Development of Individual Hydration Strategies for Athletes

Ronald J. Maughan and Susan M. Shirreffs

Athletes are encouraged to begin exercise well hydrated and to consume sufficient amounts of appropriate fluids during exercise to limit water and salt deficits. Available evidence suggests that many athletes begin exercise already dehydrated to some degree, and although most fail to drink enough to match sweat losses, some drink too much and a few develop hyponatremia. Some simple advice can help athletes assess their hydration status and develop a personalized hydration strategy that takes account of exercise, environment, and individual needs. Preexercise hydration status can be assessed from urine frequency and volume, with additional information from urine color, specific gravity, or osmolality. Change in hydration during exercise can be estimated from the change in body mass that occurs during a bout of exercise. Sweat rate can be estimated if fluid intake and urinary losses are also measured. Sweat salt losses can be determined by collection and analysis of sweat samples, but athletes losing large amounts of salt are likely to be aware of the taste of salt in sweat and the development of salt crusts on skin and clothing where sweat has evaporated. An appropriate drinking strategy will take account of preexercise hydration status and of fluid, electrolyte, and substrate needs before, during, and after a period of exercise. Strategies will vary greatly between individuals and will also be influenced by environmental conditions, competition regulations, and other factors.

Keywords: dehydration, sweat, fluid balance, sodium

Exercise is accompanied by an elevation of metabolic rate that causes body temperature to rise if heat-loss mechanisms are not invoked. In most exercise situations, the elevation of body temperature is small, but when hard exercise is combined with high ambient temperatures or restricted heat loss, substantial (2–3 °C) rises in core temperature are observed (Nadel, 1988). Exertional heat illness, which can be fatal, is the most serious outcome of a failure to limit the rise in body temperature (American College of Sports Medicine et al., 2007; Sutton, 1990). Although this condition is observed most often in hot and humid environments, it can occur even in cool weather. It is most commonly observed in athletes, military personnel, and industrial workers but can affect anyone exposed to prolonged heat stress.
Long before there is a risk to health, exercise performance is reduced in the heat. Even when it is only warm (about 20 °C), endurance capacity is less than at 10 °C (Galloway & Maughan, 1997). It is also well established that a fluid deficit incurred before exercise can increase physiological strain and reduce performance. Prior diuretic-induced loss of about 1.5–2% of body mass was shown to reduce performance in track races at distances of 1,500 m, 5,000 m, and 10,000 m (Armstrong, Costill, & Fink, 1985). Cheuvront, Carter, and Sawka (2003) have undertaken an extensive review of published studies examining the effects of a body-water deficit on endurance-exercise performance. The available evidence led them to conclude that in situations of exercise in a warm environment (defined as an ambient temperature greater than 30 °C), a loss of 2–7% of body mass consistently decreased endurance-exercise performance. The extent of the performance decrements was highly variable, however, ranging from a reduction of only 7% to a 60% decline in performance. A less consistent picture was apparent when the endurance exercise was undertaken in temperate conditions. It was concluded that dehydration by 1–2% of body mass had no effect on endurance-exercise performance when the exercise duration was less than 90 min, but performance was impaired when the level of dehydration was greater than 2% of body mass and the exercise duration was longer than 90 min.

A water loss equivalent to 2% or more of body mass appears to reduce endurance-exercise performance in both temperate and hot environments, especially when the duration of exercise is around 90 min or more. Casa, Maresh, et al. (2000) reported that oral replacement of even 50% of a 4% body-mass loss during a 20-min break was effective in restoring exercise capacity (mean performance time 35 ± 4 min) compared with a trial in which no rehydration was allowed (mean performance time 19 ± 3 min). It must, of course, be recognized that performance effects that are highly meaningful to the athlete might be far below the limits of detection when crude laboratory measures of performance are used (Hopkins, 2001). Even when a positive effect on performance is not seen, ingesting drinks does not make performance worse unless an excessive amount is consumed or the composition is inappropriate.

