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FLUID INTAKE STRATEGIES FOR OPTIMAL HYDRATION AND PERFORMANCE: PLANNED DRINKING VS. DRINKING TO THIRST

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- In humans, thirst tends to be alleviated before complete rehydration is achieved.
- When sweating rates are high and ad libitum fluid consumption is not sufficient to replace sweat losses, a cumulative loss in body water results.
- Body mass losses of 2% or greater take time to accumulate.
- Dehydration of > 2% body mass and greater is associated with impaired thermoregulatory function, elevated cardiovascular strain, and in many conditions impaired aerobic exercise performance (e.g., warmer, longer, more intense).
- Circumstances where planned drinking is optimal include: longer duration activities > 90 min, particularly in the heat; higher intensity exercise with high sweat rates; exercise where performance is a concern; when carbohydrate intake of 1 g/min is desired.
- Circumstances where drink to thirst may be sufficient include: short duration exercise < 60 to 90 min; exercise in cooler conditions; lower intensity exercise.
- *NEVER* drink so much that weight is gained.

INTRODUCTION

The two most common schools of thought regarding best fluid intake practices during exercise are programmed drinking vs. drinking to thirst or *ad libitum* drinking. Both strategies seek to prevent over/under hydration and preserve performance. However, the success of either strategy will depend on the context of the event (i.e., duration, intensity and environment), the characteristics of the individual (i.e., fitness, acclimatization status) and the goals of the individual exercising, training or competing.

Programmed drinking is defined as the use of a pre-established drinking plan. This strategy refers to drinking predetermined amounts of fluid with the purpose of minimizing fluid losses. As there is considerable variability in sweating rates and sweat electrolyte concentrations among individuals, this drinking strategy recommends a customized fluid replacement program. By drinking to approximate sweat losses, within ± 2% body mass (to prevent dehydration and over-drinking), the goal of this strategy is to attenuate potential exercise performance impairment, reduce cardiovascular and thermoregulatory strain associated with dehydration, decrease the risk of heat illness (heat exhaustion, heat stroke) and to prevent hyponatremia (Sawka et al., 2007).

Determination of sweat rate can be accomplished by measuring acute changes in body mass (BM) before and immediately after exercise. In the absence of drinking, the change in body mass can be used as an approximation of the volume of sweat lost (e.g., 1 kg = 1 L); however, there may be some small sources of error in this assumption.

Drinking to thirst has been used interchangeably with “ad libitum drinking” (Hew-Butler et al., 2006). “Ad libitum drinking” is defined as the consumption of fluid whenever and in whatever volume desired (Ormerod et al., 2003; Vokes, 1987). The objective of “drinking to thirst” is to use the innate thirst mechanism to guide fluid consumption with the goal of preventing the development of exercise associated hyponatremia and excessive dehydration (Hew-Butler et al., 2015).

FLUID BALANCE AND THIRST

Net body water balance (fluid losses = fluid gains) is regulated remarkably well day-to-day, as a result of thirst and hunger in addition to *ad libitum* access to food and beverage (Institute of Medicine, 2005). However, when fluid losses are greater than fluid intake, dehydration is the result. Because body water has a normal daily fluctuation, dehydration is defined as a body water deficit greater than normal daily fluctuation (Cheuvront & Kenefick, 2014) or when body water deficits exceed two standard deviations in normal body mass variability (> 2% BM) (Adolph & Dill, 1938; Cheuvront et al., 2004). When at rest, this level of dehydration is the approximate threshold where compensatory fluid regulatory actions (fluid conservation at the kidney) and stimulus for fluid acquisition (thirst) occurs (> 2% BM) (Reeves et al., 1998; Shirreffs et al., 2004). These compensatory actions are triggered by elevations in plasma osmolality and to lesser degree, a reduction in plasma volume (Cheuvront et al., 2013; Cheuvront & Kenefick, 2014). During exercise, particularly in the heat, plasma volume decreases because it provides the fluid for sweat, and as a result, plasma osmolality (Posm) increases because sweat is hypotonic (sodium poor) relative to plasma. It is important to remember that when total body water losses occur during exercise due to thermoregulatory sweating, these losses are shared by all fluid compartments. An increase in plasma and extracellular osmolality will pull fluid from the intracellular space so that all compartments are in non-osmotic equilibrium. A ~2% increase in Posm (~6 mmol/kg) is commonly referenced as an osmotic threshold for compensatory renal water conservation and water acquisition (thirst) which is equivalent of ~2% BM loss (1.4 L at 70 kg; Figure 1)(Cheuvront & Kenefick, 2014). The sensitivity of osmoreceptors in regulating anti-diuretic hormone release and stimulating thirst is enhanced by relatively small losses of volume. However, volume-mediated thirst requires a much larger loss (~10% blood volume, ~1 L) and plasma volume losses are only ~0.14 L with a loss of ~2% BM (Cheuvront et al., 2007).

