REHYDRATION STRATEGIES BEFORE AND AFTER EXERCISE

Abstract
Optimal hydration involves fluid intake strategies before, during and after exercise sessions. In most situations sweat losses during exercise exceed the opportunities for fluid replacement during the activity. Therefore, it is important that residual levels of hypohydration are corrected during post-exercise recovery, particularly in preparation for future exercise sessions. Athletes should aim to start each exercise session in fluid balance. At special risk are those athletes who dehydrate to `make weight' in weight division sports. Hyperhydration before exercise may be useful where fluid losses during exercise are likely to greatly exceed the potential for fluid intake. However, more research is needed before special techniques such as hyper-hydration with glycerol can be universally recommended. Rehydration after exercise requires a specific fluid intake plan since thirst and voluntary intake will not provide for full restoration of sweat losses in the acute phase (zero to six hours) of recovery. Steps should be taken to ensure that a supply of palatable drinks is available after exercise. Sweetened drinks are generally preferred and may help with carbohydrate intake goals. Replacement of sodium lost in sweat is important in maximising the retention of ingested fluids. A sodium content of 50 to 90 mmol/L may be necessary for optimal rehydration. However commercial sports drinks are formulated with a more moderate sodium content (10-25 mmol/L). It may be necessary to consume 150% of fluid losses to allow for complete fluid restoration. Beverages containing caffeine and alcohol are not ideal rehydration fluids since they promote an increased rate of diuresis. (Aust J Nutr Diet 1996;53(4 Suppl):S22-S26).
Keywords: post-exercise fluid recovery, pre-exercise hydration, involuntary dehydration.

Introduction
Optimal hydration is important for the performance, health and comfort of those undertaking exercise, particularly when this involves prolonged high-intensity activities in a hot environment. Hypohydration of as little as 2% of body mass (BM) reduces exercise endurance and performance, with the effects increasing in proportion to the magnitude of fluid deficit (1). The maintenance of fluid balance involves fluid intake strategies before, during and after exercise sessions. In most situations sweat losses during exercise exceed the opportunities for fluid replacement during the activity. Therefore, it is important that remaining fluid deficits are corrected during post-exercise recovery, particularly in preparation for future exercise sessions.

The aim of this paper is to review issues of pre-exercise rehydration, and post-exercise hydration, and to propose fluid intake guidelines for athletes and those undertaking recreational exercise.

Pre-exercise hydration correcting existing hypohydration
A primary goal of the athlete is to be in fluid balance prior to starting an exercise session. This goal is challenged by many athletes' training and competitive schedules which often provide inadequate time to replace sweat losses between sessions. Studies suggest that following significant fluid loss, it may take up to 24 hours to re-equilibrate body fluid compartments (2). Most importantly, it should be noted that thirst is not an adequate indicator of hydration status (3); there are many reports of voluntary hypohydration which can persist for many hours after intense exercise (2). In addition, there may be practical difficulties which limit fluid intake after exercise, such as the availability of fluids and gastrointestinal comfort. Post-exercise rehydration will be discussed later in this paper.

Of particular concern are those athletes who consciously dehydrate prior to competition in an effort to reduce their body mass. `Making weight', the rapid reduction of body mass to meet a competition weight division, has been well described in combative sports such as judo, wrestling (4) and boxing, as well as weight-lifting (5), light-weight rowing (6), and horse racing (7). In these sports athletes typically compete in a division or at a body mass that is considerably lower than their habitual training weight. In the case of combative sports this is undertaken to seek competition against a lighter, `weaker' opponent. In a slightly different vein, body builders are known to `cut up' immediately prior to competition, desiring to lower body fat levels and to `dehydrate the skin' so that they might increase muscle definition and vascularity (8). These pre-competition practices involve acute weight loss in the day(s) prior to the event, achieved by a combination of severe food restriction and dehydration. Dehydration may be achieved by fluid restriction, exercise in a hot environment and/or the use of diuretics or laxatives (4-8). Such extreme interventions may be associated with a loss of 5% or more of BM. In most weight division sports there are fewer than two hours between the weigh-in and the start of the event, preventing the opportunity for significant reversal of fluid deficits.