The performance of complex tasks, such as those involved in many team sports, is also impaired at relatively low levels of fluid deficit. McGregor, Nicholas, Lakomy, and Williams (1999) showed that performance of a soccer-skill test, which involved dribbling a ball between a line of seven cones each 3 m apart, deteriorated by about 5% when it was undertaken after simulated soccer activity when no drinking was allowed; in contrast, performance was maintained when drinks were ingested. The mean body-mass loss of their participants was 2.4% when no fluid was provided and 1.4% when fluids were provided. Similarly, in a study investigating the motor-skill performance of cricket bowling (Devlin, Fraser, Barras, & Hawley, 2001), participants were dehydrated by 2.8% of their body mass and their performance was compared with that in a trial in which they had drunk flavored water and limited their dehydration to 0.5% of body mass. There was no influence of trial on bowling speed, but bowling accuracy, as determined by line and distance, was significantly worse when undertaken in the dehydrated state. Edwards et al. (2007) reported that performance of a soccer-specific fitness test was worse after an exercise period without fluid intake, in which body-mass loss was 2.4% of initial body mass, than when sufficient fluid was given to limit mass loss to 0.7%.
The effects of dehydration on performance are apparent at rather small levels of water deficit, but, as highlighted previously, the relative insensitivity of many of the tests of performance used and the potentially confounding effects of the methods used to induce a fluid deficit mean that the literature is far from clear. There are undoubtedly also effects of mild dehydration on cognitive function and on mood (Petri, Dropulic, & Kardum, 2006; Shirreffs, Merson, Fraser, & Archer, 2004). What is clear is that a loss of body water—if sufficiently severe—will impair both physical and mental performance, but depending on the aspect of performance measured, this might be apparent after a 1%, 5%, or 10% loss of body mass.

The general consensus is that it is better to drink water than to drink nothing during prolonged exercise in a warm environment, but drinks with carbohydrate and electrolytes might promote better performance (American College of Sports Medicine et al., 2007). This has been shown using various exercise modes, intensities, and durations in differing environmental conditions and with both male and female participants of varying levels of fitness. Maughan, Fenn, and Leiper (1989) showed that exercise time to fatigue was about 70 min when no drink was given, 76 min when 100 ml of water was given every 10 min during exercise, 79 min when a concentrated carbohydrate drink was given at the same rate, and 91 min when a dilute carbohydrate-electrolyte drink was given. Below, Mora-Rodriguez, Gonzalez-Alonso, and Coyle (1995) later showed that the effects of providing fluid and carbohydrate were independent and additive.

It has long been known that very prolonged exposures to hard physical work in hot environments leads to muscle cramps in susceptible individuals and that ingesting water and salt (sodium chloride), but not water alone, can reduce the frequency and intensity of muscle cramps (Moss, 1923; Talbott & Michelsen, 1933). More recent data, mostly from tennis (Bergeron, 2003) and American football (Eichner, 2007; Stofan et al., 2005), have suggested that similar cramps might occur in athletes and that they are more likely to occur in players who sweat profusely, especially in those with a high sweat sodium concentration.

This means that athletes, soldiers, industrial workers, and others exposed to exercise and thermal stress must consider their hydration status before beginning exercise; the need for fluid, electrolyte, and substrate replacement during exercise; and the need to restore water and electrolyte balance after exercise. This requires considering what to drink, when to drink, and how much to drink. Noakes (2007) has argued repeatedly that the only advice needed is to drink according to the dictates of thirst, but there is ample evidence of inappropriate drinking behaviors in many sports situations. At its most serious, excessive fluid intakes can lead to hyponatremia with potentially fatal consequences (Almond, Shin, Fortescue, Mannix, & Wypij, 2005). Some of this is perhaps a result of inappropriate advice directed at inexperienced athletes, who then ignore the normal physiological signals that provide an impetus to fluid intake. It is also important to recognize, however, that practical considerations and competition regulations impose limitations on access to fluids in many situations. Whereas some sports such as, for example, tennis allow frequent opportunities for drinking at regular intervals during a game, football (soccer) and most other team sports make no such provision. Players might not be able to drink according to the dictates of thirst but should take advantage of the available opportunities, especially in hot-weather
competition. It is not unknown for teams at the elite level to ensure that stoppage of play for treatment of an injury occurs at times that are convenient for players to take drinks.

