*Proceedings of the Nutrition Society* (2009), **68**, 17–22 doi:10.1017/S002966510800877X

*The Summer Meeting of the Nutrition Society was held at the University of Nottingham on 30 June–3 July 2008*

# Conference on ‘Multidisciplinary approaches to nutritional problems’

# Symposium on ‘Performance, exercise and health’

# Hydration, fluids and performance

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Sweat evaporation can be a key thermoregulatory mechanism and it causes a loss of water from all compartments of the body. Hypohydration can also develop with restricted fluid intake or with intake of diuretics. Hypohydration can affect physical and/or mental performance and/or have implications for dietary recommendations. A variety of different types and modes of exercise performance can be influenced by hydration state. Reviews of the published literature are currently most conclusive for endurance exercise. Dehydration equivalent to 2% body mass loss during exercise in a hot environment (31–32°C) impairs endurance performance, but when the exercise is performed in a temperate environment (20–21°C) a 2% body mass loss appears to have a lesser and inconsequential effect. In cold environments a body mass loss >2% may be tolerable for endurance exercise. There is a less conclusive picture as to the effects of hypohydration on other types of physical performance, including strength and power activities, team sports and the skills component of many sports, and for mental performance. A number of physiological mechanisms are responsible for the effects observed. Fluid consumption can be used to attenuate the development of a water deficit or to correct it. The composition and temperature of a drink and the volume and rate of its consumption can all influence the physiological responses to ingestion and can impact on exercise performance.

**Hypohydration: Body mass loss: Physical and cognitive performance: Fluid consumption**

Hydration status, water consumption and the effects of hypohydration on aspects of human performance, health and wellbeing have been the topic of much public and scientific debate in recent years. The effect of body water balance on aspects of exercise performance has been extensively researched and in recent years has been reviewed comprehensively(1–3). The majority of research in this area has been undertaken in relation to endurance-exercise performance, but the effects on power, strength, skills and cognitive performance have also been investigated. These areas form the focus of the present review.

The balance between the loss and gain of fluids maintains the body water within relatively narrow limits. The routes of water loss from the body are the urinary system, the skin, the gastrointestinal tract and the respiratory surfaces. The primary avenues for restoration of water balance are fluid and food ingestion, with water of oxidation also making a contribution. The volumes of water that individuals obtain from food and drinks are highly variable, although it is generally reported that the majority normally comes from liquids with a smaller although still important proportion from solid foods.

Body water loss in human subjects results in fluid losses from both the intracellular and extracellular fluid compartments(4). The fluid losses, however, can cause very different effects on the remaining body water pools depending on the type of water loss that occurs(5,6). Hypotonic water loss, as can occur with sweating, results in an increase in body fluid tonicity, while isotonic loss causes a net fluid loss, but no increase or decrease in body fluid tonicity. Hypertonic fluid losses, as can occur with production of a concentrated urine, cause a reduction in body fluid tonicity.

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## Assessing hydration status and change in hydration status

A number of methods have been used to assess and quantify hydration status and changes in hydration status. Acute changes in body mass over a short time period can frequently be assumed to be a result of body water loss or gain; 1 ml water has a mass of 1 g(7) and therefore changes in body mass can be used to quantify water gain or loss. Over a short time period no other body component will be lost at such a rate, making this assumption possible.

Throughout the exercise literature changes in body mass over a period of exercise have been used as the main method of quantifying body water losses or gains due to sweating and drinking. Indeed, this method is frequently used as the method with which other methods are compared. Respiratory water loss and water exchange as a result of substrate oxidation are sometimes calculated and used to correct the sweat loss values, but this calculation is not always done(8,9).

## Strength, power and high-intensity endurance-exercise performance

The influence of hydration status on sprint performance has been investigated in many studies using a number of different exercise modes. It is possible that hypohydration may influence exercise performance differently depending on whether the sprinting being investigated is running, for which body mass must be supported and moved, or whether it is cycle ergometer sprinting, which does not have this requirement. If body mass is reduced it changes the work required for the running, i.e. the decreased body mass that is typically used to define the magnitude of hypohydration may compensate for any reduced muscular strength and/or power that it causes. However, whilst this factor will complicate the pure science interpretation of the findings of studies investigating sprint performance, it is the situation that occurs in real athletic situations.

