10. Phillips PA, Rolls BJ, Ledingham JG, Morton JJ. Body fluid changes, thirst and drinking in man during free access to water. *Physiol Behav.* 1984;33:357–363.
11. Merry TL, Ainslie PN, Walker R, Cotter JD. Fitness alters fluid regulatory but not behavioural responses to hypohydrated exercise. *Physiol Behav.* 2008;95:348–352.
12. Thomas DT, Erdman KA, Burke LM. Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: nutrition and athletic performance. *Med Sci Sports Exerc.* 2016;48: 543–568.
13. Goulet ED. Effect of exercise-induced dehydration on time-trial exercise performance: a meta-analysis. *Br J Sports Med.* 2011;45:1149–1156.
14. Goulet ED. Effect of exercise-induced dehydration on endurance performance: evaluating the impact of exercise protocols on outcomes using a meta-analytic procedure. *Br J Sports Med.* 2013;47:679–686.
15. Nolte HW, Noakes TD, van Vuuren B. Protection of total body water content and absence of hyperthermia despite 2% body mass loss ('voluntary dehydration') in soldiers drinking ad libitum during prolonged exercise in cool environmental conditions. *Br J Sports Med.* 2011;45: 1106–1112.
16. Tam N, Nolte HW, Noakes TD. Changes in total body water content during running races of 21.1 km and 56 km in athletes drinking ad libitum. *Clin J Sport Med.* 2011; 21:218–225.
17. Armstrong LE, Johnson EC, Kunces LJ, et al. Drinking to thirst versus drinking ad libitum during road cycling. *J Athl Train.* 2014;49:624–631.
18. Cotter JD, Thornton SN, Lee JK, Laursen PB. Are we being drowned in hydration advice? Thirsty for more? *Extrem Physiol Med.* 2014;3:18.
19. Coler C, Hoffman MD, Towle G, Hew-Butler T. Hyponatremia in an 85-year-old hiker: when depletion plus dilution produces delirium. *Wilderness Environ Med.* 2012;23:153–157.
20. Frizzell RT, Lang GH, Lowance DC, Lathan SR. Hyponatremia and ultramarathon running. *JAMA.* 1986;255: 772–774.
21. Gardner JW. Death by water intoxication. *Mil Med.* 2002; 167:432–434.
22. Garigan TP, Ristedt DE. Death from hyponatremia as a result of acute water intoxication in an Army basic trainee. *Mil Med.* 1999;164:234–238.
23. Pearce EA, Myers TM, Hoffman MD. Three cases of severe hyponatremia during a river run in Grand Canyon National Park. *Wilderness Environ Med.* 2015;26:189–195.
24. Hamilton RT, Bross TL, Hoffman MD. Hydration guidelines during exercise: what message is the public receiving? *Wilderness Environ Med.* 2015;26:e3.

REBUTTAL from "No"

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Although we appreciate a number of the points made in the response by Hoffman et al,[1] it is important to recognize several key limitations in the presented reasoning and interpretations. Notably, the response failed to define drinking to thirst (DTT) and did not consider the varying hydration needs and challenges of those who engage in sporting activities beyond the scope of endurance running. Further, exertional hyponatremia prompted the first description of the DTT approach to rehydration. However, Hoffman et al did not address exertional hyponatremia and its association with DTT beyond noting that it is prompted by excessive fluid intake, and they presented no evidence that DTT reduces the risk of exertional hyponatremia, because that evidence does not exist, to our knowledge.

Maintenance of circulating blood volume, in the presence of an accumulating total body water deficit, does not indicate the absence of an effect or burden on other fluid compartments, physical performance, or exercise metabolism. Thus, the argument by Hoffman et al[1] does not support relying solely on DTT. We present the case for a more objective approach based on individualized sweating rate for the following reasons. First, the maintenance of plasma volume precludes primary sensory neurons in the hypothalamus and cardiac atria from initiating significant thirst that is typically prompted by altered plasma osmolality and/or volume. Second, fluid intake also is highly variable due to unique individual responses to the perceptual integration of oropharyngeal sensations, stomach fullness, beverage characteristics, exercise mode/duration, and ambient temperature. This complexity explains why DTT is difficult to define and investigate in a systematic manner. Furthermore, thirst is fleeting—that is, consuming water causes it to diminish or disappear.[2–4]

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In the studies that Hoffman et al use to support DTT, we grant that performance was not compromised. However, thirst sensation cannot be confirmed to be the sole, or even primary, contributing factor prompting fluid intake in these studies, because DTT is not equivalent to self-selected or ad libitum fluid intake. Trained distance athletes likely exhibit drinking behavior influenced by individual performance history and a number of other factors that cannot be delineated or accurately weighted as they contribute to ad libitum fluid intake. Notably, a measurable degree of hypohydration can indeed reduce strength, power, local muscular endurance, and cardiovascular endurance.[5] Further, decrements in prolonged endurance exercise are evident even with a minor (ie, 1.5%) body weight loss.[6–8] Cardiovascular and thermal strain also are progressively exacerbated with fixed (or forced) pacing/intensity.[9]