Sweat rates and sweat composition depend on the ambient temperature and humidity and on exercise intensity, but they also vary greatly between individuals (Shirreffs, Sawka, & Stone, 2006). This calls into question any advice that prescribes a fixed drinking regimen, and the most recent position stand from the American College of Sports Medicine (2007) suggested that fluid intake during prolonged exercise should be sufficient to limit any body-mass loss to less than 2% of the preexercise mass and that athletes should never drink so much that they gain body mass during exercise. This latter caution might, however, not hold true if an athlete begins exercise in a severely dehydrated state. No single recommendation is best for all individuals in every situation, and development of an individualized hydration strategy is essential to protect health and preserve performance. The need to educate athletes and individualize drinking strategies was emphasized by Casa, Armstrong, et al. (2000).

The aim of this brief review is to examine some of the methodologies that can be applied to assessing athletes for the development of an individualized rehydration strategy.

**Assessment of Preexercise Hydration Status**

There is no universal agreement on the definition of the optimal preexercise hydration status, nor is there a good index of euhydration that can be applied. Some of the various options that can be used to assess hydration status have been described in detail by many authors over many years, including Armstrong et al. (1994), Shirreffs (2000), Armstrong (2005), Kavouras (2002), and Cheuvront and Sawka (2005). The primary variables that are homeostatically regulated are blood volume and plasma osmolality, but both are subject to short-term variation in response to posture change, exercise, food and fluid intake, and a number of other factors, so neither is a good index of hydration status (Armstrong et al., 1994; Popowski et al., 2001). Popowski et al. showed that changes in plasma osmolality tracked well with progressive changes in body mass during exercise (to a 5% loss of body mass). Under well-controlled conditions, plasma osmolality increased by ~5 mOsm/kg for every 2% loss of body mass by sweating, and during postexercise water ingestion, values returned toward baseline. Kovacs, Senden, and Brouns (1999), however, showed that urinary markers including osmolality, color, and electrical conductance did not correlate well with hydration status after exercise. This finding is not surprising during periods of rapidly changing body-water content, and it should be recognized that such measurements have no value.

These findings, however, cannot be generalized to other situations such as thermal sweating without exercise, and it must also be recognized that the distribution of water losses between the vascular space, the extracellular space, and the intracellular space will be affected by both the rate of sweating and the degree of sweat loss (Costill, 1977). Urine osmolality and specific gravity were less sensitive than plasma osmolality and showed delayed responses. Armstrong et al.
(1994) showed that urine indices might be more sensitive to small changes in hydration status than are blood-derived indices when measures are made over a period of days rather than minutes or hours, and they suggested using urine color in field settings when urine-osmolality or specific-gravity measures are not possible. Blood-derived indices can change from minute to minute depending on factors such as posture, acute changes in tissue osmolality (such as those resulting from a short sprint that elevates osmolality markedly for a few minutes), acute effects of fluid ingestion, and so on. The urine values will be relatively insensitive to these transient changes. An alternative measure that is simple and inexpensive is urine conductivity, which is closely related to osmolality (Shirreffs & Maughan, 1998).

Urine color is determined primarily by the amount of urochrome, a breakdown product of hemoglobin, present in the sample (Diem, 1962). When large volumes of urine are excreted, the urine is dilute and solutes are excreted in a large volume. This generally gives the urine a very pale color. When small volumes of urine are excreted, the urine is concentrated and the solutes are excreted in a small volume. This generally gives the urine a dark color. Armstrong et al. (1998) have investigated the relationship between urine color and specific gravity and conductivity. Using a scale of eight colors (Armstrong, 2000), they concluded that there is a linear relationship between urine color and both specific gravity and osmolality of the urine and that urine color could therefore be used in athletic or industrial settings to estimate hydration status when a high precision might not be needed. Urine color can be influenced by a number of dietary factors. Dark yellow or orange urine can be caused by recent use of B-complex vitamins or carotene. Betacyanins, the red compounds present in beetroot, might cause a reddish color in the urine if consumed in large amounts, and a few other food pigments might have similar effects. A few artificial food colors and medications can cause a green or blue coloring and this can depend on the pH of the sample. Athletes who routinely use these products should be aware of these changes; urine color will still be darker if they are dehydrated and the important thing is to look for changes from normal.

