Module 4. Fluid requirements for football

Unit 4.1 An Introduction to Fluid and Electrolytes for Football

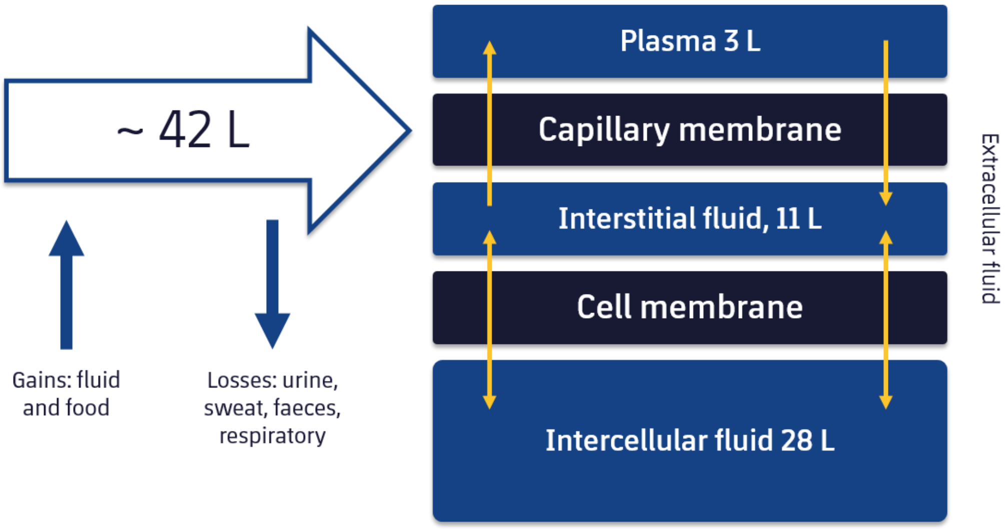
Every day, water is lost from the players' body predominantly in the form of sweat, urine and respiratory losses, whilst water is gained by the ingestion of foods and fluid in the players' diet. The kidneys regulate water balance by adjusting urine output. Although the total body water content is remarkably constant, water turnover can be very high in some conditions such as when players train or compete in hot environments. In order to maintain fluid balance, water intake should be adjusted to offset fluid losses on a daily basis (Armstrong et al., 1998; Cheuvront & Kenefick, 2014; Kavouras et al., 2012). In this unit, we discuss fluid regulation in the player's body before football specific recommendations in Unit 2.

Player's Body Water

Water has numerous functions in the player's body. Water acts as a solvent for organic and inorganic materials, it provides a medium for biochemical reactions and it transports solutes throughout the body among various tissues, supplying nutrients and removing waste. The water content of the player's body will range from 45-75% and it will depend on body composition, age, and gender. The variation of body water content due to body composition is because of muscle (fat-free mass). Muscle has a much higher water content (approximately 70%-80%) in comparison to fat tissue (approximately 10%) (L. B. Baker & Jeukendrup, 2014).

The player's total body water can be divided into two compartments: the intracellular water and the extracellular water. The intracellular compartment accounts for approximately 55%-65% of total body water, while the extracellular compartment accounts for the remaining 35%-45% (L. B. Baker & Jeukendrup, 2014). The extracellular space can be further divided into the interstitial and intravascular fluid (~7.5% of total body water) compartments. Because water is a major component of vascular volume, (blood volume is about 35%-45% red blood cells and 55%-65% water (plasma)) hydration also plays a critical role in cardiovascular function and body temperature regulation (L. B. Baker & Jeukendrup, 2014). Figure 1 illustrates the body fluid distribution in a 70 kg player.

Figure 1: Body fluid compartments that comprise 42 L of total body water in a 70 kg player, and sources of fluid gain or loss



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DID YOU KNOW?
Interstitial fluid is a thin layer of fluid that surrounds the body's cells.

