SSE #62: Rehydration and Recovery After Exercise

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KEY POINTS

1. Rehydration is a major part of the recovery process after exercise, but little attention has been focused on the need to adequately rehydrate in order to optimally perform during subsequent exercise bouts.

2. It is well established that performance of exercise in a dehydrated state is impaired, and that both high-intensity and endurance activities are affected. There is also an increased risk of heat illness in individuals who begin exercise in a dehydrated state.

3. Rehydration requires replacement of body water loss, but ingestion of plain water is not an effective way to achieve a euhydrated state. Drinks should contain moderately high levels of sodium and possibly some potassium. Ingestion of large volumes of electrolyte-free drinks causes a fall in plasma osmolality that suppresses the drive to drink, and also stimulates urine production.

4. To surmount ongoing obligatory urine losses, the volume consumed should be greater than the volume of sweat lost. Palatability of beverages is an important factor in stimulating drinking.

INTRODUCTION

The decision to hold the 1996 Olympic Games in Atlanta in the months of July and August has focused attention on the problems of living, training and competing in hot and humid environments. Over these two months in Atlanta, average minimum and maximum daytime temperatures are generally about 21°C (70°F) and 31°C (87°F) respectively, with the average relative humidity ranging from 50 to 90%. The effects of heat stress and dehydration have major implications for spectators and officials, as well as competitors. For many competitors, performance in outdoor endurance events (i.e. those lasting longer than a total time of about 20-30 min.) was impaired. A recent study under laboratory conditions showed that endurance time on a cycle ergometer at an exercise intensity that could be sustained for 92 min. at a temperature of 11°C (52°F) was reduced to 83 min. when the temperature was increased to 21°C (70°F) and to only 51 min when the temperature was increased to 30°C (86°F) (Galloway & Maughan, 1995); in the environmental conditions prevalent during an Atlanta summer, the reduction in endurance would be even greater.

The way in which an athlete deals with heat and humidity may be the largest factor influencing how climatic stress affects their performance. The successful competitor is generally prepared to employ a strategy encompassing acclimatization, rehydration, behavioral and psychological components. Behaviors designed to minimize or prevent overheating include moving indoors to an air-conditioned, cool environment, modifying warm-up procedures, and changing clothing design. The physiological mechanisms activated by the acclimatization process include an earlier onset of sweating and an increased sweating rate. Sweating is normally an effective way of removing heat, but it often results in the stress of dehydration being substituted for that of hyperthermia. Acclimatization causes an increased sweat loss and therefore increases, rather than decreases, the need for fluid replacement.

Many athletes in weight-category sports, including wrestlers, boxers and weightlifters, perform in a dehydrated state; this is generally met with disapproval by the physician and the physiologist. The disadvantage arising from competing with a body water deficit is often considered by coaches and athletes to be outweighed by the benefits of competing in a weight-category below the athlete's natural weight. In these circumstances, optimizing rehydration following weight-in is of crucial importance.

Dehydration and the associated problem of hyperthermia are two major factors that limit exercise capacity. In prolonged exercise, especially when the ambient temperature and humidity are high, a progressive dehydration seems to be almost inevitable because fluid intake usually fails to match sweat losses. The resulting loss of performance is accentuated if the athlete begins exercise in a state of hypohydration. Even in events of short duration, where there is little sweat loss, performance is impaired if the athlete is not fully hydrated at the start of exercise (Sawka & Pandolf, 1990). There are, however, several common situations in which athletes are likely to have difficulty in achieving full hydration. These include particularly:

1. Competitions held in hot environments or where large sweat losses are encountered.

2. More than one competition or training session are conducted on the same day

3. Weight-category events where athletes deliberately dehydrate to make a specific weight.

The body water of healthy individuals is conserved on a daily basis by factors that control intake and output of both water and electrolytes. Vasopressin and the renin-angiotension-aldosterone system are hormonal control mechanisms that maintain the osmolality, sodium content and volume of extracellular fluids and play a major role in the regulation of water balance. There is a continuous loss of water from the skin and respiratory tract plus intermittent losses from the kidneys and gastrointestinal tract. The kidneys, under hormonal control, regulate water and solute excretion in excess of the obligatory urine loss. Water intake occurs in the form of food and drink, with the sensation of thirst as the primary factor controlling intake. Daily fluid intake in man is usually in excess of perceived need, and water balance is maintained by urinary losses (Engell & Hirsch, 1991), but in situations where water losses are increased acutely the thirst response can be delayed, and individuals may allow themselves to become dehydrated.

