Dehydration and endurance performance: why hasn't research in this area dried up?

Mark P. Funnell, Dr Stephen A. Mears and Dr Lewis J. James focus on recent research that has begun to try and blind volunteers to their hydration status.

Setting the scene

The impact of dehydration, a loss of total body water, on human performance has been extensively studied over the past 100 years. However, whether dehydration effects performance remains hotly debated among the scientific community, despite a significant body of literature reporting that dehydration impairs numerous facets of athletic performance (for a comprehensive review see Cheuvront & Kenefick, 2014). Fluid intake during exercise is rarely sufficient to replace sweat losses, mainly due to the limited availability of fluid and/or opportunities to drink within the context of the specific activity, as well as the effects of drinking on gastrointestinal comfort.

This means, where training or competition activity is prolonged and/or high intensity in nature, athletes are likely to experience some level of dehydration. At extreme levels, dehydration leads to a loss of consciousness and eventually death, meaning the question is not if, but when does dehydration impact performance? Ordinarily, the level of dehydration experienced by athletes is mild to moderate (~1-5% body mass), which poses little threat to the health of the athlete, but the performance effects of dehydration in this range are still hotly debated. Whilst many believe these questions have been answered in the scientific literature, we argue that fundamental methodological issues within research examining dehydration and performance means these questions need revisiting.

So, what happens when we become dehydrated during exercise?

Sweat is generally hypotonic, meaning dehydration via sweat loss is characterised by reduced blood volume and increased blood osmolality (concentration). These effects increase cardiovascular/thermal strain and perceived exertion during exercise (see Figure 1), with the severity directly proportional to the level of dehydration (Cheuvront & Kenefick, 2014). Furthermore, dehydration generally induces thirst, which might cause discomfort/distraction, possibly contributing to performance impairment. Ultimately, this cascade of effects, shown in Figure 1, resulting from dehydration/fluid restriction (please note that it is difficult to separate these), likely act in concert to impair endurance performance (Cheuvront & Kenefick, 2014). Consequently, the current scientific consensus is that dehydration of >2% body mass impairs exercise performance or capacity.

So, what's the debate?

Although this body of literature is extensive, the methodology used to explore the effects of dehydration on performance is inherently flawed. Unlike other areas of sports nutrition research, where treatments are blinded from subjects using a placebo, the hydration literature is potentially confounded by a lack of study blinding caused by the overtness of the methods used to induce dehydration (i.e. fluid restriction, heat exposure, diuretic administration, etc.). It cannot be excluded that volunteers' expectations of how dehydration impacts performance may have influenced the results of previous studies (McClung & Collins, 2007), potentially invalidating a large body of work. In the case of dehydration, the lay person's view is that dehydration is a bad thing, meaning the removal of water during exercise might cause a 'nocebo' effect.

How can one blind subjects to their hydration status?

To address this issue, more recent research has begun to try and blind volunteers to their hydration status; a difficult, but necessary task. These experiments have used two methods to achieve this blinding: 1) delivery of intravenous fluids to the peripheral circulation (Wall *et al*., 2015; Cheung *et al*., 2015) or; 2) delivery of fluid directly to the stomach via a gastric feeding tube (James *et al*., 2017; Adams *et al*., in press).

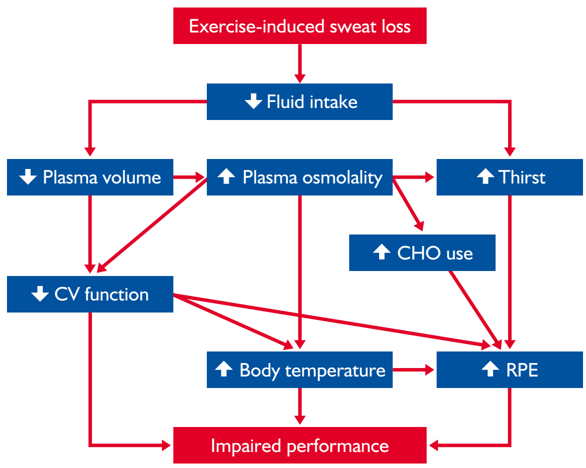


Figure 1. A basic flow diagram representing how exercise-induced dehydration impairs endurance exercise performance. CV: cardiovascular; RPE: rating of perceived exertion; CHO: carbohydrate.

In all four of these studies, researchers have used a cross-over design to compare the effects of starting an exercise performance test (cycling in all cases) in a dehydrated (~2-3% body mass reduction) or euhydrated state. Wall and colleagues (2015) had subjects exercise for 2 hours to induce dehydration of ~3% body mass. Subjects then rested for 2 hours and were intravenously infused with saline to either fully replace sweat losses (euhydrated trial) or to induce dehydration equal to 2% or 3% body mass loss. The authors reported that 25 km cycling performance at 33°C was similar between trials (i.e. dehydration did not affect performance). Similarly, Cheung *et al*. (2015) used intravenous infusion of fluid during an exercise preload, reporting no difference in subsequent 20 km cycling performance at 35°C between euhydrated (~0.5% body mass loss) and dehydrated (~2% body mass loss) conditions.