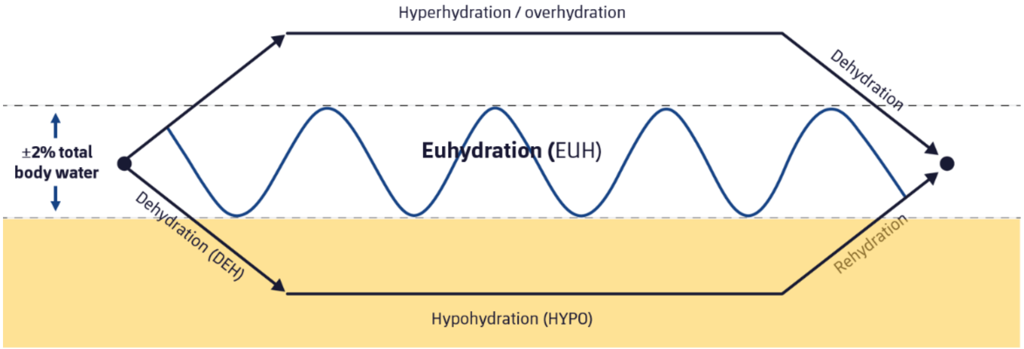
Electrolytes

An electrolyte is a substance that produces a positive or negative charge when dissolved in water. Sodium, potassium, chloride, calcium, magnesium, and phosphate are all examples of electrolytes. Sodium (a cation) and its associated anions (chloride and bicarbonate) comprise the most osmotically active components of the extracellular fluid. Consequently, sodium balance plays a key role in determining the volume of the extracellular fluid compartment and the passive water movement. Sodium achieves this by governing the osmotic gradients between the intracellular and extracellular water spaces (L. B. Baker & Jeukendrup, 2014).

The most abundant cations in the intracellular water are potassium and magnesium. The imbalance of sodium and potassium across the fluid compartments is maintained by the sodium-potassium pump. All cell functions and electrical communications throughout the player's body are reliant upon maintaining the distribution of electrolytes between the intra and extra cellular fluid.

DID YOU KNOW?
Electrolytes can carry a positive or negative charge. An electrolyte which is positively charged is called a cation and an electrolyte which is negatively charged is called an anion.

Figure 2: Daily fluctuation of a player's body water and the associated terminology



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Temperature regulation

Muscle contraction is relatively inefficient, with approximately 70-75% of energy converted to heat. Therefore, intense exercise is associated with a high level of metabolic heat production (Shirreffs et al., 2005). For every litre of oxygen consumed during exercise approximately 16 kJ (4 kcal) of heat is produced and only 4 kJ (1 kcal) is actually used to perform mechanical work. During football-specific exercise, some of this heat is stored by the player's body and results in an elevation in core temperature (38-40°C). If this heat is not dissipated, players would soon overheat and cease to exercise (Ekblom, 1986).

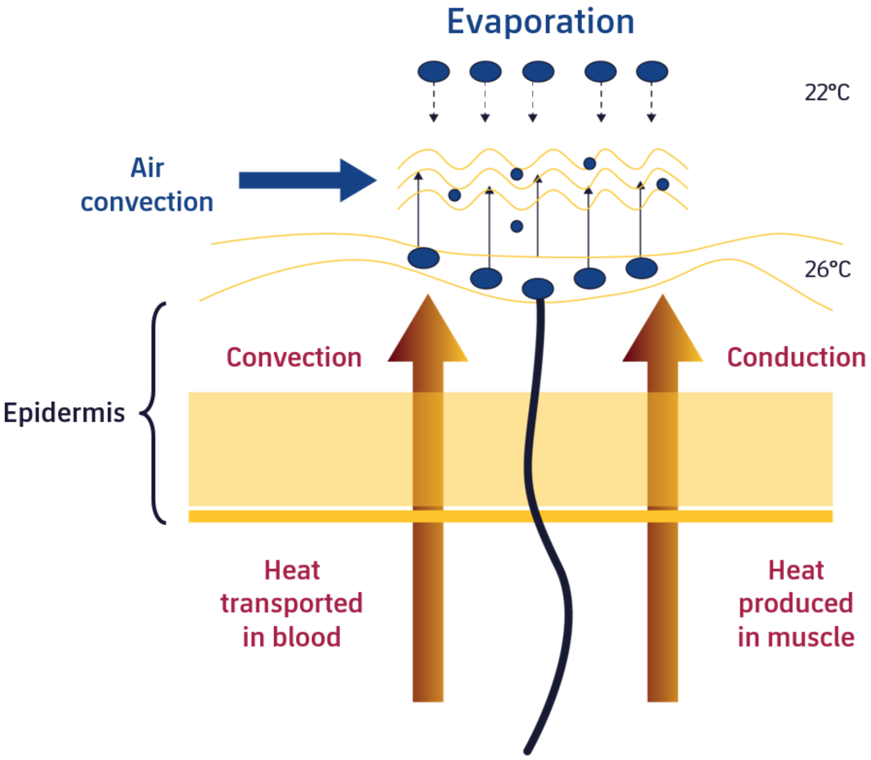
Rises in body temperature are sensed by central and skin thermoreceptors and this sensory information is processed by the hypothalamus to trigger appropriate effector responses (Gleeson, 1998).