Exercise in the heat is accompanied by significant losses of sweat as the body attempts to limit the rise in temperature that would otherwise occur. When heat and humidity are high, even a sedentary lifestyle is accompanied by a large increase in the body's water turnover. The sedentary individual living in a temperate climate normally has a daily water requirement of about 2L; in a hot, humid climate this may increase to 4-6 L. For the athlete training hard for 2-3 h/d in a hot climate, the daily water turnover may be 5-10 L, and requirements as high as 15-18 L/d have been reported in extreme situations. There are clearly some practical difficulties in meeting this demand. During the first few days of exposure to a hot environment athletes from countries with temperate climates find it difficult to increase fluid intake to match the increased losses; they are likely to be chronically hypohydrated until equilibrium is re-established.

Sweat losses during hard exercise in the heat may be as high as 2-3 L/h. Even in temperate climates, sweat losses may be greater than many athletes appreciate. For example, in soccer games played in relatively cool conditions (about 10°C or 50°F) sweat losses may be as high as 2 L in a game lasting 90 min. (Maughan & Leiper, 1994)

Plain water is not the best beverage to be consumed following exercise to replace the water lost as sweat (Costill & Sparks, 1973; Gonzalez-Alonso et al, 1992; Nose et al, 1988); the replacement of electrolytes as well as water is essential for effective rehydration. Sodium is the major positively charged ion lost in sweat and is also the most abundant ion in the extracellular space. Dietary sodium is important in assisting effective rehydration, largely as a consequence of its role as the major ion of the extracellular fluid. If sufficient amounts of sodium and water are ingested, plasma osmolality and sodium concentration do not decline, as may occur if plain water is ingested. As a result, the circulating levels of vasopressin and aldosterone are maintained, and the excess urine output that would otherwise occur, even though the body is still in net negative fluid balance, is prevented. Also, where there are no restrictions on fluid intake, maintaining the plasma osmolality and the circulating sodium concentration plays a role in maintaining the drive to drink; this helps to ensure that an adequate volume of fluid is consumed. Potassium is the major ion of the intracellular fluid but sweat potassium losses are small relative to total body stores. Nevertheless, Nadel et al. (1990) suggested that inclusion of potassium in beverages consumed after sweat loss may aid rehydration by enhancing the retention of water in the intracellular space.

In a series of studies, we have evaluated the requirements for effective post-exercise rehydration in preparation for the next bout of exercise, be it training or competition. The effects of variations in the composition of beverages, with particular regard to electrolyte content, the volume of fluid consumed, the effects of consuming food together with a drink, and the effects of consuming alcohol on rehydration have been investigated. The interactions between palatability of beverages and electrolyte content were investigated in one study where voluntary drinking was allowed, and the possibility that special considerations may apply to female athletes at different stages of the menstrual cycle were also studied.

Effects of Drink Composition

The importance of the sodium content of drinks ingested after exercise-induced dehydration equivalent to 1.9% of body mass was investigated in six fasted but fully hydrated males (Maughan & Leiper, 1995). After dehydration, subjects consumed drinks with sodium concentrations of 2, 26, 52 and 100 mmol/L over a 30-min. period beginning 30 min. after the end of exercise. To put these values in context, most soft drinks contain less than 2-3 mmol sodium per liter; sports drinks typically contain about 20-25 mmol/L, although some have only about 10-12 mmol/L; oral rehydration solutions used for the treatment of diarrhea in children usually contain about 50-80 mmol/L; the sodium concentration of plasma is typically 138-142mmol/L. The volume of fluid consumed in each trail was 1.5 times the body mass loss incurred during the exercise period; this amounted to approximately 2 L.

All the urine produced over the 5.5h after the end of the drinking period was collected and measured (no other food or drink was consumed after the rehydration period). Because the kidneys must continue to form urine during the recovery period, there is an ongoing loss of water from the body. If these losses are high, the body will quickly return to a dehydrated state. Effective rehydration requires that the ingested fluid be retained by the body.

The results of this study showed that the volume of urine produced in the few hours after exercise was influenced by the quantity of sodium consumed. Urine output was greatest when the drink with the lowest sodium content was consumed and least when the drink containing 100 mmol sodium per liter was consumed. Considering the small volumes that athletes normally drink during training or competition, the difference in net fluid balance between the trials is relatively large; between the drinks with the highest and lowest sodium concentrations, there was a difference in total body water content of 787 mL at the end of the study period.