It is important to recognize that the acute responses to posture, food intake, and changes in body-water content mean that none of the proposed markers of hydration status is likely to be reliable at times when stability of these factors is not ensured. Because of this, the first sample passed in the morning on rising is frequently selected as the testing sample (Cheuvront & Sawka, 2005). Nonetheless, these markers have been used to assess hydration status of football players and other athletes reporting for training, when the sample collected is not the first passed that day (Maughan, Merson, Broad, & Shirreffs, 2004; Maughan, Shirreffs, Merson, & Horswill, 2005). It might be argued, however, that an athlete who ingests a substantial volume of fluid between rising and the beginning of training might be well hydrated at the start of training even though the morning urine sample suggested otherwise. If more than a few hours elapse between rising and the beginning of training, fluid losses that are not replaced during that period might result in a fluid deficit at the start of training. The longer the interval between waking and training, the greater the probability that the waking urine sample will not reflect hydration status at the beginning of training. Ballauff,
Raschler, Tolle, Wember, and Manz (1991) have reported that, at least in children age 6–11 years, there is no circadian rhythm in the urine osmolality, providing some further support for the suggestion that measurements might be made on samples collected at different times of day, provided that there is some appreciation of the potential confounding factors.

Although single values might be of limited usefulness in this situation, an individual who has a consistently high urine osmolality when about to begin a training session or competition is likely to be in chronic fluid deficit to some degree. There is some evidence of a positive correlation between pretraining urine osmolality and the volume of fluid ingested during a training session in which fluids are freely available (Maughan et al., 2005). Although this seems logical—athletes who begin training with a higher urine osmolality might be likely to drink more because of a greater sensation of thirst—this relationship has not been seen in all populations studied. A urine osmolality of more than about 900 mosmol/kg is consistent with a body-water deficit of about 2% of body mass (Shirreffs & Maughan, 1998). The American College of Sports Medicine (2007) position stand suggests that a urine osmolality equal to or less than 700 mosmol/kg is indicative of euhydration.

Bioimpedance methods can be used to estimate total body-water content and have attracted much attention, because the equipment required is relatively inexpensive and the technique is straightforward and minimally invasive. Acute changes in body-water content are not reliably detected by the method, however, and it is sensitive to posture (Shirreffs & Maughan, 1994), skin temperature (Gudivaka, Schoeller, & Kushner, 1996), and other factors unrelated to body-water content (O’Brien, Young, & Sawka, 2002). The lack the precision and accuracy inherent in the methodology, together with the various confounding factors that influence results, limit its use for hydration monitoring (Institute of Medicine, 2005).

**Methodological Issues**

As mentioned previously, samples might be collected on waking or immediately before training. The choice will be affected by several factors, and interpretation of the results must take account of this. Although there is no published evidence of a significant effect, it seems wise to collect a sample in midstream or to collect and mix the whole void before retaining a sample. White polystyrene or polycarbonate drinking cups are commonly available by water fountains in locker rooms and can be conveniently used for sample collection by both male and female athletes. Only a few microliters are required to measure osmolality, but it is probably convenient to collect 5–30 ml in an appropriate clear specimen tube or white cup. This enables the athlete to relate the color of the sample to the measurement of specific gravity or osmolality. If a clear tube is used, it should be held against a white background for color assessment. In view of the sensitivity of athletes about analysis of samples for prohibited substances, numerical identifiers rather than names should be used on all samples.

Specific-gravity measurement by refractometry or reagent-impregnated strips for urinalysis (e.g., Bayer Multistix, Bayer Diagnostics) has the advantage of using equipment that is inexpensive to purchase and to operate, requires little
operator skill, is portable, and can be used in the field without requiring an electricity supply. Measuring osmolality requires a relatively expensive instrument that is not easily transported and requires an electricity supply. The osmometer requires calibration before each use with known standard solutions, and some technical competence on the part of the operator is essential. Osmolality is now most commonly measured by freezing-point depression, but equipment using vapor-pressure analysis is also used.