There are several mechanisms to dissipate heat and to maintain body core temperature in a relatively narrow range both at rest (36-38°C) and during exercise (38-40°C). Although radiation and convection (skin blood flow) contribute, it is the evaporation of sweat that is the most effective mechanism to dissipate heat from the body during exercise (Armstrong et al., 1997; Cheuvront & Kenefick, 2014). Sweat must evaporate from the body surface in order to exert a cooling effect, with the evaporation of 1 L of sweat from the skin removing 2.4 MJ of heat from the body (Wenger, 1972). Although sweating is a very effective way to dissipate heat, it may cause hypohydration if sweat losses are not replenished (Cheuvront & Kenefick, 2014; Cheuvront, Kenefick, Charkoudian, & Sawka, 2013). Hypohydration has the potential to impact on performance, which may have implications for day-to-day training and match performance.

DID YOU KNOW?

The hypothalamus is a small region, located at the base of the brain. The hypothalamus is pivotal in regulating the players body temperature but also functions to regulate various other physiological functions, including releasing hormones, appetite and emotional responses.

Figure 3: A schematic summarising the process of heat loss and sweat evaporation from skin surface to create cooling



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Dehydration and exercise performance

As the player's body becomes progressively hypohydrated, a reduction in skin blood flow and sweat rate may occur, impairing the ability to regulate body temperature. Several studies have shown that mild hypohydration, equivalent to the loss of 2% body mass (BM) can be sufficient to impair exercise performance in some conditions (ACSM, 2016). In addition, it is often reported that greater losses in BM will result in greater reductions in performance (L. B. Baker, Dougherty, Chow, & Kenney, 2007; Sawka, Cheuvront, & Kenefick, 2012), especially in hot conditions. Although the detrimental effects of hypohydration on performance are most pronounced in hot conditions, such effects have also been observed in cool conditions (Cheuvront, Carter, Castellani, & Sawka, 2005). Others have argued that performance may not be affected by mild hypohydration (Goulet, 2011). It is highly likely that there are individual differences among players in their ability to tolerate hypohydration. Therefore, there may be discussion about the exact level of hypohydration that is acceptable in football players. Sweat losses do not often exceed 2% of pre-exercise body mass during training. During matches, sweat losses may be greater, especially when matches are played in the heat. Based on the available literature, 2% hypohydration seems a practical and safe allowance for football players. It is important to note that some players may be at great "risk" of hypohydration, which will be discussed in Unit 2.

KEY POINT

Dehydration is the process of losing body water.

Hypohydration is a deficit of body water that is caused by acute or chronic dehydration.

Both decreases in maximal aerobic power (VO_2max) and decreases in endurance capacity have been reported with hypohydration in temperate conditions (McConell, Burge, Skinner, & Hargreaves, 1997), although not all studies found such an effect (R. J. Maughan, Fenn, & Leiper, 1989; Robinson et al., 1995). There are several reasons why hypohydration results in decreased exercise performance. The most dramatic consequence of dehydration-induced (5% pre-exercise BM loss) hyperthermia during exercise in extreme conditions (35°C) is a 25-30% reduction in stroke volume that is not generally met with a proportional increase in heart rate; this results in a decline in cardiac output and in arterial blood pressure (Gonzalez-Alonso, Mora-Rodriguez, Below, & Coyle, 1995). In addition, during exercise in the heat, the dilation of the skin blood vessels reduces the proportion of the cardiac output that is devoted to perfusion of the working muscles. Thus, becoming significantly hypohydrated will also impair the ability of the player's body to lose heat. Both sweat rate and skin blood flow are lower at the same core temperature when hypohydrated in comparison to when the individual is in a hydrated state. This means that body temperature rises faster during exercise when the body is hypohydrated, and this is commonly accompanied by a higher heart rate during exercise (Coyle & Gonzalez-Alonso, 2001; Montain & Coyle, 1992). Finally, the larger rise in core temperature during exercise in the hypohydrated state is associated with an increased rate of muscle glycogen breakdown (Hargreaves, Dillo, Angus, & Febbraio, 1996; Logan-Sprenger, Heigenhauser, Jones, & Spriet, 2015). Depletion of these stores could also result in premature fatigue and reductions in high intensity running towards the end of a football match (Bendiksen et al., 2012). In addition to the effects of hypohydration on endurance performance, there are also reported negative effects on perception of effort, co-ordination and cognitive functioning (L. B. Baker, Conroy, & Kenney, 2007; Logan-Sprenger et al., 2015). This is likely to impact on a player's skill and decision-making process.