Maintenance of the plasma volume is important for the individual's capacity to exercise and to regulate body temperature. In this experiment, blood samples were collected before and 30 min. after the dehydration period (immediately before the drink was consumed) and then at regular intervals until 5.5 hours after the end of the rehydration period. Plasma volume (Dill & Costill, 1974) decreased with dehydration (by about 4%) and increased following rehydration in all trials. The increase occurred less rapidly with the 2 mmol/L beverage; 1.5h after the end of the fluid ingestion period, the increase in plasma volume was 6.8% in this trial, but the plasma volume had expanded by 12.4% and 12.0% with the 52 and 100 mmol/L drinks respectively. There was no significant difference in the change in plasma volume among trials 5.5h after the end of the rehydration period, but there was a strong tendency for plasma volume to be positively related to the sodium content of the drinks.

In a second study designed to investigate the role of sodium and potassium in rehydration drinks, eight male volunteers were dehydrated by 2.1% of body mass by intermittent cycle-ergometer exercise in the heat (Maughan et al., 1994). Subjects ingested either a 1.5% glucose drink (90mmol/L), a sodium-containing drink (NaCl,60 mmol/L), a potassium-containing drink (KCI, 25 mmol/L) or a drink containing glucose, sodium and potassium. The drinks were consumed over a 30-min. period beginning 45 min. after the end of exercise in a volume equivalent to the volume of sweat lost. This amounted to approximately 1.6 L; no other food or drink was consumed during the study. All the urine excreted from the end of the rehydration period for the next six hours was collected. A smaller volume of urine was excreted following rehydration when the electrolyte-containing beverages were ingested compared to the electrolyte-free beverages.

A decrease in plasma volume of approximately 4.4% was observed with dehydration over all trails. After drinking, plasma volume increased in all trails, but the rate of recovery was slower when the KCI drink was consumed. However, by 6 h after the end of the rehydration period, the increase was not different among trials, averaging between 7% and 9%. Although different amounts of electrolytes were consumed, there was no difference in the fraction of ingested fluid retained 6 h after ingestion of the beverages that contained electrolytes. It may be, however, that because the drink volume consumed was equivalent to the volume of sweat lost, subjects were dehydrated throughout the entire study, even following the drinking period. It may not have been possible to further reduce the urine output when both sodium and potassium were ingested, over and above the reductions already induced when the sodium and potassium were ingested separately.

Fluid Volume Consumed

Because obligatory urine losses persist even when an athlete is hypohydrated, any drink consumed after sweating caused by exercise or heat exposure must be consumed in a volume greater than the volume of sweat that has been lost to even have a chance at restoring hydration status. To investigate the influence of drink volume on rehydration effectiveness, 12 male volunteers performed intermittent exercise in the heat to induce a level of dehydration equivalent to a mean of 2.1% of their initial body masses (Shirreffs et al., 1996). Over 60 min. beginning 30 min. after the end of exercise, beverage volumes equivalent to 50%, 100%, 150% and 200% of the sweat loss were consumed; six of the subjects consumed a relatively low-sodium drink (23 mmol/L), and six ingested a moderately high-sodium drink (61 mmol/L) in an attempt to investigate the possible interaction between beverage volume and sodium content. Except for these drinks, subjects consumed no other food or drink, and the entire volume of urine excreted was collected for 6 h after the end of the drinking period.

With both beverages, the urine volume produced was closely related to the total fluid volume consumed; the smallest volumes were produced when 50% of the loss was consumed and the greatest when 200% of the loss was consumed. Because different drink volumes were consumed in each of the trials, a calculation of fluid balance status relative to the situation prior to the dehydration allows for easier comparisons than the total volume of urine excreted. With dehydration, individuals move into negative fluid balance, and by drinking they return to positive fluid balance, but only if the volume consumed is greater than the sweat loss. For example, subjects were significantly hypohydrated throughout the recovery period when they consumed volumes equivalent to only half their sweat losses. With a drink volume equivalent to that of the sweat loss, subjects were also hypohydrated, but less so when the higher-sodium beverage had been consumed. When the low-sodium drink was consumed in a volume equal to double the sweat loss, subjects were still slightly hypohydrated 6 h after drink ingestion. With the high-sodium drink, subjects had retained enough of the fluid to maintain a state of hyperhydration 6 h after drink ingestion when they consumed either 150% or 200% of their sweat loss.