The effects of hypohydration on both 50 and 200 m sprint performance have been investigated in experienced but non-elite sprinters(10). The administration of the diuretic furosemide reduced body mass by 1·7 (SD 0·4) kg (equivalent to 2·2 (SD 0·5) %) but there was no significant change in performance and a non-significant reduction in completion time by 0·01 (SD 0·01) s in the 50 m event and by 0·26 (SD 0·22) s in the 200 m event. A combination of fluid and energy restriction over a period of 59 h followed by a 5 h *ad libitum* eating and drinking phase and an overnight fast has been used to reduce body mass overall by 2·0 (SD 0·4) kg (equivalent to 2·7 (SD 0·5) %) before investigating the effects on 3 × 30 m sprints(11). The subjects in this study were wrestlers and judokas, accustomed to this rapid body mass reduction, and the results indicate that this regimen has no significant effect on the 30 m sprint performance averaging 4·16 (SD 0·05) s after the body mass loss in comparison with 4·14 (SD 0·05) s on a control trial. In the earlier study with sprinters the effects of hypohydration on 400 m sprint performance were also investigated(10). Body mass was found to be reduced by 1·9 (SD 0·3) kg (equivalent to 2·5 (SD 0·4) %), again by the administration of the diuretic furosemide. No significant change was found in 400 m sprint performance and a non-significant 0·33 (SD 0·58) s increase in completion time was reported. Taken together these studies suggest that body mass reductions of 2–3 % have no significant effect on sprint performance. It is possible that sprinting would have been ‘easier’ with the lower body mass, because the runner has less mass to move. Thus, it is feasible that a reduction in physiological demand may promote improved performance, which may counteract any affects hypohydration may have on sprinting.

Jumping performance has frequently been investigated as a means of assessing the influence of a body water loss on muscle power; jump power and jump height have been most frequently measured(10,12–15). In the majority of these studies the level of body mass loss has been between 1 and 3 %(10,13,15), although a 6 % body mass loss has been investigated when energy restriction was combined with dehydration(12,14). The majority of these studies have found no significant effect of the body mass reduction on jumping power or height. As discussed earlier, jumping will also become ‘easier’ as hypohydration progresses, as the jumper must move less mass. As a result of this decrease in physiological demand and the improved performance it can promote, it may mask any potential negative effect of hypohydration on jumping performance. If hypohydration does not reduce muscle force or power, jumping performance may be improved with hypohydration. However, systematic research is required to investigate this possibility.

## Endurance-exercise performance

A review of the literature relevant to fluid balance and endurance-exercise performance was undertaken and published in 2003(1). The durations of exercise included in the review range from approximately 1 h to approximately 6 h in duration. The review concludes that dehydration equivalent to between 2 and 7 % body mass loss significantly reduces exercise performance, particularly in hot environmental conditions (i.e. >30°C). No data were available to indicate what happens with reductions in body mass of >7 %, but there is no reason to suspect that it will improve performance. The authors also conclude that dehydration equivalent to a body mass reduction of between 1 and 2 % body mass loss does not have any influence on endurance-exercise performance when the exercise duration is <90 min and the environmental conditions are temperate (20–21°C). However, if the dehydration is equivalent to a body mass loss of >2 % body mass, endurance performance is impaired in these temperate conditions, especially if the exercise duration is >90 min.

More recently, the results have been published of a study designed to investigate, amongst other factors, the impact of hypohydration induced by fluid restriction on endurance-exercise performance(16). After 48 h of fluid restriction body mass was found to be reduced by 3·2 (SD 0·5) % compared with a 0·6 (SD 0·4) % reduction in the control trial. Despite the magnitude of the body mass reduction, performance in a 30 min time trial performance test undertaken in moderate environmental conditions of 20°C and 60 % relative humidity was not found to be different from that when no hypohydration was present.

