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VIEWPOINTS

VIEW: Is Drinking to Thirst Adequate to Appropriately Maintain Hydration Status During Prolonged Endurance Exercise? Yes

Martin D. Hoffman, MD; James D. Cotter, PhD; Éric D. Goulet, PhD; Paul B. Laursen, PhD

From the Department of Physical Medicine & Rehabilitation Department of Veterans Affairs, Northern California Health Care System, and University of California Davis Medical Center, Sacramento, CA, USA (Dr Hoffman); the Exercise and Environmental Physiology, School of Physical Education, Sport and Exercise Sciences Division of Sciences, University of Otago, Dunedin New Zealand (Dr Cotter); the Research Centre on Aging, Faculty of Physical Activity Sciences, University of Sherbrooke, Sherbrooke, QC Canada (Dr Goulet); and the High Performance Sport New Zealand, and Sports Performance Research Institute New Zealand (SPRINZ) Auckland University of Technology, Auckland New Zealand (Dr Laursen).

Importance of the Question

The importance of adequate fluid intake during exercise has been stressed for sport and cardiovascular performance, for management of thermal stress,[1,2] and for prevention of exercise-induced muscle cramping[1,2] and acute kidney injury from rhabdomyolysis.[1] For these reasons, several recent guidelines recommend that mass loss during exercise should not exceed 2% of body mass.[1,2] We will show why we believe that such recommendations are not well supported by ecologically valid science, and may even induce harm.

Exercise-associated hyponatremia (EAH) is a primary concern for fluid intake beyond that which is physiologically appropriate before, during, and after exercise.[3] The behavior of overhydration typically occurs from misunderstandings about fluid needs during exercise, coupled with excessive concerns about dehydration and the need for adequate hydration to prevent decline in performance, heat illness, and muscle cramping, likely fueled by various organizational hydration guidelines. Because there have been several deaths, as well as other morbidity, from EAH,[3] a discussion to clarify current knowledge about proper hydration during exercise extends beyond merely being of academic interest.

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Corresponding author: Martin D. Hoffman, M.D., Department of Physical Medicine & Rehabilitation (117) Sacramento VA Medical Center 10535 Hospital Way, Sacramento, CA 95655-1200; Phone: 916-843-9027; Fax: 916-843-7345; (e-mail: mdhoffman@ucdavis.edu).

Fluid Balance During Exercise

Glycogen oxidation during exercise results in mass loss, the extent of which depends on the intensity and duration of the exercise. Associated with the oxidation of glycogen is release of water, as 1 to 3 g of water are stored with every gram of glycogen.[4] Thus, it is important to recognize that a loss of body mass during moderate-to-high-intensity exercise does not necessarily imply dehydration or a reduction in the cardiovascular fluid compartment, as is commonly inferred. In fact, total body water has been found to be maintained despite a loss in body mass of approximately 3.5% among runners participating in a 56-km ultramarathon[5] and a loss in body mass of approximately 2% among soldiers during a 14.6-km march.[6] Furthermore, when well-trained cyclists lost 3% of body mass by performing 2 hours of submaximal exercise (walking and cycling) in the heat, and were then reinfused with saline in a blinded fashion so that they were 0%, 2%, or 3% below their initial body mass before a 25-km bike ergometer time trial in the heat, blood volume returned to baseline during the time trial irrespective of the extent of fluid restoration.[7] Thus, consistent with conclusions made several decades ago,[8] humans are well designed to resist volume depletion of the vascular compartment through renal and hormonal adjustments in sodium and osmolality, and body mass losses of at least 2% to 3% during prolonged exercise may be necessary to maintain euhydration.

Excessive concern about hypohydration?