`Making weight' strategies are likely to reduce exercise performance through the combined effects of hypohydration and low muscle fuel stores. The most severe performance impairments will be experienced by those athletes who are required to lose the greatest amount of weight, and whose events require prolonged high intensity exercise, and/or a series of bouts or races over the duration of
competition, rather than a single event. Exercising in a hot environment when hypohydrated may also incur greater decrements to performance than when exercise is undertaken in mild conditions. Despite these performance decrements, and the continued disapproval of medical, educational and research bodies, `making weight' persists within the culture and practice of most weight-category sports. However, it might also be argued that success in competition does not necessarily require `optimal performance' from the athlete; but rather, performance that is superior to that of their opponent(s). Anecdotaly, there appears to be evidence in some sports that the decrement in performance due to `making weight' is often less than the advantage gained by the competitor who is bigger than their opponents. Therefore, there may be reason to tolerate the continuation of `making weight' practices in some sports. Nevertheless, more judicious use of this strategy appears necessary to minimise potential harm to the health and performance of the athletes involved.

**Pre-exercise hyperhydration**

Pre-exercise hyperhydration may be a useful strategy for those athletes who are susceptible to large mismatches between rates of fluid loss and opportunities for fluid intake during exercise sessions. This may occur because of high sweat rates and/or situations in which there is little opportunity for fluid intake during the event or sport.

There is some evidence to suggest that hyperhydration prior to physical activity may confer positive changes in fluid balance and exercise capacity. There is a substantial body of evidence showing that the ingestion of large volumes of fluid prior to an exercise bout will result in an expanded plasma volume and lower rectal temperatures and heart rates during exercise (2). However, one of the problems of pre-exercise fluid ingestion is a marked diuresis, particularly when plain water is consumed in large volumes (2). To overcome this problem it might be advantageous to either ingest or infuse saline. These options, however, may be limited by issues of palatability and practicality.

A recent study has investigated the effects of chronic hyperhydration (forced water intake) (9). When subjects doubled their normal fluid intake for seven days, resulting in a gain in body mass of approximately 0.6 kg (presumed to be retained water), an increase in heat tolerance during cycling exercise was observed. In a separate trial, acute hyperhydration (consuming two litres of water one hour prior to exercise) was compared to the seven-day forced water intake protocol (9). While acute hyperhydration had no effect on the time taken to complete a cycling task in mild conditions, the chronic hyperhydration protocol resulted in a significantly reduced time (i.e. performance increase). The results of this study merit further investigation, particularly in relation to the suggestion that subjects altered the `set point' of their body water regulation following chronic fluid overload.

Glycerol has also been studied as a potential hyperhydrating agent since it is rapidly absorbed and evenly distributed among body fluid compartments where it contributes an osmotic effect. Recent data collected from moderately-trained subjects undertaking prolonged sub-maximal exercise indicate that the addition of glycerol (1 g/kg BM) to pre-exercise fluid may increase fluid retention and thus provide protection against exercise-induced hypovolaemia, particularly when exercise is conducted in thermally stressful environments (10). Compared to hyper-hydration with plain water, the ingestion of large volumes of water and glycerol in the two to three hours before exercise resulted in a lower urine output prior to exercise and an elevated sweat rate and decreased rectal temperature during the exercise bout (
Although these data support the hypothesis that glycerol-induced hyperhydration can reduce the thermal strain of exercise in the heat, further studies utilising well trained athletes competing at high absolute work rates need to be undertaken to determine whether performance benefits actually occur. One study has reported improved endurance time in moderately trained men following glycerol hyperhydration. However, the responses of individual subjects were variable and the mechanism of action was not clear (11). More promising results in competitive cyclists have recently been reported by Hitchins and coworkers (12) who studied performance following acute hyperhydration with a commercial sports drink or a sports drink-glycerol mixture. The glycerol hyperhydration protocol resulted in the retention of approximately 600 mL of additional fluid compared to the sports drink beverage, and was associated with a significant improvement (2.4%) in cycling performance in hot humid conditions. However, the mechanism of improved performance was not apparent and no thermoregulatory advantages were observed with the glycerol hyperhydration beverage. Clearly, further investigation is warranted before guidelines for hyperhydration with glycerol can be provided.