Plasma volume was estimated to have decreased by approximately 5.3% with dehydration. Six hours after finishing drinking, the general pattern in plasma volume, irrespective of which drink had been consumed, was for the increase to be a direct function of the drink volume consumed; also, the increase tended to be greater for those individuals who ingested the high-sodium drink.

Food and Fluid Consumption

In some situations there may be opportunities to consume solid food between exercise bouts, and in most situations this should be encouraged unless it is likely to result in gastrointestinal disturbances. To investigate the role of food intake in promoting rehydration, eight volunteers (5 males, 3 females) were dehydrated by 2.1% of body mass, then over 60 min. (commencing 30 min. after the end of exercise) they consumed either a solid meal plus flavored water or an electrolyte containing beverage (Maughan et al., 1996a); the volume of fluid contained within the meal plus water was the same as the volume of the electrolyte beverage consumed. For 6 h after the end of eating and/or drinking, the entire volume of urine excreted was collected.

The volume of urine excreted following food and water ingestion was less than when the electrolyte beverage was consumed. Plasma volume decreased by 5.4% with dehydration over all trails and increased following rehydration on all trials; there was no difference in the increase between the food and water trial (11.7±0.7%) and the drink-only trial (13.2±1.5%). The quantity of water consumed with both rehydration methods was the same, but the meal had a greater electrolyte content. It seems most likely that the greater efficacy of the meal-plus-water treatment in restoring whole body water balance was a consequence of the greater total content of sodium, potassium, and other positively charged ions.

Alcohol Consumption

Because of the well know diuretic properties of alcohol and caffeine, it is usual to advise against the consumption of drinks containing these substances when fluid replacement is a priority. However, many people enjoy consuming these beverages, and where large volumes of fluid must be consumed in a relatively short time, a wide choice of drinks will help to stimulate consumption. In many sports, particularly team sports, alcohol intake is a part of the culture of the sport, and athletes are resistant to suggestions that they should abstain completely. We therefore investigated the effect of consuming alcohol following exercise in the heat that caused dehydration equal to about 2% of body mass (Shirreffs & Maughan, 1995, 1996). Over 60 min. (beginning 30 min. after the end of exercise) subjects consumed beer shandy (a peculiarly British drink produced by mixing beer with lemonade) in a volume equivalent to 150% of their sweat losses); the drinks contained 0, 1, 2 or 4% alcohol, but in all other respects did not differ in composition.

The volume of urine excreted for the 6 h following drink ingestion was related to the quantity of alcohol consumed, but despite a tendency for the urinary output to increase with increasing alcohol intake, only with the 4% beverage did the increased value approach significance. The calculated decrease in plasma volume with dehydration was approximately 7.6% across all trails. With rehydration, the plasma volume increased, but the rate of increase seemed to be related to the quantity of alcohol consumed; 6 h after finishing drinking, the increase in plasma volume relative to the dehydrated value was 8.1 ± 1.3% with 0% alcohol, 7.4 ± 1.1% with 1%, 6.0 ± 1.4% with 2% and 5.3 ± 1.4% with 4%.

Voluntary Fluid Intake

In the preceding studies, a fixed volume of fluid was consumed in all trials. In practice, intake will be determined by the interaction of physiological and psychological factors. In a study to examine the effect of palatability and the solute content of beverages in promoting rehydration after sweat loss, eight males exercised in the heat to lose 2.1% of their mass (Maughan & Leiper, 1993). Over a 2 h period following exercise, subjects were allowed to drink as much as they wished of each of the test drinks; the drinks they received, each on a separate occasion, were an oral rehydration solution, carbonated water, a commercial sports drink, and an orange juice/lemonade mixture.

Subjects drank greater volumes of the sports drink and of the orange juice/lemonade mixture, and this reflected the preference that subjects expressed for the taste of these drinks. After exercise, the subjects were in negative fluid balance, and by drinking they moved into positive fluid balance on all trials. Urine output was greatest with the low-electrolyte drinks that were consumed in the largest volumes, and was smallest after drinking the oral rehydration solution. The results of this trial clearly demonstrate the importance of palatability for promoting consumption, but also confirm the earlier results which showed that a moderately high electrolyte content is essential if the ingested fluid is to be retained in the body.