Samples for osmolality analysis are generally stable for some days at room temperature or on refrigeration. Some precipitation of calcium salts is likely after a short period of storage. This will not affect the osmolality or specific gravity to any significant degree, but the turbidity that ensues will preclude a reliable measure of color. The precision of the method depends on the equipment used and on the individual operator, but highly reproducible results should be obtainable.

**Interpretation of Findings**

Athletes should be made aware that both health and performance might be at risk if they begin exercise in a state of severe dehydration. Personal observations are the preferred option, with the athletes taking responsibility for monitoring urine frequency, volume, and color. Regular monitoring is much preferred to single spot measures because of the factors that could confound a single measurement. Athletes should be alert to any change from their normal, but those who are chronically in fluid deficit might be accustomed to infrequent urination and a dark urine color. Laboratory measurement of specific gravity or osmolality might be seen by athletes and coaches as having more credibility and can be used periodically to reinforce other measures. A pretraining or precompetition urine osmolality in excess of 900 mosmol/kg should be recognized as a need to increase fluid intake; values in excess of 700 should be conveyed to the athlete as being borderline and perhaps indicating a need for increased fluid. Values of less than 200 mosmol/kg likely indicate the recent ingestion of a large amount of fluid. It is not unknown for athletes to manipulate samples; any sample that is cold on delivery for analysis should be viewed as suspect unless there is a good reason for a time delay between collection and delivery.

**Change in Hydration Status and Sweat Loss During Exercise**

The amount of sweat lost during training or competition can be estimated from changes in body mass, with corrections applied for any fluid intake and urine passed. Fluid intake can be assessed easily by change in mass of drink bottles, provided that athletes do not spit out fluid or use it to pour over their skin. Some of the body-water loss is not in the form of sweat, but rather as respiratory water loss, and this route of water loss can be substantial during hard work in dry environments.

Sweat loss is influenced by a number of factors, including especially the exercise intensity and duration, the environmental conditions, the amount of clothing worn, and the aerobic fitness and acclimation status of the individual. There is also
large individual variability that appears not to be explained by these factors. Single measurements are therefore of limited value; they provide comparative data on athletes in a group but might not help individuals develop a strategy that will meet their needs in different environments. Drinking behaviors also change in different environments and are influenced by the ease of access to fluids and the choice of drinks available.

The effects of potential confounding factors on the interpretation of body-mass changes have been discussed in detail by Maughan, Shirreffs, and Leiper (2007); for practical purposes, they can generally be ignored. A loss of body mass of more than 2–3% usually results in some loss of performance, and a gain of body mass is to be discouraged.

**Methodological Issues**

Accurate measurement of body-mass change requires a scale readable to 10 or 20 g. Small errors, however, are generally unimportant, and a precision of 0.1 kg might be adequate. The measurement period should be long enough to ensure that sweat loss is sufficient for the mass change to be recorded with a reasonable degree of precision—probably at least 10 times the readability of the scale. Measurements should ideally be made with participants nude, because clothing will absorb an unknown and variable amount of sweat and will thus weigh more after sweat loss than before. When an accurate result is required, participants should shower and towel dry before the first measurement of mass and repeat this process before the postexercise measurement to ensure the same degree of wetness of skin and hair. When nude measurements are not possible, participants should wear minimal clothing and change into identical dry clothing for the postexercise measurement. It might be convenient to ask participants to urinate and defecate if necessary before the first measurement, because any urine or feces passed during the measurement period should be collected and weighed. This is conveniently done using a dietetic measuring scale, which is typically readable to 1–2 g. The weight of any food or fluid consumed during the measurement period should also be measured.

Athletes should be cautious about measurements made on different scales, and measures made on different scales should not be compared. Domestic bathroom scales might not give an absolute value that is correct but can usually give a reliable measure of a change in weight, provided that simple precautions are followed. This means ensuring a stable, level, and hard base on which to place the scale and placing a marker on the scale to ensure consistent positioning of the feet.