`Pre-loading' to assist gastric emptying of fluids during exercise

Even if hyperhydration is not desirable, the intake of a large bolus of fluid (300-400mL) immediately prior to exercise may be a useful strategy to assist an athlete to consume fluids during exercise. It has been demonstrated that gastric distention promotes increased gastric emptying, and may permit greater volumes of fluid to be delivered to the intestine for absorption during exercise (13). 'Priming' the stomach for optimum delivery of fluid during exercise may be important in situations where large sweat losses are expected and the athlete wishes to maximise fluid replacement during the session.

Post-exercise rehydration--voluntary intake of fluid

In general, day-to-day maintenance of fluid balance in healthy individuals is well regulated by thirst and urine losses. However, under conditions of exercise and environmental stress, thirst may not be a sufficient stimulus for maintaining euhydration (3). Athletes typically drink during exercise at a rate that matches only 30 to 70% of their sweat losses (14,15). Furthermore, mild to moderate levels of hypohydration persist for a prolonged period after exercise, even when fluids are made freely available. Adolph and coworkers (16) first described the failure to fully replace fluid losses as, voluntary dehydration' and noted that it was exacerbated by factors that reduced the accessibility or palatability of fluids. However, this phenomenon has been more recently renamed `involuntary dehydration' in recognition of the fact that the dehydrated individual has no volition to rehydrate even when fluids and opportunity are available (3). The causes of involuntary dehydration are multifaceted, and include behavioural issues such as social customs of drinking, as well as a genetic predisposition to be a reluctant or habitual drinker (3).

The palatability of post-exercise fluids is an important issue in determining ad libitum fluid intake; there is some evidence that flavoured beverages promote greater fluid consumption in the recovery phase than plain water (17). In addition, the provision of carbohydrate in beverages to be ingested during recovery may address another goal of post-exercise nutrition; the promotion of resynthesis of muscle glycogen stores (see below). The temperature of fluids may also be important in determining palatability; cool and cold beverages are preferred to warm beverages (18).

From a practical point of view, there are a number of factors that can interfere with the accessibility of
fluids after exercise. These include limited availability of fluids at the exercise venue, and the distraction of other post-exercise commitments and priorities (e.g. coaches' meetings, drug tests, equipment maintenance, warm-down activities). It is important that steps are taken to ensure that fluids are available during all post-exercise activities.

**Electrolyte replacement and fluid retention**

Post-exercise rehydration is dependent not only on the voluntary consumption of fluids by athletes, but by the subsequent retention and re-equilibration of fluid within the various body compartments. As sweating and obligatory sweat losses continue during the rehydration phase, fluids must be consumed in volumes greater than the post-exercise fluid deficit to restore euhydration.

The ingestion of water following exercise-induced dehydration results in a decrease in plasma osmolality and sodium content, increasing diuresis and reducing thirst. Nose and coworkers (19) rehydrated subjects with water plus sodium capsules or water plus placebo capsules, and reported that the intake of sodium (equivalent to a solution of approximately 80 mmol/L) achieved more rapid restoration of plasma volume than the water alone. This was due to a greater voluntary intake of fluid and lower urine output.

Similarly, Maughan and Leiper (20) monitored dehydrated subjects during six hours of recovery with test drinks providing varying levels of sodium. After 90 minutes there was a significant treatment effect, with greater urine losses being observed in subjects who consumed drinks containing 2 mmol and 26 mmol sodium per litre, than in those who consumed solutions with 52 and 100 mmol sodium per litre. At six hours the difference in mean urine output between subjects who consumed sodium-free drinks and drinks containing 100mmol sodium per litre was approximately 800 mL. Subjects were euhydrated by the end of the recovery period when they consumed the two beverages with higher sodium content, but were still in net negative fluid balance on the low sodium and sodium free beverages, despite the intake of a volume of fluid that was 1.5 times their estimated sweat losses.

