Scand J Med Sci Sports 2010: 20 (Suppl. 3): 40–47
doi: 10.1111/j.1600-0838.2010.01207.x

SCANDINAVIAN JOURNAL OF
MEDICINE & SCIENCE
IN SPORTS

Review

Dehydration and rehydration in competative sport

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Accepted for publication 22 July 2010

Dehydration, if sufficiently severe, impairs both physical and mental performance, and performance decrements are greater in hot environments and in long-lasting exercise. Athletes should begin exercise well hydrated and should drink during exercise to limit water and salt deficits. Many athletes are dehydrated to some degree when they begin exercise. During exercise, most drink less than their sweat losses, some drink too much and a few develop hyponatraemia. Athletes should learn to assess their hydration needs and develop a personalized hydration strategy that takes account of exercise, environment and individual needs. Pre-exercise hydration status can be assessed from urine frequency and volume, with additional information from urine color, specific gravity or osmolality. Changes in hydration status during exercise can be estimated from the change in body mass: 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. An appropriate, individualized drinking strategy will take account of pre-exercise hydration status and of fluid, electrolyte and substrate needs before, during and after a period of exercise.

Exercise is accompanied by an elevation of metabolic rate that will cause 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 is debilitating and can be fatal, is the most serious outcome of a failure to limit the rise in body temperature (Sutton, 1990; Sawka et al., 2007). While 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 may 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 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 dehydration of about 1.5–2% of body mass can reduce performance in track races at distances of 1500, 5000 and 10 000 m (Armstrong et al., 1985). In spite of the negative effects of beginning exercise in a hypohydrated state, it seems quite common for athletes in various sports to begin training or competition with some degree of fluid deficit. Maughan et al. (2007a, b) showed that 11 of 31 football players provided pre-match urine samples with an osmolality of >900 mOsm/kg before an important match, suggesting some degree of hypohydration. Osterberg et al. (2009) reported that about half of a sample of elite (NBA) basketball players had pre-game urine specific gravity values in excess of 1.020, again consistent with hypohydration. Volpe et al. (2009) showed that 66% of 263 male and female collegiate athletes from various sports showed pre-competition urine specific gravity values consistent with some degree of hypohydration.

In endurance exercise, a fluid deficit will be incurred during training or competition if fluid intake is less than sweat loss, even if athletes begin exercise well hydrated. Prior hypohydration will amplify the effects of any fluid deficit incurred during exercise. Cheuvront et al. (2003) have undertaken an extensive review of published studies examining the effects of dehydration on exercise performance. The available evidence led the authors to conclude that, in situations of exercise in a warm environment (defined as an ambient temperature >30 °C), dehydration to the extent of 2–7% of body mass consistently decreased endurance exercise performance. However, the extent of the performance decrements was highly variable, ranging from 7% to 60%. In contrast to the observations in a warm environment, a less consistent picture in terms of the effect on performance was

apparent when the endurance exercise was undertaken in temperate conditions. It was concluded that, in temperate conditions, dehydration by 1–2% of body mass had no effect on endurance exercise performance when the exercise duration was <90 min, but performance was impaired when the level of dehydration was $>2\%$ of body mass and the exercise duration was longer than 90 min. Where body mass has to be moved against gravity, the lower body mass that results from fluid loss might counteract some of the negative effects on performance, but the available evidence does not support deliberate dehydration. It must, of course, be recognized that performance effects that are highly meaningful to the athlete may be far below those that can be measured by the crude laboratory measures of performance that are commonly used (Hopkins, 2001). Because of the variability in the methods used to induce dehydration, in the time course of the studies, in the nature of the tests examined, and in the characteristics of the subjects used, it is not possible to establish whether any relationship exists between the extent of hypohydration and the effect on performance.

There is some evidence that the performance of complex tasks, such as those involved in many team sports, is also impaired at relatively low levels of fluid deficit, but because of the difficulties in assessing performance in skilled tasks, these studies often suffer from methodological limitations. McGregor et al. (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 given. The mean body mass loss of their subjects was 2.4% when no fluid was given and 1.4% when fluids were given. Similarly, in a study investigating the motor skill performance of cricket bowling (Devlin et al., 2001), subjects were dehydrated by 2.8% of their body mass and performance was compared with that in a trial they drank 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, where 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 hypohydration on performance become apparent at rather small levels of water deficit, but, as highlighted above, 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 (Shirreffs et al., 2004; Petri et al., 2006). What is clear is that hypohydration – if sufficiently severe – will impair both physical and mental performance, but depending on what aspect of performance is measured, this may be apparent after a 1%, 5% or 10% loss of body mass.