**Interpretation of Findings**

A loss of body mass in excess of 1–2% of the starting mass might be reason for concern and should at least be discussed with the athlete (Table 1). For some individuals, this might not be detrimental to performance, but for most athletes, increasing fluid intake might be advisable. It is important to recognize that single measurements might not be applicable to other exercise situations or other environmental conditions. Sport scientists working with athletes should try to ensure that monitoring occurs in a variety of exercise situations; single measurements may be difficult to interpret.
The athlete’s hydration strategy should take account not only of the amount of fluid that is required but also of other nutrient needs such as carbohydrate and energy. One liter of a typical sports drink contains about 60 g of carbohydrate, providing 240 kcal. When very high fluid losses are encountered, the energy intake that accompanies use of these drinks might exceed the athlete’s energy budget. Diluting sports drinks with water will also dilute the electrolyte content, so the potential for conflict in meeting the needs for water, electrolytes, and carbohydrate must be considered. Individual taste preferences will also vary between athletes and also over time in any individual; taste fatigue is likely when large volumes are consumed, so a variety of beverages should be available.

### Table 1 Effects of Loss of 1%, 2%, or 3% on Body Mass

<table>
<thead>
<tr>
<th>Initial mass (kg)</th>
<th>Amount of Body-Mass Loss</th>
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<tbody>
<tr>
<td></td>
<td>1%</td>
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<tr>
<td>50.0</td>
<td>49.5</td>
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<tr>
<td>55.0</td>
<td>54.5</td>
</tr>
<tr>
<td>60.0</td>
<td>59.4</td>
</tr>
<tr>
<td>65.0</td>
<td>64.4</td>
</tr>
<tr>
<td>70.0</td>
<td>69.3</td>
</tr>
<tr>
<td>75.0</td>
<td>74.3</td>
</tr>
<tr>
<td>80.0</td>
<td>79.2</td>
</tr>
<tr>
<td>85.0</td>
<td>82.2</td>
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<tr>
<td>90.0</td>
<td>89.1</td>
</tr>
<tr>
<td>95.0</td>
<td>94.1</td>
</tr>
<tr>
<td>100.0</td>
<td>99.0</td>
</tr>
<tr>
<td>105.0</td>
<td>104.0</td>
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<tr>
<td>110.0</td>
<td>108.9</td>
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</tbody>
</table>

Salt Loss

Along with water, large sweat losses will lead to a loss of electrolytes, especially sodium and chloride, with smaller amounts of potassium and smaller still amounts of calcium, magnesium, iron, and other minerals. Sweat is invariably hypotonic relative to body fluids, but the composition is influenced by many different factors including sweating rate, diet, and acclimation status, but there remains a large interindividual variability even when these factors are constant (Robinson & Robinson, 1954). Given the potential link between salt loss and muscle cramps, it seems important to identify athletes with large salt losses that might predispose them to exercise-related cramp (Stofan et al., 2005). There are also concerns that high dietary salt intake might adversely affect blood pressure and cardiovascular risk, so it would be unwise to recommend that all athletes consume a high-salt diet or consume drinks with a high sodium content during exercise.
Methodological Issues

The composition of sweat can be assessed in several different ways, and the method of choice will depend on several factors. Although some variant of the whole-body wash-down technique will give the most precise result (Shirreffs & Maughan, 1997), for most practical purposes the regional absorbent patch method is preferred. In essence, this consists of applying an absorbent swab to an area of skin that has been cleaned and dried. The swab is covered with an adhesive nonporous film to prevent evaporation of sweat. After a suitable time interval, the patch is removed and the sweat extracted for analysis. The method of extraction depends on the size of the swab used and the amount of sweat present; if there is a substantial volume of sweat, the most convenient method might be to put the sweat into the barrel of a small (e.g., 5- or 10-ml) syringe and express it by depressing the plunger. If the sweat volume is too small for this to be effective, the patch can be placed in a suitable container (e.g., 30 ml) that is then sealed. The weight of sweat in the patch is determined gravimetrically, and a known volume (about 1–2 ml) of deionized water added; after thorough mixing, a sample is removed for analysis. Alternatively, the patch can be added to a centrifuge tube with a filter, and the sweat removed after centrifugation. Regardless of the method used, care must be taken to ensure that no sweat can evaporate from the patch after it is removed from the skin.