## Masking and exacerbating factors when investigating hypohydration and exercise performance

When the influence of hypohydration on exercise performance has been the aim of scientific investigation, it has not always been the only aim of the research. While this research has contributed information to the published literature, it has meant that some of the studies may have factors that mask or exacerbate the contribution of hypohydration to the study results. Also, whilst some research into hydration status and aspects of performance has been undertaken as basic science, some has been carried out with applied science in mind, which has influenced the way in which the hypohydration has been induced or the type of performance investigated. Masking factors will magnify the effects of hypohydration on the performance tests and therefore overemphasise the effects attributed to hypohydration(3). Examples of these factors are (1) energy restriction, sometimes seen when fluid restriction and/or fasting is the tool used to induce hypohydration; (2) body temperature increase, sometimes seen when exercise or heat exposure is used to induced hypohydration by sweating; (3) fatigue, sometimes seen when exercise is used to induce hypohydration via sweat production. Exacerbating factors will underestimate the effects of hypohydration on the performance tests and therefore underestimate the effects of hypohydration on performance by attenuating them(3). Exacerbating factors include the decrease in body mass typically accompanying hypohydration or an increase in total body water that can occur with training. In a recent review of the influence of hypohydration on muscle strength, power and high-intensity endurance exercise the published literature was carefully examined to identify the studies with results that were not influenced by either masking or exacerbating factors(3). It was concluded that body mass reductions in the order of 3–4 % appear to consistently attenuate strength (by approximately 2 %), power (by approximately 3 %) and high-intensity endurance (by approximately 10 %). However, some of these conclusions are based on a very limited number of published studies.

In a practical situation the individual who is performing is not interested in the mechanism whereby his or her performance is affected or whether any effect of hypohydration is magnified or attenuated. However, typically with hypohydration body mass is lighter than when the individual is euhydrated, because of the lower body water content. As described earlier, this body mass reduction is typically the measure used in the published literature to quantify the extent of hypohydration. The question that arises is whether this reduction in body mass can actually lead to an improvement in performance of some tasks by virtue of the lower body mass reducing the work required to do a task. A good example of the type of performance that could easily benefit in this way by hypohydration is uphill cycling performance in which power:mass could be increased. This potential benefit has been investigated in subjects who completed a 2 h bicycle ride during which they drank either 2·4 litres sports drink (the control euhydrated condition) or 0·4 litres water plus carbohydrate gels to give the same carbohydrate intake as given by the sports drink (the experimental hypohydrated condition)(17). In the hypohydrated condition body mass was reduced by 2·5 (SD 0·5) % compared with a reduction of only 0·3 (SD 0·4) % in the euhydrated condition. On completion of the 2 h cycle ride an uphill (8 % gradient) bicycle exercise-capacity test was completed in warm (30°C) conditions. It was found that all subjects completed less exercise in the hypohydrated condition compared with the euhydrated condition. It was concluded that, at least when exercise is undertaken in warm conditions, hypohydration is detrimental to laboratory cycling uphill despite reducing the power output required for a given speed. It will be interesting to see the results of other studies investigating the effects of hypohydration in other conditions and with other types of performance.

## Skills and sporting tasks performance

Many sports such as football, rugby, basketball, hockey and tennis are stop–start in nature and consist of prolonged periods of exercise with repeated intermittent high-intensity bursts interspersed with lower-intensity exercise. Successful performance in these sports involves fatigue resistance, but also relies on cognitive function for decision making as well as proper execution of complex skills, which makes assessment of sport performance challenging to study. However, a number of protocols have been developed that have attempted, amongst other things, to investigate the effect of hydration status may have on aspects of sports performance(18,19). In many of the studies undertaken in this area the protocol used involves allowing dehydration to develop on one trial and preventing it on another by provision of drinks. However, the drink provided has frequently been a sports drink, which means that the influence of carbohydrate or other components in the drink on the outcomes measured cannot always be distinguished from any effects that result from the prevention of dehydration.