The optimal sodium level for a post-exercise rehydration fluid is still being debated. The World Health Organization recommends a sodium level of 90 mmol/L for oral rehydration solutions used in the treatment of diarrhoea-induced dehydration (21). However, this is based on the need to replace the sodium lost through diarrhoea as well as to optimise intestinal absorption of fluid and retention of ingested fluid. The loss of sodium through sweat varies markedly, with typical sweat sodium levels believed to be in the range of 20-80 mmol/L (22). While a post-exercise rehydration drink with sodium levels of around 50 mmol/L may well be justified, issues of palatability and general consumer appeal have lead to a more moderate level of sodium in commercial sports drinks (10-25mmol/L). Gonzalez and workers (23) reported that a commercial sports drink (6% carbohydrate with 20 mmol sodium per litre) was more effective than plain water in promoting restoration of fluid levels after exercise-induced dehydration, principally due to decreased urine losses. Thus it appears that commercial sports drinks may confer some rehydration advantages over plain water, in terms of palatability as well as fluid retention. Nevertheless, where maximum fluid retention is desired, the sodium levels of rehydration fluids must be increased to levels above those provided in typical sports drinks (20). Alternatively, additional sodium may be ingested via foods containing sodium, or via salt added to meals (24).

**Alcohol and caffeine--potential diuretics**
Diuresis may be stimulated by several factors commonly found in beverages consumed by dehydrated athletes. It has been reported (23) that consumption of a diet cola drink containing caffeine resulted in less effective replacement of body fluid losses than water or a sports drink; urine losses were significantly increased with the cola drink and there was a small but significantly greater loss of fluid through continued sweating and respiratory losses.

Alcohol consumption has also been shown to increase urinary losses; subjects consuming drinks containing 4% alcohol reported greater urinary losses than when drinks containing zero, one or two per cent alcohol were consumed (Maughan RJ et al., University Medical School, Aberdeen, 1995, unpublished observations). This is an important finding in view of observations that team sport athletes may consume large amounts of alcohol in the post-competition setting (25).

**Recovery of muscle glycogen stores**

The restoration of muscle fuel stores is another issue of postexercise recovery. The key issue in muscle glycogen storage appears to be the provision of adequate carbohydrate intake; athletes are generally guided to consume intakes equivalent to 7 to 10 g of carbohydrate per kilogram of BM per day to maximise muscle glycogen synthesis (26). However, it appears that the early intake of carbohydrate is useful in enhancing post-exercise recovery. The immediate intake of approximately 0.7 to 1.0 g of carbohydrate per kilogram of BM per day promotes increased glycogen storage during the first two hours of recovery compared to delayed carbohydrate intake (27). This strategy may be useful where the athlete is required to train or compete within six to 12 hours of the initial session. Since many athletes report loss of appetite after strenuous exercise, the intake of drinks containing carbohydrate may provide a practical way to meet carbohydrate intake goals during the immediate post-exercise phase.

**Summary and guidelines**

Fluid intake before and after exercise plays an important role in maintaining fluid balance. Since fluid intake during exercise is typically unable to match the rate of sweat loss, exercise usually causes mild to moderate hypohydration. Rehydration is an important goal of recovery, particularly before subsequent exercise bouts are undertaken. Practical guidelines which address fluid intake goals before and after exercise are summarised below (28).

**Guidelines for pre-exercise fluid intake**

1. Athletes should not rely on thirst, or even their habitual fluid intake practices, to achieve optimal hydration particularly in hot environmental conditions. Instead they must individualise a plan for fluid intake before, during and after exercises according to the likely sweat losses and opportunities for hydration on each occasion.

2. Rehydration between training or competition sessions is an important part of preparation for each exercise session. In the absence of loss of body fat, monitoring of morning BM may provide a general guide to the success of day-to-day rehydration.