In our examination of the literature, we find no controlled, laboratory-based studies using exercise protocols mirroring real-world exercise conditions (ie, those in which athletes are free to alter exercise intensity according to perceived exertion and the knowledge of completed and uncompleted distance and time) showing that drinking-to-thirst-associated hypohydration of at least 2% of body mass impedes running[9,10] or cycling[11] performance, compared with a scheduled rate of fluid intake aimed at preventing loss in body mass. What these studies collectively show is that thirst-driven fluid intake induces no performance disadvantage compared with programmed fluid intake, although it is evident that drinking less than what is dictated by thirst impairs endurance performance.[11,12] Furthermore, a meta-analysis found that hypohydration up to 4% of body mass did not impair endurance performance during real-world exercise conditions.[13]

So, why is it that there is a widespread belief that hypohydration of at least 2% of body mass impairs performance? We believe it is because those controlled-laboratory studies arriving at such conclusions used methodologies that render them invalid in determining the real impact of hypohydration during outdoors conditions.[14] In fact, in addition to preventing athletes from drinking before or during exercise, most studies have failed to provide appropriate convective cooling or blinded subjects from the hydration treatment received. When studies are designed so that subjects are allowed to quench their thirst during exercise, receive adequate ventilation, or are blinded to the experimental conditions, hypohydration greater than 2% has systematically been demonstrated not to impair performance or result in serious elevations in core temperature.[7,9,11]

It is also noteworthy that it is quite common for observational field studies to report significant negative correlations between body mass loss and performance time. In other words, those with the greatest loss in body mass tend to be the fastest. The fastest long-distance triathletes,[15] marathoners,[16] and ultramarathoners[17] often complete races with body mass losses of 4% to 9%. Thus, mass losses in excess of 2% to 3% during prolonged exercise are well tolerated by elite athletes, but optimal hydration levels remain unknown.

With regard to exercise-associated muscle cramping, growing evidence from experimental[18] and cohort[19] studies indicates that cramping results from neurologic changes rather than uncompensated water and sodium losses incurred during exercise. A lack of difference between those with and without cramping in postrace body mass change, plasma sodium concentration, and sodium intake provides further evidence that exercise-associated muscle cramping is not related to fluid and sodium imbalances.[20]

Thirst As A Stimulus To Maintain Appropriate Hydration

The sensation of thirst in animals is a behavioral urge, driven largely by physiologic mediators that are activated when total body water content is low and antidiuresis is maximal. The 2 main sensors that detect physiologically relevant decreases in body water are the osmoreceptors located within the hypothalamus and baroreceptors located within the cardiac atria. Small (1%–2%) elevations in the effective osmotic pressure of plasma can stimulate central osmoreceptors and trigger thirst.[21] Thirst generally occurs when plasma osmolality exceeds 288 mOsmol/kg H_2O,[22] which is still within the normal physiological range of 275 to 295 mOsmol/kg H_2O, although wide individual variation exists with regard to osmotic stimulation thresholds for both thirst and arginine vasopressin release.[23] Peripheral baroreceptors stimulate thirst when circulating plasma volume decreases by more than 10% to 15%.[22] Thus, thirst is stimulated to bring water into the body to either dilute rising blood solute concentrations or restore plasma volume, or both.

Subjects hypohydrated by performing light exercise have demonstrated that 65% of the variance in fluid intake was accounted for by changes in plasma osmolality or volume.[24] Thus, factors other than thirst likely contribute to fluid intake, including oropharyngeal factors, mouth state, stomach fullness, beverage temperature, competing homeostatic mechanisms (ie, hunger, blood glucose), psychological factors, and situational factors including ambient temperature, exercise context, and duration. Older humans are also thought to have a lower thirst sensitivity to hypertonicity compared with younger individuals.[25]

Nevertheless, laboratory trials have demonstrated that drinking according to thirst is adequate to avoid body mass losses greater than 2% during low to moderate intensity exercise in the heat, as well as attenuate thermal and circulatory strain.[26] Field studies have also shown that drinking to thirst, even during prolonged exercise up to 30 hours under hot ambient conditions, will allow maintenance of what we consider to be proper hydration when considering mass loss from stored fuel.[5,6,27] Even when athletes begin aerobic exercise hypohydrated, the drive to drink during exercise is substantially magnified to optimally regulate plasma volume and osmolality[28] and endurance performance.[29]