Measurements of sweat composition can be made at different body sites, and it has long been known that there are regional differences in sweat electrolyte content: Johnson, Pitts, and Consolazio (1944) ascribed the first report of this to Kittsteiner in 1911. The normal practice, therefore, is to make measurements at several sites and combine the results as an arithmetic mean or to use a weighting factor to account for regional differences in composition. Sites that are commonly used include the forehead, forearm, chest, back, thigh, and calf. Lemon, Yarasheski, and Dolny (1986) derived several equations for estimating whole-body urea loss in sweat based on regional sampling at the upper back, lower back, chest, stomach, and thigh. Patterson, Galloway, and Nimmo (2000) compared sweat samples obtained from 11 regional collection sites with the whole-body wash-down method and found that sodium concentrations at the calf and thigh were more highly correlated with the wash-down values than was the case for composite data from four or eight regional sites. Using a single sampling site, however, will tend to increase the potential for error.

The ionic composition of sweat can be measured using a variety of different methods. For nutritional recommendations, sodium is the major ion of interest and is normally measured by flame photometry, ion chromatography, or ion-selective electrode. The precision of the analytical method is good (coefficient of variation of about 1%) relative to the variation in sodium content with sweating rate, at different body sites and between individuals. The information necessary to systematically investigate the test–retest repeatability of measurements of sweat composition is not in the published literature at present, however.

The normal range for sodium concentration of human sweat is about 10–80 mmol/L. Values outside this range are not impossible but should be treated with caution. High values are encountered in individuals with cystic fibrosis (mean values are in excess of 100 mmol/L; Wallis, 1997) and in a few rare genetic conditions. Values in excess of 80 mmol/L are most likely the result of contamination of the sample because of failure to remove old sweat from the skin surface; of allowing evaporation of some or all of the sweat sample, thus concentrating the
sample; or of an inappropriate collection method. Measuring potassium concentration in the sample might be helpful; if the sample is above the normal range of 4–8 mmol/L, there is likely to be a problem with the sample.

**Interpretation of Findings**

The link between high sweat sodium losses and muscle cramps seems clear in industrial settings, in which a whole working day might be spent in hot and humid conditions. Moss (1923) established that such cramps in coal miners could be eliminated by adding salt to their drinking water. This is less certain in sport, where sweat losses are generally smaller, but there is evidence that individuals with high salt losses might be more prone to muscle cramps (Stofan et al., 2005). Not all cramps are related to disturbances of electrolyte balance, but it seems prudent to suggest that athletes prone to cramps might benefit from increased intake of sodium before, during, or after exercise. For those with high salt losses, oral rehydration solutions intended for use as a treatment of diarrheal disease might be effective; they typically have a sodium concentration of 60–80 mmol/L as opposed to the 20–25 mmol/L found in most sports drinks.

Salt losses in sweat might exceed 20–30 g/day when sweat losses are high; this is far in excess of the upper limit of dietary intake recommended for those at risk for hypertension, which is typically set at about 6 g/day. Athletes with high salt losses might need encouragement to increase their dietary salt intake. Some foods that are rich in sodium are shown in Table 2.

<table>
<thead>
<tr>
<th>Food item</th>
<th>Sodium (mg/100 g)</th>
<th>Amount of food (g) needed to replace 50 mmol of Na⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bread (white)</td>
<td>520</td>
<td>221</td>
</tr>
<tr>
<td>Onion, pickled</td>
<td>450</td>
<td>255</td>
</tr>
<tr>
<td>Baked beans</td>
<td>530</td>
<td>217</td>
</tr>
<tr>
<td>Salmon, smoked</td>
<td>1,880</td>
<td>61</td>
</tr>
<tr>
<td>Lamb curry</td>
<td>830</td>
<td>139</td>
</tr>
<tr>
<td>Sausage, grilled</td>
<td>1,100</td>
<td>105</td>
</tr>
<tr>
<td>Bacon, fried</td>
<td>1,910</td>
<td>60</td>
</tr>
<tr>
<td>Omelet, plain</td>
<td>1,030</td>
<td>112</td>
</tr>
<tr>
<td>Cheese, Danish blue</td>
<td>1,260</td>
<td>91</td>
</tr>
<tr>
<td>Pizza</td>
<td>570</td>
<td>202</td>
</tr>
<tr>
<td>Corn flakes</td>
<td>1,110</td>
<td>104</td>
</tr>
<tr>
<td>Tomato juice</td>
<td>230</td>
<td>500</td>
</tr>
<tr>
<td>Potato chips</td>
<td>1,070</td>
<td>108</td>
</tr>
<tr>
<td>Peanuts, dry roasted</td>
<td>790</td>
<td>146</td>
</tr>
</tbody>
</table>