It was previously thought that muscle strength and anaerobic performance were less likely to be affected by hypohydration (Ali & Williams, 2013; Cheuvront & Kenefick, 2014). However, a meta-analysis revealed that hypohydration, or factors associated with dehydration, are likely to be associated with practically important decrements in muscle endurance, strength, and anaerobic power and capacity (Savoie, Kenefick, Ely, Cheuvront, & Goulet, 2015). It would be intuitive to consider whether reductions in body mass through dehydration during football exercise could be advantageous to force production and vertical jump height (Viitasalo, Kyrolainen, Bosco, & Alen, 1987). However, in one study, a diuretic-induced reduction in body mass of 2.5% had no effect on sprint or power performance (Watson et al., 2005). Likewise, there was no correlation between the reduction in body mass and vertical jump height (Watson et al., 2005). These results suggest that hypohydration provides no advantage for weight-bearing activities required for football. Some have argued that "faster" runners lose more body mass during exercise (Knechtle, Knechtle, Wirth, Alexander Rust, & Rosemann, 2012; Knechtle, Rust, Knechtle, & Rosemann, 2012; Rust, Knechtle, Knechtle, Wirth, & Rosemann, 2012). Whilst this may be true, it is important to realise that faster runners will have higher sweat rates. Furthermore, these are simply correlation studies that do not show causality and it is even possible that there is some natural selection: those that can tolerate larger fluid losses are more competitive.

Football requires not only aerobic performance, but also a sustained level of technical and skill proficiency throughout exercise (Harper, West, Stevenson, & Russell, 2014; Russell & Kingsley, 2014). Owen, Kehoe, and Oliver (2013) examined the effect of dehydration on football skills (i.e., passing and shooting) and intermittent high-intensity running performance after the 90-minute Loughborough Shuttle Running Test (LIST) protocol in a temperate environment (19°C, 59% relative humidity). Despite differences in fluid intake (no fluid, *ad libitum* and prescribed volume) and hypohydration (2.5%, 1.1% and 0.3%, respectively), football skills and intermittent high-intensity exercise performance were similar after the LIST (Owen, Kehoe, & Oliver, 2013). These results were in contrast to McGregor and colleagues (McGregor, Nicholas, Lakomy, & Williams, 1999) who were the first to test the effects of dehydration on football-specific performance. In this study, ratings of perceived exertion were higher toward the end of the 90-minute LIST (13-20°C, 57% relative humidity (RH)) when no fluid was given to the players (resulting in 2.5% hypohydration) compared to when fluid was provided (resulting in 1.4% hypohydration). Likewise, 2.5% hypohydration slowed sprint time at the end of the LIST in comparison to 1.4% hypohydration. This study also showed that football-specific skill performance (i.e. dribbling skill) decreased by 5% from pre- to post-LIST with 2.5% hypohydration, but it was maintained when hypohydration was limited to 1.4% pre-exercise body mass. However, 2.5% hypohydration had no impact on football players' mental concentration test scores at the end of the LIST (McGregor, Nicholas, Lakomy, & Williams, 1999).

Morris, Nevill, Boobis, Macdonald, and Williams (2005) later reported that prolonged, intermittent, high-intensity shuttle running in the heat (33°C, 28% RH) resulted in earlier onset of exhaustion in comparison to exercise in a moderate environment (17°C, 63% RH). Interestingly, while muscle glycogen utilization was elevated by heat stress, low muscle glycogen concentration was not reported to be the cause of the earlier exhaustion. Instead, the onset of exhaustion was associated with hyperthermia (Morris, Nevill, Boobis, Macdonald, & Williams, 2005). In support of these findings, a study which asked football players to complete a treadmill-based football protocol at 18°C and 30°C revealed total distance covered and sprint distances to be significantly reduced when exercise was performed in the hot environment (Aldous et al., 2015). Specifically, the reduction in sprint distance in hot conditions was accompanied with higher heart rate and an elevated core temperature (~0.4°C) (Aldous et al., 2015). Therefore, maintaining the ability to thermoregulate and reduce the rate of rise in core temperature is of benefit to football performance. The importance of thermoregulation for football players is further exacerbated in matches held in warm environments that exceed 90 min, i.e. in extra time (Harper et al., 2014).