In contrast to drinking according to thirst, forced fluid replacement during exercise has been shown to enhance gastrointestinal distress.[9,30] If severe enough, gastrointestinal-related problems may impede endurance performance.[30]

Problems With Alternative Methods For Maintaining Proper Hydration

Various alternative methods for maintaining proper hydration during exercise have been suggested, but each may be impractical, unnecessary, invalid, or potentially dangerous depending on the circumstances. Perhaps the most commonly recommended method is based on a calculated sweat rate from body mass change during a known duration of exercise. This method is subject to the myriad of personal, exercise-related, clothing, and environmental factors that dynamically affect sweating. Small errors in estimating sweat rate could precipitate major imbalances in fluid homeostasis during prolonged exercise. For example, an overestimate of only 100 mL/h during a 161-km ultramarathon could result in a fluid overload of 3 L when urine production is suppressed by nonosmotic arginine vasopressin secretion, a volume that would be adequate to induce EAH.

Plasma osmolality is the criterion (nonbehavioral) index of hydration status. It is physiologically regulated and functionally important and has a high sensitivity for functional hypohydration. But it is usually impractical to monitor and is one-dimensional. Urine-based measures, such as color, osmolality, specific gravity, production rate, and micturition frequency, are convenient but also reflect fluid and nonfluid-regulatory influences on renal function and are thus subject to problems of sensitivity and specificity (eg, confounding of urine color by vitamin supplementation or rhabdomyolysis, urine volume reduction that could be present with EAH despite overhydration). As such, thirst appears to be the most viable method for proper hydration given the disparate circumstances under which humans perform.

Conclusions

In the preceding paragraphs, we have offered scientific support for our premise that 1) some mass loss is appropriate during exercise, 2) exercise performance is not necessarily impaired nor is the risk of heat illness necessarily increased with modest mass loss, 3) drinking to thirst will generally be adequate to maintain hydration levels within a few percent of body mass loss, and 4) methods of maintaining hydration besides drinking to thirst are fraught with problems. The very few studies directly comparing prescribed vs self-determined drinking support our case. Nevertheless, even without considering the scientific evidence related to this essential question, one would have to believe it remarkable that the human species would exist if thirst were inadequate to guide drinking during exercise.

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COUNTERVIEW: Is Drinking to Thirst Adequate to Appropriately Maintain Hydration Status During Prolonged Endurance Exercise? No

Lawrence E. Armstrong, PhD; Evan C. Johnson, PhD; Michael F. Bergeron, PhD

From the Department of Kinesiology, Human Performance Laboratory, Unit 1110, University of Connecticut, Storrs, CT (Dr Armstrong); the Division of Kinesiology and Health, Human Integrated Physiology Laboratory, University of Wyoming, Laramie, WY (Dr Johnson); and the Youth Sports of the Americas, Birmingham, AL (Dr Bergeron).

No, drinking to thirst (DTT) is not adequate to maintain hydration status or optimal performance during prolonged endurance exercise (which should not be limited to timed events). Enough individual and athletic scenarios exist that preclude the DTT recommendation from being an absolute, unwavering, universally effective guideline suitable for all participants. Importantly, "drinking to thirst" is not equivalent to ad libitum fluid intake,[1] and we are certainly not supporting drinking in excess or "as much as tolerable" during or after exercise. However, optimal fluid intake during any prolonged, repeated, or intermittent physical activity is indeed situation- and individual-specific, which can partially rely on thirst as part of an evidence-informed advanced-planned fluid intake strategy.

To further elucidate, we begin by defining terms and underscoring the key relevant issues. The phrase *appropriately maintain hydration* may be applied in terms of preventing fluid overload, or from the perspective of optimally supporting training-competitive athletic performance. Specific to fluid overload (ie, intake and retention of water exceeding the rate of fluid loss), the concept of DTT (ie, relying solely on one's personal

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Corresponding author: Lawrence E. Armstrong, PhD, University of Connecticut, Department of Kinesiology, Human Performance Laboratory, Unit 1110, Storrs, CT 06029-1110 (e-mail: lawrence.armstrong@uconn.edu).