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REVIEW

Hydration in sport and exercise: water, sports drinks and other drinks

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Summary

There is evidence to suggest that exercise-induced dehydration can have a negative impact on exercise performance, and restoration of fluid balance should be achieved after exercise. It is equally well known that muscle glycogen must be restored after exercise if subsequent performance is not to be negatively affected. Sports drinks are ideally placed to fill both these roles. However, while muscle glycogen restoration can be comfortably achieved by consumption of solid food, the same is not true for restoration of hydration status.

Clear evidence is available that drinking during exercise can improve performance, provided that the exercise is of sufficient duration for the drink to be emptied from the stomach and absorbed in the intestine. Generally, drinking plain water is better than drinking nothing, but drinking a properly formulated carbohydrate–electrolyte 'sports' drink can allow for even better exercise performance.

Of importance for rehydration purposes after exercise is consumption of both an adequate volume of fluid (greater than the net deficit of the sweat volume lost) and quantity of sodium. Without both of these, rehydration will be neither rapid nor complete and maintained. There is, however, no good evidence for the inclusion of any other electrolytes. The current generation of commercially available sports drinks are generally formulated to meet the needs of many athletes in many different situations.

Keywords: exercise, hydration, performance, rehydration, sports drinks

Introduction

Competitive and recreational exercisers alike may drink before, during and/or after exercise. Their reasons for drinking can be wide ranging, for example, to minimise dehydration, to provide a substrate or to refresh the mouth. However, while it is also common for solid food to be consumed before and after exercise, it is much less common for solid food to be consumed during exercise, with the exception perhaps of ultra-endurance exercise.

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The decision of whether to eat and/or drink or do neither during exercise will be made based upon whether the exerciser wants to do so for comfort reasons, for hydration reasons or for substrate consumption. If substrate provision is the main aim, then solid food may be as effective as liquid 'food' provided that both can be equally well tolerated. Significant amounts of carbohydrate can be provided by a relatively concentrated drink. If, however, hydration is the aim, then it is unlikely that solid food can provide the quantities of water desired. Therefore drinks play an important role in the diet of exercisers who need to pay attention to their hydration. This is the focus of this article.

Sweat loss in exercise

Body mass changes, rather than any measure of body water change, is typically used in research studies (and applied practice) to quantify a change in hydration status. In order to ascertain the significance of these findings, it is necessary to have an understanding of the extent of body mass reductions, largely due to water loss, that an individual may experience.

Typically, maximum sweat rates are in the order of 2–3 litres per hour. Therefore, body mass reductions of up to 2–3% could feasibly occur in many exercise situations and reductions of this magnitude, and more, are reported in the scientific literature. However, it is important to remember that there is a 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. For example, the study of football (soccer) has provided descriptive data to the published literature of sweat losses, and net body mass changes during training and competition. Some of these data were reviewed by Shirreffs *et al.* (2006) for a Fédération Internationale de Football Association (FIFA) Medical Assessment and Research Centre meeting and it demonstrates clearly the substantial variability in sweating response and drinking behaviours even when players are doing the same training at the same time. This has also been shown to be the case in match play (Maughan *et al.* 2007). Therefore, while some individuals may readily lose 2% or more of their body mass when sweating, other individuals may never or rarely reach this extent of body mass loss.

Hydration, fluid intake and performance

Acute mild and moderate hypohydration can be relatively common in individuals exercising or who are exposed to warm environments due to the loss of sweat. It may also occur in situations of restricted fluid intake or due to consumption of diuretics. The effect of hypohydration on different types of exercise performance has been investigated including physical performance of strength, power and high-intensity endurance, endurance performance and skill accomplishment, cognitive performance, mood and mental readiness. In some of these areas, however, there are a relatively small number of scientific investigations which impacts on the strength of the conclusions that can be drawn. Nevertheless, the available evidence suggests that:

(1) Reductions in body mass in the order of 3–4% appear to consistently attenuate strength (by ~2%), power (by ~3%) and high-intensity endurance (by ~10%) suggesting that alterations in total body water do affect some aspect of muscle force generation (Judelson *et al.* 2007).
(2) Reductions in body mass in the order of 2–3% appear to have no significant effect on sprint running performance, that is, when body mass is 'carried' (Judelson *et al.* 2007).
(3) Reductions in body mass in the order of 2–7% significantly reduce endurance exercise performance, particularly in environments that are warmer than 30°C (Cheuvront *et al.* 2003).
(4) Reductions in body mass in the order of 1–2% appear to have no influence on endurance exercise performance when the exercise duration is less than 90 minutes and environment is temperate (20–21°C) (Cheuvront *et al.* 2003).