*Note.* The third column shows the amount of each item that must be consumed to replace the amount of sodium lost in 1 L of sweat with a sodium concentration of 50 mmol/L. Values are based on Holland et al. (1991).
Athlete Feedback

Information provided to athletes is often couched in general terms; they are told to turn up for events well hydrated and might be told to drink a prescribed amount of fluid during an event. This information is often unhelpful. Information provided to athletes and coaches, and to medical and other support staff, must be presented in such a way as to offer both a record of the data collected and some constructive suggestions on any modifications required to current hydration practice. Based on the measures described here, athletes can be given some guidance as to whether their current hydration practices are optimal and should be continued. If this is not the case, some specific guidance as to the changes to be made can be given.

It is suggested that athlete feedback should consist of a single page of information that includes a record of the date and environmental conditions and a brief description of the training or exercise session. Information should be presented in graphical form, with a short narrative description of each of the measurements made. It might be appropriate to show data for hydration status, sweat-loss volume, salt loss, and fluid intake. Values for each should be set in context, and the athlete should be told whether their current hydration status and fluid intake are appropriate.

Practical Messages

Although athletes often look to support staff to inform them of what they should do, there are several simple steps that they can take themselves to determine whether their current hydration practice is appropriate to their needs.

- Athletes should be encouraged to weigh themselves before and after training sessions of different durations and intensities and in different weather conditions to estimate their sweat losses. Weight loss should generally not exceed about 1–2% of body mass. If more than this has been lost, they probably did not drink enough and should drink more next time. If body-mass loss was less than this, fluid intake was probably greater than was necessary for hydration purposes.

- Any athlete who is passing urine less often than normal might be dehydrated. If urine volume is small and urine color becomes darker, fluid intake should be increased. The aim should not be for urine to be as pale as possible.

- Athletes should be encouraged to think about why and when they drink and relate this to the sweat loss and urine output they observe. If they drink whenever they are thirsty but frequently seem to be dehydrated (according to assessments made) or they become significantly dehydrated during exercise, their thirst stimulus might not be sufficient to drive an adequate intake. If, however, they frequently gain weight during exercise when they seem to be well hydrated at the start of that exercise or if they frequently urinate large volumes of very pale urine, perhaps what they perceive as thirst is in fact hunger, a dry mouth, or some other feeling.
• “Salty sweaters” might need drinks with more salt and more salt in food when sweat losses are high. The use of salt tablets is seldom, if ever, warranted. Self-assessment of salt losses can be done by wearing a black T-shirt and looking for salt stains. High salt losses are in some cases a contributing factor to muscle cramp.

• An athlete’s hydration strategy should take account not only of the amount of fluid that required but also of other nutrient needs such as carbohydrate and energy. Care should be taken to ensure that when large volumes of drink are consumed to meet hydration needs, the drink’s carbohydrate content is not such that the energy intake that accompanies intake exceeds the athlete’s energy budget. Diluting sports drinks with water is not necessarily a solution because this will dilute the electrolyte content.

Summary

Dehydration impairs both physical and mental performance, so fluid-replacement strategies are necessary in exercise situations in which large sweat losses occur. Some sodium should be added to drinks and/or to food when losses are high. Water and salt losses vary greatly, so individual prescription is required. Athletes should take responsibility for identifying their own rehydration strategy, which means assessing their own hydration status before exercise, assessing sweat rates and the adequacy of current drinking behavior, and estimating their need for salt replacement.

References


Wallis, C. (1997). Diagnosing cystic fibrosis: Blood, sweat and tears. Archives of Disease in Childhood, 76, 85–91. Author: Read proofs carefully. This is your ONLY opportunity to make changes. NO further alterations will be allowed after this point.