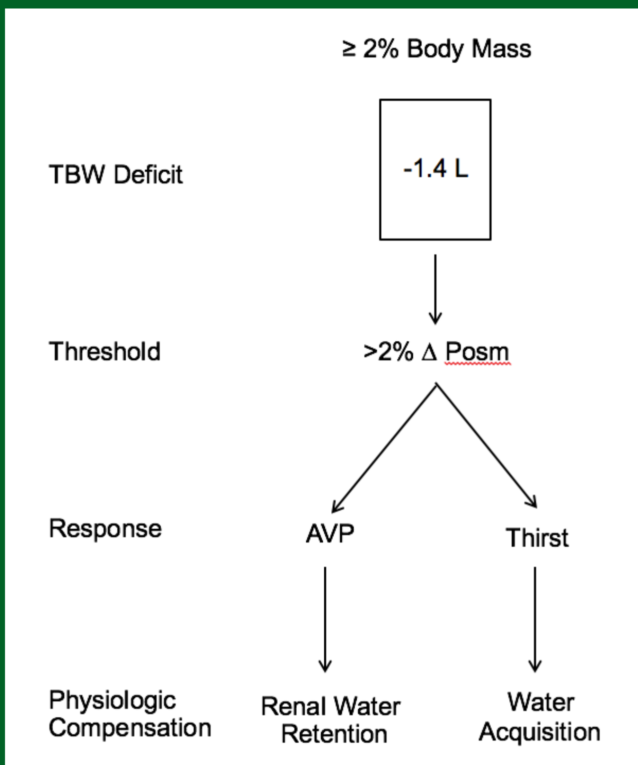

Figure 1. Regulation of body water balance in response to body water deficit typical of exercise/fluid restriction for a 70 kg individual. Schematic includes the estimated magnitude of dehydration (2% body mass loss) required to stimulate the osmotic-dependent response for compensatory water conservation and acquisition (thirst). TBW, total body water; Posm, plasma osmolality; AVP, arginine vasopressin.

A change in TBW is equated with a change in body mass (1 L = 1 kg), whereby dehydration is then expressed as a percentage of body mass in accordance with: (Δ body mass/initial body mass)*100 or for this example, (1.4 kg/70 kg)*100 = 2%.