Menstrual Cycle Effects - Concerns for Female Athletes

Retention of excess body water is reported by many women during their menstrual cycle; this is due to the cyclical variation in the release of steroid hormones. It is possible, therefore, that variations related to the stage of the menstrual cycle may have an acute effect on fluid balance in the hours after exercise-induced sweat loss. To investigate this, five female subjects, each with a normal menstrual cycle, exercised in the heat to dehydrate themselves by 1.8% of body mass (Maughan et al., 1996b). They did this at three different stages of their menstrual cycle (2 days before plus 5 days and 19 days after the onset of menses). Over a 60 min. period (beginning 30 min. after the end of exercise) they consumed the same quantity of the same beverage. The volume consumed was 150% of sweat loss, and the drink was a commercially available sports drink. For 6 h after the end of the rehydration period, the entire volume of urine excreted was collected and measured. There was no difference in the urine volume and hence in the volume of the ingested fluid that was retained at the different stages of the menstrual cycle. These results suggest that the acute replacement of body water lost in sweat due to exercising in the heat is not affected by the normal menstrual cycle. Therefore, women seem not to be disadvantaged compared to men when rapid and complete restoration of exercise-induced sweat loss is required.

Conclusions

Complete restoration of fluid balance after exercise is an important part of the recovery process and becomes even more important in hot, humid conditions. If a second bout of exercise must be performed after a relatively short interval, the speed and completeness of rehydration become of crucial importance. Rehydration after exercise requires not only replacement of volume losses, but also replacement of the electrolytes, primarily sodium, lost in the sweat. The electrolyte composition of sweat is highly variable among individuals; although it might be theoretically optimal to match electrolyte loss with equal quantities in a rehydration drink, this is virtually impossible in a practical situation. Provided that the volume intake is sufficient and that renal function is not impaired, any excess sodium ingested will be lost in the urine as the kidneys restore equilibrium.

Sweat composition not only varies among individuals but also varies with time during exercise, and is further influenced by the state of acclimatization (Taylor, 1986). Typical values for sweat sodium and potassium concentrations are about 50 mmol/L and 5 mmol/L, respectively. Drinks intended specifically for rehydration should therefore probably have higher electrolyte content than drinks formulated for consumption during exercise.

When sweat losses are large, the total sodium loss will be high; 10L of sweat at a sodium concentration of 50 mmol/L amounts to about 29 g of sodium chloride. However, a moderate excess of salt intake appears to be beneficial as far as hydration status is concerned. This excess has no detrimental effects on health, provided that fluid intake is in excess of sweat loss and that renal function is not impaired.

It is clear from the results of numerous studies that rehydration after exercise can only be achieved if sweat electrolyte losses as well as water are replaced. The Oral Rehydration Solution (ORS) recommended by the World Health Organization for the treatment of acute diarrhea has a sodium content of 60 to 90 mmol/L (Farthing, 1994), reflecting the high sodium losses that may occur in some types of diarrhea. In contrast, the sodium content of most sports drinks is in the range of 10-25 mmol/L (Maughan, 1991) and in some cases is even lower. Most commonly consumed soft drinks contain virtually no sodium, and are therefore unsuitable when the need for rehydration is crucial. The problem with a high sodium concentration in drinks is that some people find the taste undesirable, resulting in reduced consumption. However, drinks with a low sodium content are ineffective at rehydration, and they will also reduce the stimulus to drink.

Addition of an energy source is not necessary for rehydration, but a small amount of carbohydrate may improve the rate of intestinal uptake of sodium and water and will improve palatability. When sweat losses are high, rehydration with carbohydrate solutions has implications for energy balance. For example, 10 L of soft drink will provide approximately 1000 g of carbohydrate, equivalent to about 4000 calories. The volume of beverage consumed should be greater than the volume of sweat lost to compensate for the ongoing obligatory urine losses, and palatability of the beverage is a major issue when large volumes of fluid must be consumed.

Although water alone is inadequate for rehydration, when food is also consumed the electrolytes lost in sweat can be replaced. However, there are many situations in which intake of solid food is avoided. This is particularly true in weight-category sports when the interval between the weigh-in and competition is short; it is also the case in events in which only a few hours intervene between succeeding rounds of the competition. It is particularly important in these situations that electrolytes be present in the drinks consumed. The need for adequate fluid and electrolyte consumption is also important in many real-life settings when continued exposure to a hot environment increases fluid requirements beyond that reflected in laboratory studies.

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