In 2003, the International Olympic Committee held its second Consensus Conference on Nutrition for Sport. The conference considered the impact of hydration status on sport and exercise and concluded the following with regards to hydration in its consensus statement (Consensus Statement 2004):

> "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 2 h. 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".

In addition, the following conclusions were drawn from the two papers that covered the topic of hydration:

(1) Sodium should be included in fluids consumed during exercise if the exercise lasts more than 2 hours. It should also be included in fluids consumed by individuals in any event who lose more than 3–4 g of sodium in their sweat (Coyle 2004).
(2) Normally, before commencing exercise, euhydration should be ensured. Urine osmolality, specific gravity and colour are markers that can be used as a guide (Shirreffs *et al.* 2004).

(3) After exercise that has resulted in body mass loss due to sweat loss, water and sodium should be consumed in a quantity greater than the losses to optimise recovery of water and electrolyte balance (Shirreffs *et al*. 2004).

In addition to the hydration benefits imparted by drinking during exercise, ingestion of cold drinks has been shown to influence body temperature when exercising in moderate or warm environments (Lee & Shirreffs 2007; Lee *et al*. 2008a, 2008b) and to improve exercise capacity in hot conditions (Lee *et al*. 2008b).

Water, sports drinks and other drinks

Sports drinks mean different things to different people. In its simplest sense, a sports drink is a drink consumed in association with sport or exercise – either in preparation for exercise, during exercise itself or as a recovery drink after exercise. By definition, a drink is a liquid substance and as such, water is a main ingredient. However, a sports drink can contain a variety of nutrients and other substances. Therefore consumption of a sports drink will provide a large amount of water in addition to other components which could otherwise be obtained from food.

The formulation of sports drinks is related to that of oral rehydration solutions designed for the treatment of diarrhoea, in that water, carbohydrate and sodium are the key ingredients. The majority of mainstream sports drinks have a carbohydrate content close to 6% weight/volume and contain small amounts of electrolytes, the main one being sodium (see Table 1).

The main aims of sports drink consumption do vary according to the exercise situation, but, from a hydration point of view, are likely to be one or more of the following: to speed rehydration, to stimulate rapid fluid absorption, to reduce the physiological stress of exercise and to promote recovery after exercise.

Hydration during exercise

In any exercise task lasting longer than about 30–40 minutes, carbohydrate depletion, elevation of body temperature and reductions in the circulating fluid volume may be important factors in causing fatigue. All of these can be manipulated by the ingestion of fluids, but the most effective drink composition and the optimum amount of fluid will depend on individual circumstances. Water is not the optimum fluid for ingestion during endurance exercise, and there is compelling evidence that drinks containing added substrate and electrolytes are more effective in improving performance. Increasing the carbohydrate content of a drink will increase the amount of fuel available, but will tend to decrease the rate at which water can be made available (Vist & Maughan 1995). Where provision of water is the priority, the carbohydrate content of a drink and its total osmolality should be low, thus restricting the rate at which substrate is provided. The composition of a drink will thus be influenced by the relative importance of the need to supply fuel and water, which in turn depends on the intensity and duration of the exercise task, on the ambient temperature and humidity and on the physiological and biochemical characteristics of the individual athlete. Carbohydrate depletion will result in fatigue and an inability to sustain exercise intensity, but is not normally a life-threatening condition. Disturbances in fluid balance and temperature regulation can have potentially serious consequences, and it may be

Table 1 The composition of selected UK based sports drinks and other beverages. Carbohydrate content is taken from drink labels. Other data from samples analysed in the laboratory

	Carbohydrate (%)	Sodium (mmol/l)	Potassium (mmol/l)	Osmolality (mosmol/kg)
Gatorade	6	20	3	280
Isostar	7	30	*	289
Lucozade Sport	6.4	22	3	285
Powerade	6	23	2	280
Orange juice	10	4	45	660
Apple juice	13	1	26	*
Tomato juice	3	10	7	*
Cola	11	3	1	700
Oral rehydration solution	2	45	20	250
Bottled water	0	0	0	9
Milk	5	26	37	288

*Not measured.

therefore that the emphasis for many participants in endurance events should be on proper maintenance of fluid and electrolyte balance.

