost during exercise, and such losses could be well beyond 2% of body mass in ultra-endurance activities, hyperhydration can occur when the commonly promoted hydration guidelines of avoiding more than 2% body mass loss are followed during prolonged exercise. Hyperhydration can cause the potentially serious complication of EAH, so ultra-endurance athletes should be cautioned to avoid drinking beyond the dictates of thirst and taking in excessive sodium during prolonged exercise.

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No potential conflict of interest was reported by the authors.

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