There may not be universal agreement on the amount of fluid that should be consumed during prolonged exercise in warm environments, but the general consensus is that it is better to drink water than to drink nothing and that drinks with CHO and electrolytes may promote better performance than water alone (Sawka et al., 2007). This has been shown using various exercise modes, intensities and durations in differing environmental conditions and with both male and female subjects of varying levels of fitness. Maughan et al. (1989) showed that exercise time to fatigue during a cycling test at about 70% of VO_{2max} 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. Carbohydrate alone can improve performance, and the effects of providing fluid and carbohydrate are independent and additive (Below et al., 1995). It has long been known that very prolonged exposures to hard physical work in hot environments will lead to muscle cramps in susceptible individuals and that ingestion of water and salt (sodium chloride) 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 (Stofan et al., 2005; Eichner, 2007; Horswill et al., 2009), have suggested that similar cramps may occur in athletes and that they are more likely to occur in players who sweat profusely and 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 for restoration of water and electrolyte balance after exercise. This requires a consideration of what to drink, when to drink, and how much to drink. Noakes (2007) has argued 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 hyponatraemia with potentially fatal consequences (Almond et al., 2005). Some of this is

perhaps due to inappropriate advice directed at inexperienced athletes, who then ignore the normal physiological signals that provide an impetus to fluid intake. Sweat rates and sweat composition depend on the ambient temperature and humidity and on exercise intensity, but they also vary greatly between individuals (Shirreffs et al., 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 (Sawka et al., 2007) has suggested that fluid intake during prolonged exercise should be sufficient to limit any body mass loss to $<2\%$ of the pre-exercise mass and that athletes should never drink so much that they gain body mass during exercise. This latter caution may, 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 for the protection of health and preservation of performance.

Restoration of water and salt losses is an important part of the post-exercise recovery process. Along with replacement of muscle glycogen stores and the provision of a source of amino acids to support protein synthesis, the recovery meal should contain sufficient water and salt ensure a return to euhydration (Maughan and Shirreffs, 2007). Where solid food is eaten and this food contains adequate amounts of salt, ingestion of plain water in an amount in excess of the sweat loss will allow effective recovery (Maughan et al., 1996). Where only fluids are ingested, these should contain sodium in amounts equal to the sweat sodium losses (Shirreffs et al., 1996). If renal function is normal, excess water and salt will simply be excreted.

The assessment of the effects of dehydration on performance requires careful standardization of the methods used to assess hydration status and of the tasks used to assess performance. This review will focus on some of the methods that can be used to assess water and salt balance and of changes in hydration status.

Assessment of pre-exercise hydration status

There is no universal agreement on the optimum pre-exercise 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, including Armstrong et al. (1994), Shirreffs (2003), 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. (2001) showed that changes in plasma osmolality tracked well with progressive changes in body mass during exercise in the heat (to a 5% loss of body mass). Under well-controlled conditions, plasma osmolality increased by about 5 mOsm/kg for every 2% loss of body mass by sweating, and values returned toward baseline during post-exercise water ingestion. Kovacs et al. (1999), however, showed that urinary markers, including osmolality, color and electrical conductance, did not correlate well with hydration status after exercise. This 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 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 may 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 have suggested the use of urine color in field settings when urine osmolality or specific gravity measures are not possible.

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 position stand suggested that a urine osmolality ≤ 700 mOsmol/kg or a urine specific gravity of <1.020 g/mL can be used as an index of euhydration (Sawka et al. 2007). 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 compound that results from the breakdown 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 and the urine is a very pale color. When small volumes of urine are excreted, the urine is concentrated: this generally gives the urine a dark color. Armstrong et al. (1998) have investigated the relationship between urine color and specific gravity and conductivity, and have developed a scale of eight colors (Armstrong, 2000). They concluded that a linear relationship existed 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 may not be needed.

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 when stability of these factors is not assured. Because of this, the first sample passed in the morning on rising is frequently selected as the testing time (Cheuvront & Sawka, 2005). However, the athlete who ingests a substantial volume of fluid between rising and the beginning of training may be well hydrated at the start of training even though the first morning urine sample suggests otherwise. Likewise, if more than a few hours elapse between rising and the beginning of training, fluid losses that are not replaced during that period may result in hypohydration 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. With training or competition late in the day, the morning sample may have little relevance. These markers have been used to assess hydration status of football players and other athletes reporting for training, where the sample collected is not the first passed that day (Maughan et al., 2004, 2005; Osterberg et al., 2009; Volpe et al., 2009). While some athletes may skip breakfast before training, accounting for some of the high urine osmolality values reported in athletes undergoing morning training sessions, there are also reports of hypohydration in athletes training or competing late in the day (Maughan et al., 2007a, b). Ballauff et al. (1991) have reported that, at least in children aged 6–11 years, there is no circadian rhythm in the urine osmolality, providing some further support for the suggestion that measurements may be made on samples collected at different times of day, provided that there is some appreciation of the potential confounding factors.