A shuttle running test has been developed that aimed to simulate the intense ‘stop and go’ nature of sports such as football(18). The same research group have reported that fluid replacement with flavoured water, sufficient to limit body mass loss to 1·4 %, prevents a reduction in soccer-skill performance(20) in comparison with performance when body mass is reduced by 2·5 %. More recently, the influence of hydration status on the movement patterns in football has been investigated(21) using the ‘yo-yo’ intermittent recovery test(19,22). This test evaluates an individual’s ability to repeatedly perform intense exercise, typical of that undertaken in football. Body mass reductions of 2·4 (SD 0·8) % and 2·1 (SD 0·6) % were found to result in reductions of 13 % and 15 % respectively in ‘yo-yo’ test performance in comparison with a trial in which drinking was found to result in a body mass reduction of only 0·7 (SD 0·4) %.

In a study investigating the motor skill performance of cricket bowling subjects were dehydrated by 2·5 (SD 0·6) kg (equivalent to 2·8 (SD 0·5) % body mass) and their performance was compared with that when they drank flavoured water and limited their dehydration to 0·5 (SD 0·5) kg (equivalent to 0·5 (SD 0·4) % body mass)(23). The results of the study indicate that there is no influence of hydration status on bowling speed, but bowling accuracy, as determined by line and distance, is markedly worse when undertaken in the dehydrated state.

## Cognitive performance

Most sport and exercise situations and everyday tasks and activities involve some aspect of cognitive function, mental readiness, reaction response and/or motor control. Mild dehydration equivalent to 1–2 % body mass loss has not been shown to be associated with mental function decrements or reduced reaction time(24). The football-type study described earlier also investigated whether the body mass reductions when no drinking took place would have an impact on mental concentration, and the results indicate that there was no impact(21).

Cognitive readiness and decision making have also been shown to be preserved during water deprivation causing body mass reductions ≤ 2·6 %(25). The same study also demonstrated that cognitive motor function is preserved during water deprivation causing the same reduction in body mass (i.e. 2·6 %). However, increased tiredness and reduced alertness may be consequences of prolonged moderate dehydration. The induction of hypohydration equivalent to 2·7 (SD 0·6) % body mass loss in healthy volunteers by 37 h of voluntary fluid restriction has been shown to be sufficient to cause subjects to report feelings of headache, tiredness, reduced levels of alertness and greater difficulty in concentrating(26). Such feelings may impact on a variety of types of performance. Taken together, these data suggest that mild to moderate dehydration, without adverse heat stress, is not likely to be associated with reductions in cognitive function and mental readiness. However, this level of dehydration may be approaching the limits of compensatory mechanisms to preserve alertness and mood status.

After short-term exercise or heat-induced dehydration decrements in cognitive aptitude have been observed in normal healthy individuals at a moderate dehydration level of ≥ 2·5 %(27–29). An initial drop in short-term memory immediately after acute exercise-induced dehydration (2·8 % body weight loss) has been shown to return to baseline levels 3·5 h later, independent of water intake(28).

Dehydration of >3 % body mass losses is likely to negatively affect cognition, mood and mental status during exercise and at rest(27). The reduction in performance and mental readiness is proportionate to the extent of dehydration >3 % body mass losses. In addition, during longer-duration exercise events dehydration is likely to be one of several stressors contributing to exercise performance decrements(30). Thus, athletes should limit dehydration to <2·5 % body mass losses to preserve alertness and cognitive function at all times, in particular during days with high ambient temperatures.

## Sweat losses in athletes

As is clear from the preceding discussion, body mass changes, rather than any measure of body water change, are used in the literature to quantify a change in hydration status. In order to ascertain the importance of these findings it is necessary to have an understanding of the extent of body mass reductions, largely as a result of water loss, that an individual may experience. Typically, maximum sweat rates are of the order of 2–3 litres/h. Thus, 2–3 % body mass reductions could readily occur in exercise situations.

However, it is important to remember that there is a very large inter-individual variation in sweating, even when the same or similar exercise is carried out in the same conditions or when individuals are exposed to the same heat stress. It is easily observed and commonly reported in the published literature. For example, the study of football (soccer) has contributed some descriptive data on sweat losses and net body mass changes during training and competition. A review of some of these data for a meeting of Fédération Internationale de Football Association/F-MARC (an independent research body of the Fédération Internationale de Football Association uniting an international group of experts in football medicine) demonstrates clearly the substantial variability in sweating response and drinking behaviours even when players are doing the same training at the same time(31). Similar variability has also been shown to be the case in match play(32). Thus, whilst some individuals may readily lose ≥ 2 % body mass when sweating, other individuals may never or rarely reach this extent of body mass loss.