Carbohydrate

The optimum type and concentration of sugars in a drink will depend on individual circumstances. High carbohydrate concentrations will delay gastric emptying, thus reducing the amount of fluid that is available for absorption: very high concentrations will also result in secretion of water into the intestine and thus temporarily increase the likelihood of dehydration (Evans *et al.* 2009a). Perhaps because of this effect, high sugar concentrations (>10%) may result in an increased risk of gastrointestinal disturbances. Where there is a need to supply an energy source during exercise, however, increasing the sugar content of drinks will increase the delivery of carbohydrate to the site of absorption in the small intestine.

Electrolytes

The available evidence indicates that the only electrolyte that may need to be added to a drink consumed during exercise is sodium, which is usually added as sodium chloride, but which may also be added as other salts e.g. sodium citrate. Sodium will stimulate sugar and water uptake in the small intestine and will help to maintain extracellular fluid volume as well as maintain the drive to drink by keeping plasma osmolality high (Noakes *et al.* 1985; Maughan 2001). As is clear from Table 1, most soft drinks of the cola or lemonade variety contain virtually no sodium (1–2 mmol/l), and water is also essentially sodium free; sports drinks commonly contain ~20–25 mmol/l sodium, and oral rehydration solutions intended for use in the treatment of diarrhoea-induced dehydration have higher sodium concentrations, in the range 30–90 mmol/l. A high sodium content may be important in stimulating jejunal absorption of glucose and water, but it may make drinks unpalatable.

Some degree of hyperthermia and hypernatraemia are relatively common in endurance events held in the heat. It has, however, become clear that a small number of individuals at the end of very prolonged events may be suffering from hyponatraemia: this may be associated with either hyperhydration or hypohydration. The total number of reported cases is small, and the great majority of these have been associated with ultramarathon or prolonged triathlon events. Many of the drinks consumed in endurance events, whether plain water, soft drinks or sports beverages, have relatively little or no electrolyte content. Most carbohydrate–electrolyte drinks intended for consumption during exercise have a low electrolyte content, with sodium concentrations typically in the range of 20–25 mmol/l. This is adequate in most situations (Vrijens & Rehrer 1999), but may not be so when sweat losses and fluid intakes are high. Some supplementation with sodium chloride in amounts beyond those normally found in sports drinks may be required in extremely prolonged events where large sweat losses can be expected and where it is possible to consume large volumes of fluid. However, electrolyte replacement during exercise is not a priority for the majority of participants in most sporting events.

Cardiovascular, metabolic and performance effects

Many of the published studies investigating the effects of fluid ingestion on exercise performance have failed to include appropriate controlled trials that allow the separate effects of water replacement and substrate provision to be assessed. Generally, the studies in the literature have reported either no effect of fluid ingestion on exercise performance or a beneficial effect. There seems to be a lessened hyperthermia and cardiovascular drift during prolonged moderate intensity exercise (Hamilton *et al.* 1991; Montain *et al.* 1992a, 1992b; Bosch *et al.* 1994) which is attributed to fluid replacement during the exercise. A better maintenance of blood glucose, which can be used by the exercising muscles with a consequent reduction in the need for mobilisation of the limited liver glycogen reserves (*e.g.* Maughan *et al.* 1989; McConell *et al.* 1994), appears to be the major benefit of carbohydrate consumption during exercise. The studies that have reported adverse effects of fluid ingestion on exercise performance have generally been studies in which the fluid ingestion has resulted in gastrointestinal disturbances.