While sensation of thirst works well at rest (Greenleaf & Sargent, 1965), it is less sensitive during exercise. Mechanisms that stimulate sensation of thirst are subject to numerous influences (Greenleaf & Morimoto, 1996), and sensitivity to these signals during exercise is likely different given the physiological state during exercise. This includes elevated heart rate and respiration, decreased renal blood flow and plasma volume, and elevated anti-diuretic and other fluid regulatory hormones. Observations of the insensitivity of thirst in the maintenance of total body water during exercise have been reported over many years. Dill et al. (1933) observed that when a man and a dog walked 32 km in a hot environment with ad libitum water availability, the dog maintained weight balance while the man lost about 3 kg. During periods when sweating rate was high (> 1.0 L/hr), humans practicing *ad libitum* drinking have been reported to significantly under-consume fluids (Adolph, 1947; Adolph & Dill, 1938; Greenleaf & Sargent, 1965; Greenleaf et al., 1983). Greenleaf and Sargent (1965) reported that when drinking ad libitum, subjects consumed approximately half of fluids lost during exercise in cool and hot environments. Even when drinking ad libitum, subjects performing a half-marathon reported feeling more thirsty when compared to programmed drinking trials (Dion et al., 2013). Cheuvront et al. (2007) examined group means from 14 marathon studies conducted in a range of environments (10 – 28°C), with runners of wide ranging abilities (2 hr, 10 min to 4 hr; Figure 2) and concluded that *ad libitum* drinking commonly led to dehydration in excess of 2% BM loss.

Thirst is also alleviated before complete rehydration is achieved (Greenleaf, 1992) as oropharyngeal cues trigger thirst satiation before volume is fully restored (Bourque, 2008; Geelen et al., 1984; Rolls et al., 1980; Takamata et al., 1995; Thompson et al., 1987). For example, Greenleaf & Sargent (1965) also reported that following experimental trials with ad libitum access to fluid, subjects reported feeling fully recovered and were not thirsty despite having a water deficit of 4-5 L. Lastly, it is important to note that sensation of thirst has been reported to be less sensitive during exercise in elderly individuals (Kenney & Chiu, 2001).

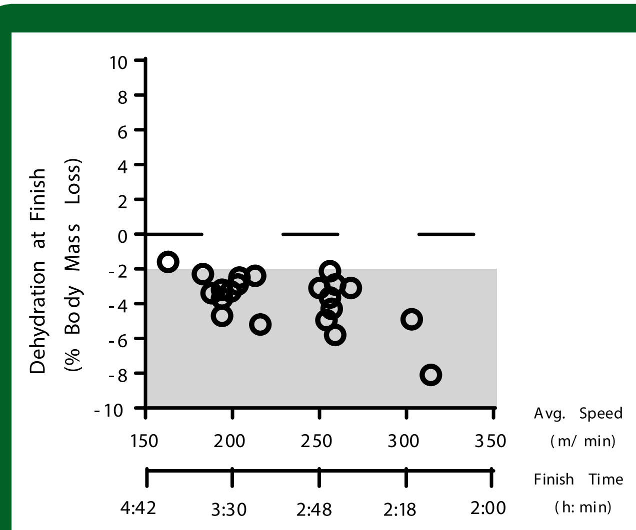

Figure 2. Level of post-race dehydration (y axis; % body mass loss) vs. average running speed and finishing time for 42 km (x axis) when drinking ad libitum. Adapted from Cheuvront et al. (2007).

DEHYDRATION: PHYSIOLOGICAL RESPONSES AND EXERCISE PERFORMANCE

The majority of the dehydration/exercise performance literature suggests that during exercise, dehydration increases physiological strain as measured by elevations in core temperature, heart rate and perceived exertion responses (Sawka & Coyle, 1999). Also, the greater the body water deficit, the greater the increase in physiological strain (Adolph, 1947; Montain & Coyle, 1992; Montain et al., 1995; Sawka et al., 1985). Dehydration has also been reported to reduce the sweating rate at any given body core temperature, decrease the evaporative heat loss (Sawka et al., 1985) and increase heat storage (Fortney et al., 1984). Furthermore, due to a reduction in circulating plasma volume as a result of dehydration, heart rate increases secondary to a reduction in stroke volume (Gonzalez-Alonso et al., 2000; Saltin, 1964). Heat stress combined with dehydration further exacerbates these cardiovascular responses because it creates competition between the central and peripheral circulation for limited blood volume (Rowell, 1986) further magnifying physiologic strain for a given exercise task (Montain & Coyle, 1992; Montain et al., 1995).