Interestingly, it is highly likely that individual players may be more or less sensitive to hypohydration. The magnitude of exercise-heat stress "fatigue/response" has high inter-individual variation due to training and acclimation status, which are influenced by genetic/phenotypic variations of favourable traits associated with innate thermal tolerance and its acquirement (Horowitz, 2014; Nybo, Rasmussen, & Sawka, 2014).

Higher muscle temperatures within the quadriceps and elevated core temperatures have been reported when playing football in the heat, compared to temperate environments (Mohr & Krustrup, 2013).

Well-trained individuals seem to tolerate higher core temperatures than less trained individuals (up to 40.3°C), and this coincides with prolonged time to exhaustion during constant paced exercise (Cheung, 2010; Sawka, Leon, Montain, & Sonna, 2011). One theory is that the degree of hypohydration which can be tolerated by the player may be a result of the degree of hypohydration which the player has become accustomed to or routinely experiences. Research in cycling demonstrated that as little as four familiarisation sessions, designed to habituate the individual with the dehydration protocol, attenuated the performance decrement observed when 2.4% hypohydrated (Fleming & James, 2014). Nevertheless, it is important to note that performance following habituation was still lower than when exercise was completed hydrated. Interestingly, there were no physiological mechanisms to explain the results (i.e., familiarization did not attenuate cardiovascular strain) so the advantage was likely a result of improved perceptual/psychological response (Rating of perceived Exertion (RPE)). Although this study was performed in cycling and football-specific research is yet to be completed, players and coaches are advised to not allow hypohydration to become the “norm” and become accustomed to consistent sub-optimal performance.

Determinants of fluid intake

The net body water balance of the player (fluid losses = fluid gains) is regulated remarkably well day-to-day, as a result of their thirst and hunger combined with the access to food and beverages. However, when fluid losses are greater than fluid intake, it results in hypohydration. Because a player’s body water has a normal daily fluctuation, hypohydration may be defined as a body water deficit greater than normal daily fluctuation (Cheuvront & Kenefick, 2014). Hypohydration may also be defined as a negative change in body water which exceeds 2 percent of the normal body mass variability (Cheuvront, Fraser, Kenefick, Ely, & Sawka, 2011).

When a football player is at rest, the approximate threshold level of hypohydration where compensatory fluid regulatory actions (fluid conservation at the kidney) and stimulus for fluid acquisition (thirst) occurs is approximately >2% of their body mass (Shirreffs, Armstrong, & Cheuvront, 2004). These compensatory actions are triggered by elevations in blood plasma osmolality and to lesser degree, a reduction in plasma volume. During football exercise, particularly in the heat, plasma volume decreases because it provides the fluid for sweat, and as a result, plasma osmolality increases because sweat has a low sodium content relative to blood plasma (Kenefick, 2018).

It is important to remember that, when total body water losses occur during football exercise due to thermoregulatory sweating, these losses are shared by all fluid compartments (Kenefick, 2018). An increase in plasma and extracellular osmolality will pull fluid from the intracellular space so that all compartments are in non-osmotic equilibrium. A ~2% increase in plasma concentration is commonly referenced as an osmotic threshold for compensatory water retention at the kidneys and water acquisition (thirst), which is also equivalent of ~2% BM loss. These losses would be the equivalent of 1.4 L of fluid for a 70 kg player.

It is important to note that metabolic water production can also contribute to water gain during exercise. Water is produced as a result of aerobic metabolism. The rate of water formation is primarily dependent upon energy expenditure and, to a lesser extent, upon the type of substrate. The water produced through metabolism has been estimated to be approximately 250 to 350 mL per day for sedentary persons and up to 500 to 600 mL per day for physically active individuals (L. B. Baker & Jeukendrup, 2014). Finally, although only small, it is also important to recognise that non-sweat sources (metabolic mass loss from substrate metabolism and respiratory water losses) may also contribute to body mass losses during exercise (Cheuvront & Montain, 2017).