## Fluid intake and performance

In 2003 the International Olympic Committee held its second Consensus Conference on nutrition for sport. In addition to other topics, the conference considered the impact of hydration status on sport and exercise and in its consensus statement came to the following conclusion in relation to hydration: ‘Dehydration impairs performance in most events, and athletes should be well hydrated before exercise. Sufficient fluid should be consumed during exercise to limit dehydration to less than about 2 % of body mass. .........Sodium should be included when sweat losses are high, especially if exercise lasts more than about 2h. Athletes should not drink so much that they gain weight during exercise. During recovery from exercise, rehydration should include replacement of both water and salts lost in sweat.’ (33).

In addition, and specifically from the two papers that covered the topic of hydration(2,34), the following conclusions were drawn:

1. a reduction in body mass of 2 % is tolerable in temperatures of ≤ 22°C but impairs absolute power production and predisposes athletes to heat illness in ambient temperatures >30°C(2);
2. Na should be included in fluids consumed during exercise if the exercise lasts >2 h. It should also be included in fluids consumed by individuals in any event who lose >3–4 g Na in their sweat(2);

3. normally, before commencing exercise euhydration should be ensured. Urine osmolality, specific gravity and colour may be markers that can be used as a guide(34);
4. after exercise that has resulted in body mass loss because of sweat loss, water and Na should be consumed in quantities greater than those lost to optimise recovery of water and electrolyte balance(34).

The evidence on which these comments were based can be found within the cited papers(2,34) and will not be further discussed here.

In addition to the hydration benefits imparted by drinking during exercise, ingestion of cold drinks has been demonstrated to influence body temperature when exercising in moderate or warm environments(35–37) and even to improve exercise capacity in hot conditions(36).

## Conclusions

Acute mild and moderate hypohydration as a result of sweat losses can be relatively common in individuals who are exercising or who are exposed to warm environments. It may also occur in situations of restricted fluid intake or as a result of consumption of diuretics. A variety of different types and modes of human performance have been investigated in association with hypohydration, i.e. physical performance of strength, power and high-intensity endurance through to endurance performance and skill accomplishment. Cognitive performance, mood and mental readiness have also been investigated. However, for some of these areas, there have been a relatively small number of investigations, which therefore impacts on the strength of the conclusions that can be drawn. Nonetheless, the available evidence suggests that:

1. reductions in body mass of the order of 3–4 % appear to consistently attenuate strength (by approximately 2 %), power (by approximately 3 %) and high-intensity endurance (by approximately 10 %), suggesting that alterations in total body water do affect some aspect of muscle force generation;
2. reductions in body mass of the order of 2–3 % appear to have no significant effect on sprint running performance, i.e. when body mass is ‘carried’;
3. reductions in body mass of the order of 2–7 % markedly reduce endurance exercise performance, particularly in environments that are warmer than 30°C;
4. reductions in body mass of the order of 1–2 % appear to have no influence on endurance exercise performance when the exercise duration is $<90$ min and the environment is temperate (20–21°C);
5. mild to moderate dehydration ($\leq 3\%$ body mass loss), without heat stress, is unlikely to be associated with reductions in cognitive function, mood and mental readiness;
6. higher levels of hypohydration ($>3\%$ body mass loss), or the more moderate levels combined with heat stress, may influence cognitive function, mood and mental readiness.

Overall, hypohydration, if of a sufficient level, can affect physical and cognitive performance, but not all hypohydration negatively affects performance. The environmental conditions experienced by an individual can influence both the hydration status, by means of influencing sweat loss, and the physiological responses to that hydration status.

## Acknowledgements

S. S. has in the past received research funding from commercial companies and other organisations that manufacture and/or sell and/or promote drinks including Coca Cola, London, UK, GlaxoSmithKline, Brentford, Middlesex, UK, Britvic, Chelmsford, Essex, UK, PepsiCo, Richmond, Surrey, UK, Mars, Slough, Berks., UK and The Milk Development Council. She has also been funded for travel to conferences and meetings from these companies.

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