There is an overall consensus in the literature that dehydration of ≥ 2% BM represents a threshold at which aerobic exercise performance or endurance becomes impaired (Cheuvront & Kenefick, 2014; Cheuvront et al., 2010; Sawka, 1992; Sawka & Noakes, 2007; Sawka et al., 2007). In a review evaluating 34 endurance exercise/dehydration studies which included 60 separate observations (Figure 3), 41/60 observations (68%) were significantly impaired by dehydration ≥ 2% BM (Cheuvront & Kenefick, 2014). Independent of statistical significance, the number of observations reporting a reduction in endurance exercise performance with subjects ≥ 2% BM loss was 53/60 or 88%. More comprehensive reviews are recommended for greater detail regarding the impact of dehydration on physiological responses and exercise performance (Cheuvront & Kenefick, 2014; Institute of Medicine, 2005; Mack & Nadel, 1996).

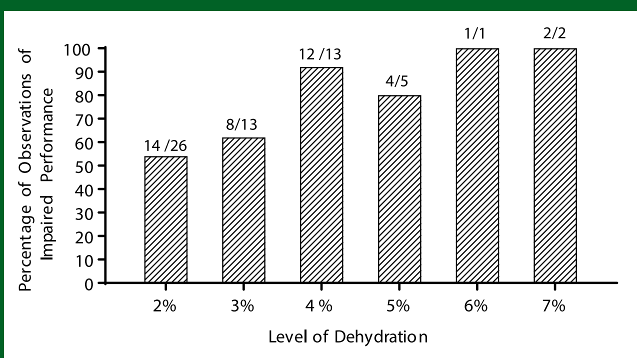

Figure 3. Review of dehydration effects on performance in 34 endurance exercise/dehydration studies. Fractions above bars represent the number of statistically significant (P<0.05) observations (numerator) of total observations (denominator) at the specified level of dehydration. 41 of 60 total observations (68%) were significantly (P<0.05) impaired by dehydration ≥ 2% body mass. Adapted from Cheuvront and Kenefick (2014).

One general criticism of the endurance exercise/dehydration studies reviewed is that they were conducted in a laboratory where conditions differ from those outdoors. Valid criticisms of this literature include achievement of dehydration before (rather than during) exercise and unrealistically low air flow rates. However, a review of dehydration studies where water loss occurred during exercise reported the same conclusions (Cheuvront et al., 2003). In one of the better examples of a field-valid study of endurance sport, Casa et al. (2010) examined the impact of dehydration (~2% BM loss) on trail running performance and reported ~5% slower times when subjects completed the race while dehydrated.

It is important to note that when exercise commences in a well hydrated state, accumulated fluid loss and the subsequent development of sensations of thirst can take time and will be dependent on numerous factors (e.g., environment, exercise intensity and duration, sweat rate). To bolster this point, sweat losses were predicted for two hypothetical runners of small and larger body sizes over distances of 5 km to 42 km (marathon) in temperate (22°C) and warm conditions (30°C) (Kenefick & Cheuvront, 2012). These predictions illustrate differences in fluid needs for differing exercise durations, intensities, environments and body sizes. Fluid losses were expressed as the percent loss in body mass relative to a threshold of 2% loss over the duration of each event (Figure 4 A, B). What can be observed is that for finishing times typical of the majority of runners, fluid losses are < 2% BM for distances up to 21 km and it is not until marathon distance in hot conditions (30°C) that larger individuals (80 kg) lose > 2% BM by the very end of the event (Figure 4 A). For faster, more competitive runners (Figure 4 B), fluid losses are greater for both smaller and larger runners and exceed 2% body mass loss in both warm and hot conditions during the marathon but are below 2% BM loss for the other distances (5–21 km). These modeled loss estimates are conservative; however, they do illustrate that fluid replacement becomes increasingly critical during higher intensity and longer duration exercise, particularly in warmer temperatures.