Hoffman et al[1] indicate that methodologies used in controlled laboratory studies "render them invalid in determining the real impact of hypohydration during out-of-doors conditions." We acknowledge that a lack of convective cooling is a practical limitation; however, this is somewhat offset by the absence of solar radiation in a laboratory environment. Additionally, they neglect to cite contrary evidence of competitive and paced studies conducted in field settings.[10,11] We further argue that body weight loss and finish time interpretations in field studies are often measurably compromised by insufficient evidence and insight regarding the factors that contribute to body weight change (eg, voiding bladder and bowel just prior to race start) or performance (eg, training, diet, years of experience, age). That is, a single measure correlation does not provide sufficient evidence for causal statements regarding a complex outcome such as race finish time.[12]

Also, we refute the notion that sodium replacement plays no role in exertional muscle cramping. Skeletal muscle cramps have multiple etiologies, including comparatively sudden-onset, localized muscle cramps related to muscle overload or fatigue and intermittent, progressively widespread muscle cramping prompted by a whole-body exchangeable sodium deficit and a contracted interstitial fluid compartment.[13] For those athletes who sweat excessively, especially repeatedly, it is important to closely match daily sodium intake with individual sweat sodium losses, so that body water is better retained and distributed to all fluid compartments. This underscores the value of an individualized rehydration plan in achieving complete rehydration. Notably, after extensive exercise and significant sweat losses, circulating sodium concentration is predictably normal or somewhat elevated. Accordingly, postexercise serum sodium concentration should not be used to indicate the presence or absence of a whole-body exchangeable sodium deficit.[14]

We again recognize a continuum of progressive and varying hydration needs in different athletic activities that require different hydration strategies—whereas, Hoffman et al[1] apparently consider a DTT hydration strategy for elite finishers of marathon road races to be applicable to all athletes in all scenarios. However, there are numerous practical sport applications in which this approach fails to be a universally effective guideline that is suitable for all participants.

Finally, we agree that thirst-guided drinking has survival value in the wilds of nature, where the fittest survive. However, it is logically erroneous to extend this premise to modern-day running and cycling events that last 7 to 30 hours (ie, in advanced civilizations) because today's organized, sophisticated, sponsored ultra-endurance events were not selective pressures on the evolution of humans. Moreover, based on our personal field and laboratory observations, we are confident that employing nude or seminude body weight change to assess sweat rate is not impractical, invalid, or dangerous. Indeed, pre-exercise to postexercise body weight fluctuations are affected by exercise duration and intensity, as well as environmental factors—that is precisely the point of being guided by individualized, practical field measurements that simulate training and competition. Accordingly, a hydration strategy that is situation- and individual-specific with a proportionate emphasis on DTT or an advance-planned rehydration strategy in combination with DTT remains a sensible approach with the greatest widespread utility and effectiveness.

References

1. Hoffman MD, Cotter JD, Goulet ÉD, Laursen PB. Is drinking to thirst adequate to appropriately maintain hydration status during prolonged endurance exercise? Yes. *Wilderness Environ Med*. 2016;27:192–195.
2. Armstrong LE, Ganio MS, Klau JF, Johnson EC, Casa DJ, Maresh CM. Novel hydration assessment techniques employing thirst and a water intake challenge in healthy men. *Appl Physiol Nutr Metab.* 2014;39:138–144.
3. Obika LF, Okpere SO, Ozoene JO, Amabebe E. The role of oropharnygeal receptors in thirst perception after dehydration and rehydration. *Niger J Physiol Sci.* 2014; 29:37–42.
4. Arai SR, Butzlaff A, Stotts NA, Puntillo KA. Quench the thirst: lessons from clinical thirst trials. *Biol Res Nurs.* 2014;16:456–466.
5. Judelson DA, Maresh CM, Anderson JM, et al. Hydration and muscular performance: does fluid balance affect strength, power and high-intensity endurance? *Sports Med.* 2007;37:907–921.
6. Armstrong LE, Costill DL, Fink WJ. Influence of diuretic-induced dehydration on competitive running performance. *Med Sci Sports Exerc.* 1985;17:456–461.

7. Bardis CN, Kavouras SA, Kosti L, Markousi M, Sidossis LS. Mild hypohydration decreases cycling performance in the heat. *Med Sci Sports Exerc*. 2013;45: 1782–1789.
8. Bardis CN, Kavouras SA, Arnaoutis G, Panagiotakos DB, Sidossis LS. Mild dehydration and cycling performance during 5-kilometer hill climbing. *J Athl Train*. 2013;48: 741–747.
9. Moran DS, Montain SJ, Pandolf KB. Evaluation of different levels of hydration using a new physiological strain index. *Am J Physiol*. 1998;275:R854–R860.
10. Casa DJ, Stearns RL, Lopez RM, et al. Influence of hydration on physiological function and performance during trail running in the heat. *J Athl Train*. 2010;45: 147–156.
11. Lopez RM, Casa DJ, Jensen K, et al. Comparison of two fluid replacement protocols during a 20-km trail running race in the heat. *J Strength Cond Res*. Epub 2016 Jan 29.
12. Armstrong LE, Johnson EC, Muñoz CX. Alternative interpretations of a field study. *B J Sports Med*. Available at: http://bjsm.bmj.com/content/early/2010/11/15/bjsm.2010.074641/replycontent-block. Accessed April 29, 2016.
13. Bergeron MF. Muscle cramps during exercise: is it fatigue or electrolyte deficit? *Curr Sports Med Reports*. 2008;7: S50–S55.
14. Armstrong LE, Casa DJ, Emmanuel H, et al. Nutritional, physiological and perceptual responses during a summer ultra-endurance cycling event. *J Strength Cond Res*. 2012; 26:307–318.