These interesting studies have important implications as they suggest that when someone's knowledge of their hydration status is removed, dehydration of 2-3% does not impair exercise performance, meaning that it is possible that previous studies were confounded by the lack of blinding. However, the methodology used might also account for the results observed. In these studies, subjects were rehydrated with approximately isotonic saline, meaning serum osmolality remained elevated at concentrations consistent with dehydration in both euhydrated and dehydrated trials. Additionally, neither study provided oral fluid intake (i.e. the swallowing of fluid), which appears to play an important role in fluid regulatory/perceptual (Figaro & Mack, 1997) and performance (Arnoutis *et al*., 2012) responses to rehydration.

Our research group has also been investigating the same question, but using a different method to blind subjects to their hydration status. We hypothesised that once knowledge of hydration status was removed, mild dehydration would not affect cycling performance. In contrast to the previous two studies, we used a gastric feeding tube to deliver fluid directly to the stomach. This tube can be inserted orally or nasally (see Figure 2) and fluid can

Figure 2. An example set up of nasogastric tube fluid infusion.

be infused without the subject knowing how much or what is delivered. To achieve this, water was infused behind the subject's back, at body temperature and in small volumes (~50 mL) to prevent subjects from detecting water infusion, or lack thereof.

We had subjects perform an intermittent preload (120 min cycling at 34°C) during which water was infused (or not) every 5 min, with a small volume of water (~15 mL) drunk every 10 min in both trials, achieving dehydration of ~0% or ~2.4% body mass at the start of the performance test. Additionally, we used the cover story that we were investigating drinks of different composition and that delivery through the tube was required as the drinks were so different in composition they would be identified by subjects. We believed this was important as it meant that subjects were not aware their hydration status was being manipulated, meaning their performance would be unlikely to be influenced by their pre-conceptions.

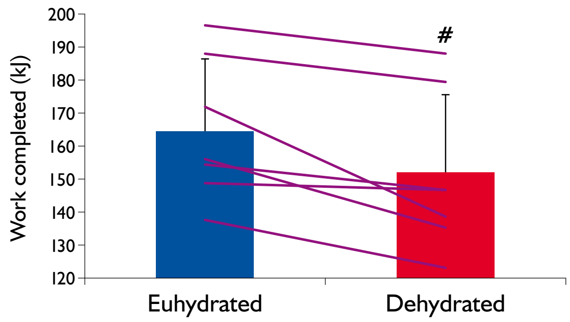


Figure 3. Work completed during a 15-minute cycling performance test for blinded euhydrated and dehydrated trials. # significantly different from euhydrated. Bars are Mean (SD), with lines representing individual data. Adapted from James *et al.* (2017).

In contrast to our hypothesis and the studies of Wall *et al*. (2015) and Cheung *et al*. (2015), we showed that dehydration decreased the amount of work done in a 15 min cycling performance test by ~8% (see Figure 3). We observed all the typically reported physiological and perceptual differences between euhydrated and dehydrated conditions, with the exception that core temperature was not different between trials. Additionally, subjects were not aware they were dehydrated (confirmed in an exit questionnaire). These results were surprising to us and interestingly suggested that if all the main symptoms associated with dehydration are present, endurance performance is impaired. This suggests that, at least some of the impairment in performance previously reported in the literature, is caused by a real effect associated with dehydration. It is important to note that the results do not provide evidence against the existence of a nocebo effect.

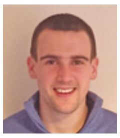
More recently, Adams *et al*. (in press) used the same technique as our research group to blind subjects to dehydrated and euhydrated conditions, but blunted thirst in both through the drinking of 25 mL water every 5 min. The authors reported 5 km cycling performance at 35°C was decreased by ~6% with dehydration equivalent to ~2.2% body mass. Again, these results do not demonstrate that thirst is not involved in the performance impairment caused by dehydration, just that the effects of dehydration are not fully mediated by thirst.

Where does hydration research go from here?

The studies using intragastric rehydration to blind subjects to their hydration status suggest there is a real effect of dehydration, but they do not rule out that a nocebo effect might have influenced the results of some previous studies. Additionally, when these four blinded studies are considered together, we are far from a consensus and there is a clear need for further research in this area, which is something we are currently pursuing here at Loughborough University. In this context, we believe it is vital that the methods chosen to induce dehydration in future studies replicate both the physiological (i.e. decreased blood volume and increased blood osmolality) and perceptual (i.e. increased thirst sensation) responses characteristic of exercise-induced dehydration. We have found this is possible using a combination of intragastric and oral fluid delivery. The use of these techniques opens up the possibility of exploring, in depth, the mechanisms that explain the effects of dehydration on endurance performance.

Key take home points

- Typical methods used to induce dehydration have meant that subjects are aware of their hydration status. Thus, results observed could be influenced by common pre-conceptions surrounding dehydration.
- Recent novel studies have demonstrated that if subjects are blinded to their hydration status and typical symptoms associated with dehydration are induced, endurance performance, at least in the heat, is compromised by dehydration of >2% body mass.
- Future studies should use intragastric rehydration to blind subjects from their hydration status to remove any potential nocebo effects and to further explore the mechanisms underpinning the effects of dehydration on performance. ■



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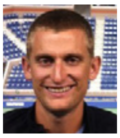

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