AD LIBITUM DRINKING AND EXERCISE PERFORMANCE

Overall, the findings of the *ad libitum*/drink to thirst literature support the idea that maintaining fluid balance within ± 2% BM is dependent on the environment, exercise intensity and duration of the event. *Ad libitum*/drink to thirst studies have been conducted in low ambient temperatures (Daries et al., 2000; Knechtel et al., 2010), during events of 2 hr or less (Berkulo et al., 2016; Daries et al., 2000; Dion et al., 2013; Dugas et al., 2009) and when they are longer in duration (ultra-events) (Hoffman & Stuempfle, 2014; Hoffman et al., 2013; Knechtel et al., 2010), they tend to have lower exercise intensities. Many of the *ad libitum*/drink to thirst studies have been performed in field settings or during competition (vs. laboratory), where there is greater air flow, greater convective heat loss and as a result, reduced cardiovascular and thermoregulatory strain. Also, in the majority of field studies or competitions, volunteers start exercise in a euhydrated state and progressively dehydrate during the event or trial. Thus, > 2% BM loss may not be achieved until end of event or not at all, in the case of shorter events/trials. Furthermore, there is considerable difficulty in making precise measures (e.g., body mass, food/fluid intake, urine/fecal losses) in a field setting.

Ad libitum or drink to thirst studies involving endurance running (Daries et al., 2000), half marathon (Dion et al., 2013) and marathon (Beis et al., 2012) events have reported greater cardiovascular and thermoregulatory strain (Dion et al., 2013), but no differences in plasma volume or osmolality (Daries et al., 2000), and no differences in running performance (Beis et al., 2012; Daries et al., 2000; Dion et al., 2013). *Ad libitum* cycling studies have reported that cardiovascular responses (Berkulo et al., 2016), thermoregulation (Berkulo et al., 2016; Dugas et al., 2009), and performance (Berkulo et al., 2016; Dugas et al., 2009) are not different from programmed drinking. In contrast, Bardis et al. (2017) recently compared *ad libitum* to prescribed drinking during a 30 km cycling performance in the heat and concluded that matching fluid intake with sweat losses provided a performance advantage due to lower thermoregulatory strain and greater sweating responses.

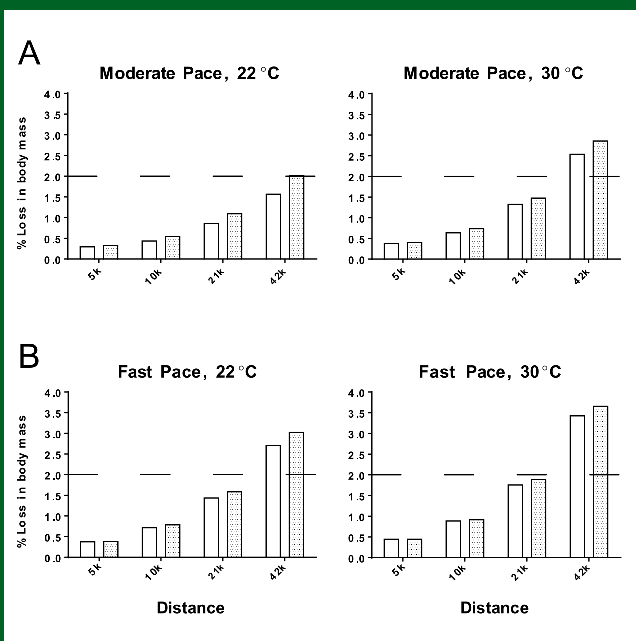

Figure 4. Percent loss in body mass predicted from sweat rate for 60 kg (clear bars) and 80 kg (speckled bars) runners of average ability (A) during 5 km (25 min), 10 km (60 min), 21 km (130 min), and 42 km (270 min) and competitive ability (B) during 5 km (21 min), 10 km (43 min), 21 km (95 min), and 42 km (200 min) road races. Dotted line demarks 2% body mass loss. Losses assume no fluid intake. Adapted from Kenefick and Cheuvront (2012).