3. Athletes, especially those in `weight category.' sports should continue to be educated that hypohydration is not a suitable means of long-term control of BM, and that `making weight' will reduce performance in many sports events. Ideally, athletes should compete in an appropriate weight division, and weight loss should be achieved by a combination of sound dietary and training strategies to
reduce body fat levels. Mild hypohydration (1-2%) may be acceptable in the final preparation to meet a competition weight division, provided that the athlete hydrates between the weigh-in and the actual event. Fluids containing carbohydrate and sodium are recommended to facilitate voluntary consumption and fluid retention.

4. Pre-exercise hyperhydration may be considered for athletes who are likely to incur high levels of hypohydration despite best possible fluid intake practices during exercise. However, further research is required before general recommendations or guidelines can be made for techniques such as glycerol hyperhydration. At present any athlete intending to experiment with such practices should receive supervision and/or individual advice from an appropriate sports scientist.

5. The considerable inter-individual variability with regard to gastric comfort and gastric emptying rates makes it difficult to provide exact recommendations. Instead, each athlete should experiment with the practice of consuming as large a volume as can be comfortably tolerated (300-500mL) before exercise to determine a suitable plan. It is particularly important to fine tune fluid intake strategies intended for use immediately pre-competition and during competition since the effects of gastrointestinal disturbances during exercise can be severe.

Guidelines for post-exercise fluid intake

1. Gastric comfort may dictate the rate and amount of fluid intake. Maximum gastric emptying of fluids is achieved when the stomach is distended. Therefore, when the athlete needs to replace large amounts of fluid rapidly, it is useful to begin with the maximum volume that can be comfortably tolerated and then ‘top up’ with smaller amounts of fluid at regular intervals. For example, an athlete might consume 500 mL of fluid immediately after exercise, followed by 150 mL every ten minutes for the next three hours to achieve three litres of fluid intake. This technique of 'priming' the stomach may also be useful immediately before an exercise session to promote optimal gastric emptying of fluids consumed during exercise.

2. Carbohydrate-electrolyte beverages, such as commercial sports drinks, provide advantages for post-exercise rehydration compared to plain water, by promoting greater fluid intake and slightly better fluid retention (through reduced urine production). Use of these drinks may also address other goals of post-exercise recovery nutrition such as providing immediate intake of carbohydrate for rapid glycogen synthesis.

3. It is important to replace electrolytes, particularly sodium, to maximise fluid retention during post-exercise rehydration. The optimum sodium concentration in rehydration fluids appears to be 50-90 mmol/L. This can be provided by commercial oral rehydration solutions, but is greater than the levels typically provided by popular sports drinks (10-25mmol/L). Alternatively, sodium can be consumed in post-exercise recovery meals or snacks, either as a component of food or added to the meal. Sodium replacement will be an important strategy where an athlete needs to rehydrate quickly and/or the fluid deficit is significant (e.g. greater than 2% BM).

4. Fluids containing caffeine (e.g. cola drinks) and alcohol may be less suitable as rehydration beverages since they promote increased diuresis.

5. Differences between pre-and post-exercise BM provide a guide to net fluid loss; this may be used to
assess the adequacy of fluid intake during the session as well as a target for post-exercise fluid recovery. (A loss of one kilogram indicates a fluid deficit of one litre). Since fluid losses will continue after the exercise session has finished (due to continued sweating, respiratory water losses and urine losses) the athlete will need to consume a greater volume of fluid than the existing fluid deficit to allow for these further losses. For example, an athlete may need to consume a volume equivalent to 150% of the post-exercise fluid deficit over the subsequent four to six hours to achieve complete fluid replacement.

References


By Louise M. Burke

Portions of this manuscript were presented at the 10th Biennial Conference on Exercise and Thermoregulation, University of Sydney, 1995. Department of Sports Nutrition, Australian Institute of Sport L.M. Burke, PhD BSc GradDipDiet, Head Correspondence: L.M. Burke, Dept of Sports Nutrition, Australian Institute of Sport, PO Box 176, Belconnen ACT 2616

Copyright of Australian Journal of Nutrition & Dietetics is the property of Wiley-Blackwell and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.