Single values may be of limited usefulness in the assessment of athletes, but an individual who has a consistently high urine osmolality when about to begin training sessions or competitions is likely to be hypohydrated to some degree. There is some evidence of a positive correlation between pre-training urine osmolality and the volume of fluid ingested during a training session where fluids are freely available (Maughan et al., 2005). While this seems logical – athletes who begin training with a higher urine osmolality may be likely to drink more due to a greater sensation of thirst – this relationship has not been seen in all populations studied (Osterberg et al., 2009).

Bioimpedance methods can be used to estimate total body water content, and have attracted much attention, as the equipment required is relatively inexpensive, and the technique is straightforward and minimally invasive. However, acute changes in body water content are not reliably detected by the method, and it is sensitive to posture (Shirreffs & Maughan, 1994), skin temperature (Gudivaka et al., 1996) and other factors unrelated to body water content (O'Brien et al., 2002). The lack of 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).

A single measure of body mass can give no indication of hydration status, but morning body mass will fluctuate by less than about 1% in well hydrated individuals who are in energy balance (Sawka et al., 2007). Where serial measures are possible, a change of more than this may be used as an indication of hypohydration, but the addition of other measures can provide confirmation.

Methodological issues

Urine samples for assessment of hydration status may be collected on waking or may be collected immediately before training or competition. It seems likely that athletes who are alerted to the fact that measurements will be made will make an effort to ensure good hydration on the day of measurement. The choice of collection time 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 mid-stream or to collect and mix the whole void before retaining a sample. Only a few microliters are required for measurement of osmolality, but it is probably convenient to collect between 5 and 30 mL in an appropriate clear specimen tube. In view of the sensitivity of athletes about analysis of samples for WADA-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, Bridgend, UK) has the advantage of using apparatus 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. These methods also allow more or less immediate feedback to be given to the athlete, and allow for prompt action to correct any hypohydration. Measurement of osmolality requires use of a relatively expensive instrument that is not easily transported, requires an electricity supply, and requires some technical competence on the part of the operator. Osmolality is now most commonly measured by freezing point depression, but equipment

using vapor pressure analysis is also used. Unpublished data from our laboratory show that 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 will depend on the equipment used and on the individual operator, but highly reproducible results should be obtainable.

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 food or fluid intake and any urine passed. Some examples of typical calculations are shown in Table 1. Fluid intake can be assessed easily by change in mass of drinks bottles and food intake by weighing of food items or by the use of items of known mass (e.g. energy bars). 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. Although, unlike sweat, respiratory water loss is electrolyte-free it will still result in a loss of body water, so differentiation between these routes of loss is probably unimportant. A further route of water loss is by diffusion through the skin and this is again a loss of solute-free water: losses by this route depend on body surface area but are independent of temperature and sweating rate, and amount to about 17 mL/h for a man with a body surface area of 2 m^2 (Dill et al., 1966). This is typically sufficiently small to be ignored. Some body mass loss also results from substrate oxidation, but the amounts will be small – typically 200–300 g/h in hard exercise – relative to the total body water pool. Substrate oxidation also generates water of oxidation, which is added to the body water pool: each gram of CHO oxidized results in the formation of 0.6 g of water, which is added to the body water pool. Oxidation of 1 g of fat results in the formation of about 1 g of water, depending on the degree of saturation of the fatty acids being oxidized. The effects of these factors on the interpretation of body mass changes has been discussed in detail by Maughan et al. (2007a, b): they can generally be ignored when sweat rates are high, but are significant at low sweat rates as is illustrated by the following example.

In a game of football played by elite level male players at an intensity of about 75% of VO_{2max}, total substrate oxidation will be about 300 g, mostly in the form of carbohydrate (Bangsbo et al., 2006). This will generate about 200 g of water of oxidation, meaning that a loss of body mass of about 500 g is possible with no effective loss of body water. This is generally ignored when estimating sweat losses, and is small relative to the sweat losses of many athletes in training. Some football players, however, will not lose more than about 1 kg over the course of a 90 min training session (Maughan et al., 2005), which means that, for these individuals, sweat rate is over-estimated by 100%. The decision on whether or not to correct body mass changes for factors other than sweat loss will depend on the circumstances, and will also depend on how reliably these other components can be estimated. Interpretation of changes in hydration status is complicated by changes in the storage of water in association with glycogen and by changes in the tonicity of body fluids as a result of loss of hypotonic sweat. As much as 3 g of water may be stored in skeletal muscle in association with each gram of glycogen (Olsson & Saltin, 1970), and the progressive utilization of the muscle glycogen store during prolonged exercise might be expected to release some of this water into the body water pool. The fate of this water during rapid changes in body glycogen stores is unclear (Maughan et al., 2007a, b), but Pastene et al. (1996) estimated that about 1300 mL of water would be made available to the body water pool in this way during the course of a marathon race.