Drinking plain water can improve performance in endurance exercise, but there are further performance improvements when carbohydrate and electrolytes are added. The study of Below *et al.* (1995) attempted to distinguish between the effects of carbohydrate provision from the water replacement properties of a drink. Eight men undertook the same cycle ergometer exercise on four separate occasions. After 50 minutes exercise at 80% of VO_{2max}, a performance test at a higher exercise intensity (completion of set amount of work as quickly as possible) was completed; this test lasted approximately 10 minutes. On each of the four trials, a different beverage consumption protocol was followed during the

50-minute exercise; nothing was consumed during the performance tests. The beverages were electrolyte-containing water in a large (1330 ml) and small (200 ml) volume and carbohydrate–electrolyte solutions (79 g) in the same large and small volumes; the electrolyte content of each beverage was the same, 619 mg (27 mmol) of sodium and 141 mg (3.6 mmol) of potassium, respectively. The results indicated that performance improved by 6.5% after consuming the large volume of fluid in comparison with the smaller volume and improved by 6.3% after consuming the carbohydrate-containing rather than carbohydrate-free beverages; the fluid and carbohydrate each independently improved performance and the improvements were additive. The mechanism for the improvements in performance with the large fluid replacement *vs.* the small fluid replacement was attributed to a lower heart rate and oesophageal temperature when the large volume was consumed. The authors were unable to identify the mechanism by which carbohydrate ingestion improved performance (Below *et al.* 1995).

Hydration after exercise

Until the electrolytes (particularly sodium) lost in sweat are replaced after exercise, water balance will not be effectively restored and maintained (Shirreffs & Maughan 1998). We do not lose plain water when we sweat and plain water alone will not allow us to recover effectively.

Practical issues

The quantity of electrolytes lost in sweat is highly variable between individuals and although the optimum drink may be one that matches equal quantities with the electrolyte loss, this is virtually impossible in a practical situation. Sweat composition and loss varies considerably between individuals, and also with environment and clothing worn and may be further influenced by the state of acclimation. However, a moderate excess of salt intake would appear to be beneficial as far as hydration status is concerned, without any detrimental effects on health, provided that fluid intake is in excess of sweat loss and that renal function is not impaired. Concerns over the possible adverse effects of a high salt intake on health have led some athletes to restrict dietary salt intake (Bergeron 1996). For athletes with large sweat losses, sodium loss will be correspondingly high: loss of 5 litres of sweat with a sodium content of 50 mmol/l requires ingestion of almost 15 g of sodium chloride to restore balance. This amount of sweat can easily be lost in 2–3 hours of hard exercise in hot, humid conditions. Although the diet will make a major contribution to replacement, normal daily salt intake from food is only about 6–8 g for the UK population, about half of whom rarely or never add salt to food at the table (Gregory *et al.* 1990). There is clearly a high risk of salt deficit when losses are high.

Conclusions

A properly formulated sports drink has a valuable role to play in the diet of many athletes. This is particularly true in situations where solid food is not available or not desired by the athlete or where hydration is the main concern.

During exercise, there are few situations where sports drinks have had a negative impact on exercise performance and where this has occurred, it is generally because of gastrointestinal distress rather than via another physiological mechanism. Provided appropriate quantities are consumed, drinking plain water is generally better than drinking nothing at all, but drinking a properly formulated carbohydrate electrolyte sports drink may allow for an improved exercise performance with benefits being gained from both its carbohydrate content and the water and electrolyte content.

In order to achieve effective rehydration after exercise in the heat, or heat exposure or any type of exercise sufficient to cause sweat loss, the rehydration beverage should contain moderately high levels of sodium (e.g. 50 mmol/l). A source of substrate is not necessary for rehydration, although a small amount of carbohydrate (<2%) may improve the rate of intestinal uptake of sodium and water, and a larger quantity of carbohydrate should not negatively impact post-exercise rehydration provided an appropriate volume for rehydration can be consumed (Evans *et al.* 2009b, 2009c) The volume of beverage consumed should be greater than the net volume of sweat lost in order to make a provision for the ongoing obligatory urine losses. The palatability of the beverage is of importance as many individuals lose substantial amounts of sweat and so need to consume large amounts of fluid to replace them and this is more likely to be achieved if the taste is perceived as pleasant.

Ultimately, the choice of drink to be consumed will depend on the individual and their particular circumstances. Replacement of substrate in addition to water and electrolyte losses may be of importance in the post-exercise period in preparation for a further bout of exercise. In terms of sustaining life, substrate (muscle and liver glycogen) depletion is unlikely to have an adverse effect in an otherwise healthy individual, but water depletion, if not replaced, may have serious consequences. The current generation of commercially available sports drinks are generally a good compromised formulation to meet the needs of many athletes in many different situations.

Conflict of interest

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