Ultra-running studies examining *ad libitum* drinking have concluded that this strategy led to no incidences of hyponatremia (Knechtel et al., 2010), did not impact performance despite body mass losses > 3% (Hoffman & Stuempfle, 2014; Hoffman et al., 2013) and concluded that drinking beyond thirst is not required to maintain hydration during ultra-endurance events. Where ultra-endurance exercise (activity consisting of many hours/days) is concerned, as previously mentioned, activities of these distances/durations can result in significant non-fluid mass losses and non-water fluxes that make determination of body mass changes, fluid losses, food/fluid intake and bowel/bladder losses difficult to determine and interpret.

CONCLUSIONS

It stands to reason that during exercise, a fluid replacement strategy that maintains hydration state within ± 2% BM, would be successful in the preservation of physiological and exercise performance. As demonstrated by our fluid need predictions, fluid loss of 2% BM can take time to accumulate and will be dependent on body size, the environment, and exercise intensity and duration of the event. Thus, it would appear that conditions exist where *ad libitum*/drink to thirst fluid intake *will* be sufficient to meet needs, i.e., maintenance of fluid balance within ± 2% BM. For individuals who are less concerned with performance or performing activities at lower intensities, particularly in cooler weather, a fluid replacement plan may not be as important because fluid losses may not approach 2% BM loss. These conditions include activities or competition: of < 1 to 2 hr of duration; that are of lower exercise intensity; and that take place in cool or temperate environments. However, there are also conditions where programmed drinking is necessary to meet fluid requirements and a tailored programmed drinking strategy will need to be employed to avoid potential thermoregulatory, cardiovascular and exercise performance impairments (2% BM loss). These conditions include activities or competitions that: are longer in duration, > 90 min to 2 hr; are of higher exercise intensity; take place in warm or hot environments; or where fuel intake at a particular rate is desired (e.g., 1 g carbohydrate/min). Thus, a programmed drinking strategy should be tailored to prevent losses or gains of ± 2% BM (Sawka et al., 2007). It is important to remember that "performance" as discussed in this review has been related to aerobic exercise tasks. The impact of dehydration on team sport performance is less clear as these activities are made up of various components aside from aerobic endurance, including motor and cognitive function (e.g., ball dribbling, throwing, passing, shooting, hitting), decision-making and anaerobic power or strength. Thus, the impact of dehydration will likely depend on the relative contribution of factors that comprise the specific skill or task being performed, as well as the energy systems used for the task (Cheuvront & Kenefick, 2014).

As the practice of *ad libitum*/drink to thirst fluid intake appears to replace about half of fluid losses (Greenleaf & Sargent, 1965), this strategy would appear to be successful in the prevention of hyponatremia. However, humans consume fluids for reasons outside of thirst/fluid replacement and while rare, cases have been documented where individuals have consumed fluids "according to thirst" but over-drank and became hyponatremic (Hew-Butler et al., 2015). It is also important to note that over-drinking typically occurs when there is abundant access to water or other hypotonic fluid, which is common in longer duration events. When consuming fluid *ad libitum*/to thirst or if consuming fluid according to a predetermined program, *never* consume so much fluid that weight is gained.

PRACTICAL APPLICATIONS

- Planned drinking should be considered for: longer duration activities > 90 min, particularly in the heat; higher intensity exercise; high sweat rates, exercise where performance is a concern; and when carbohydrate intake of 1 g/min is desired.

- Drink to thirst should be considered for: short duration exercise < 60 to 90 min; exercise in cooler conditions; lower intensity exercise.
- Individuals with high sweat rates or those concerned with exercise performance should determine sweat rates under conditions (exercise intensity, pace) and environments similar to that anticipated when competing and tailor drinking to prevent body mass losses > 2%.
- *NEVER* drink so much that weight is gained.

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