Table 1. Examples of change in hydration status calculations

	Pre-exercise body mass (kg)*	Post-exercise body mass (kg)*	Total body mass loss or gain (g) †	Drinks consumed during exercise (g or mL) ‡	Urine excreted during exercise (g or mL)§	Sweat volume (mL)	Hydration status (%)†
60 min run	70.00	68.00	−2000	0	200	1800	−2.9
3 h walk	70.00	70.00	0	500	400	100	0.0
2 h cycle	70.00	70.20	+200	1000	0	800	+0.3

*Body mass measured nude with dry skin.

†+, water gain; −, water loss; 0, no change in water balance.

‡Drinks consumed any time between the two body mass measurements.

§Urine emptied from the bladder any time between the two body mass measurements.

Methodological issues

Accurate measurement of body mass change requires a balance readable to 10 or 20 g. 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 balance. Measurements should ideally be made with subjects nude, as clothing will absorb an unknown and variable amount of sweat and will thus weigh more after sweat loss than before. Where an accurate result is required, subjects should shower and towel dry before the first measurement of mass and repeat this process before the post-exercise measurement to ensure the same degree of wettedness of skin and hair. Where nude measurements are not possible, subjects should wear minimal clothing and should change into identical dry clothing for the post-exercise measurement. It may be convenient to ask subjects to micturate and defecate if necessary before the first measurement as any urine or feces passed during the measurement period should be collected and weighed.

Salt loss

Along with water, 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 inter-individual 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 those athlete with large salt losses which may predispose to exercise-related cramp (Stofan et al., 2005). There are also concerns that high dietary salt intake may 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. While some variant of the whole body washdown technique should give the most precise result (Shirreffs & Maughan, 1997), for most practical purposes the regional absorbent patch method is preferred. In essence, this consists of the application of an absorbent swab to an area of skin that has been cleaned and dried. The swab is covered with an adhesive non-porous 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 will depend 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 may be to put the sweat into the barrel of a small (e.g. 5 or 10 mL) syringe and express the sweat by depressing the plunger. If the sweat volume is too small for this to be effective, the patch can be placed into a suitable container (e.g. 30 mL) which 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 no evaporation of sweat can take place from the patch after removal from the skin. Measurements of sweat composition may be made at different body sites, and it has long been known that there are regional differences in the sweat electrolyte content: Johnson et al. (1944) ascribed the first report of this to Kittsteiner in 1911. The normal practice, therefore, is to make measurements at several sites and to 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 et al. (1986) derived several equations for estimation of whole body urea loss in sweat based on regional sampling at the upper back, lower back, chest, stomach and thigh. Patterson et al. (2000) compared sweat samples obtained from eleven regional collection sites with the whole body washdown method, and found that the sodium concentration at the calf and thigh was more highly correlated with the washdown values that was the case for composite data from four or eight regional sites. The use of 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. However, the information necessary to systematically investigate the test–retest repeatability of measurements of sweat composition is not in the published literature at present.

Practical messages

Some of the methods outlined above require equipment or expertise that are not available to all athletes. 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 identify whether their current hydration practice is appropriate to their needs.

1. Athletes should get into the habit of weighing 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, then 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. Some allowance, though, should be made for pre-exercise hydration status and more fluid may be needed if exercise begins in a hypohydrated state.
2. Any athlete who is passing urine less often than normal may be dehydrated. If urine volume is small and urine color is darker than usual, fluid intake should be increased. The aim should NOT be for urine to be as pale as possible.
3. ''Salty sweaters'' may need drinks with more salt and may need 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 on the chest and under the armpits where the sweat has evaporated. High salt losses are a contributing factor in some cases of muscle cramp.

Summary

Dehydration, if sufficiently severe, will impair both physical and mental performance and pose a health risk, especially during or after exercise in warm climates. Low levels of hypohydration are well tolerated in cool environments, but the effects of dehydration on performance are more marked at high ambient temperatures. Fluid replacement strategies are essential in exercise situations where 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 the need for salt replacement.

Key words: sweat, sodium, water, hydration, exercise.

Acknowledgement

Conflicts of interest: The authors have no potential conflicts of interest.

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