Table 1: The water content range for selected foods

Percentage	Food item
100%	Water
90% - 99%	Fat-free milk, cantaloupe, strawberries, watermelon, lettuce, cabbage, celery, spinach, pickles, squash (cooked)
80% - 89%	Fuit juice, yogurt, apples, grapes, oranges, carrots, broccoli, (cooked), pears, pineapple
70% - 79%	Bananas, avocados, cottage cheese, ricota cheese, potato (baked) corn (cooked) shrimp
60% - 69%	Pasta, legumes, salmon, ice cream, chicken breast
50% - 59%	Ground beef, hot dogs, feta cheese, tenderloin steak (cooked)
40% - 49%	Pizza
30% - 39%	Cheddar cheese, bagels, bread
20% - 29%	Pepperoni sausage, cake, biscuits
10% - 19%	Butter, margarine, raisins
1% - 9%	Walnuts, peanuts (dry roasted), chocolate chip cookies, crackers, cereals, pretzels, taco shells, peanut butter
0%	Oils, sugars

Source: (Popkin, D'Anci, & Rosenberg, 2010)

Monitoring hydration status

Assuming the player is in energy balance, daily hydration status may be estimated by tracking early morning body weight (measured upon waking and after voiding) since acute changes in body weight generally reflect shifts in body water (Thomas, Erdman, & Burke, 2016). Urine analysis may also be a useful indicator of a player's hydration status. Urinary-specific gravity and urine osmolality may be used to approximate hydration status by measuring the concentration of the solutes in urine (Thomas et al., 2016). Ideally, the urine should be collected from a midstream collection of the first morning urine sample. As a guide, a urinary-specific gravity of less than 1.020, perhaps ranging to 1.025 to account for individual variability, is generally indicative of euhydration. Urinary osmolality reflects hypohydration when greater than 900 mOsmol/kg, while euhydration is considered as less than 700 mOsmol/kg (Thomas et al., 2016).

Most likely, the easiest method for the player to assess their hydration status is the volume and colour of their urine. If a large volume of urine is produced and the urine in pale yellow in colour, the player is most likely hydrated or drank sufficient fluid with their meals. If the urine is very dark in colour (dark orange/brown), it is likely that they have not drank enough volumes of fluid following their last bout of football activity or with their last meal. In this case, fluid intake should be adjusted accordingly (Unit 2). Practically, placing "hydration" reminders or urine colour charts (Armstrong et al., 2010) above urinals in male toilets or in female cubicles serve as a behavioural "nudge" for players to remember to monitor their hydration status. Likewise, targeted hydration education around pre-season and during periods of fixture congestion are recommended.

Summary

- Water accounts for approximately 55-60% of the player's body mass.
- A player's total body water will naturally fluctuate throughout the day.
- The player's total body water can be divided into intracellular water and extracellular water. Sodium is the main electrolyte in extracellular water.
- Fluid is lost during exercise as players sweat to keep the body cool.
- Body water losses >2% of pre-exercise body mass may negatively impact exercise performance.

Unit 4.2 Fluid and Electrolytes for Football

Every day water is lost from the players' body in the form of sweat, urine and respiratory losses, whilst water is gained by the ingestion of foods and fluid in the players' diet (Unit 1). Hypohydration of $\geq$2% body mass deficit has been shown to impair football-specific performance, including intermittent high-intensity sprinting and dribbling skills. It is often observed that football players start a practice or match play already in a dehydrated state, probably as a result of cumulative dehydration from previous training or matches. Therefore, fluid intake on a daily basis may be as important as fluid intake strategies during competition (we present a summary of both scenarios, i.e. daily habits and exercise). In this Unit, we discuss how players can be educated to assess their hydration status and modify the intake of fluid depending on the demands of exercise and environmental conditions.

Player Sweat Rates

Sweat rates vary greatly among players and are primarily influenced by the intensity of exercise, environmental conditions and acclimation status (Duffield, McCall, Coutts, & Peiffer, 2012). During training and matches, sweat rates have been reported to range from 0.5 L/h to 2.5 L/h (L. B. Baker, Barnes, Anderson, Passe, & Stofan, 2016; Shirreffs et al., 2005), and are generally lower in female players because of lower body mass and absolute work rates (Kilding et al., 2009). The mechanisms by which sweating-induced hypohydration might impair football performance are not completely understood, but may include increased cardiovascular strain (Armstrong, Costill, & Fink, 1985), impaired cognitive function (Ganio et al., 2011), increased perception of effort (McGregor et al., 1999), reduced physical function (Mohr & Krustrup, 2013), and reduced technical skills (McGregor et al., 1999). Players are therefore advised to drink sufficient fluids to prevent a deficit of $\geq$2% of pre-exercise body mass loss during exercise (Sawka et al., 2007). Conversely, it is important to note that players must avoid gains in body mass (hyperhydration) during exercise.

During training and matches, players should pay attention to ingesting an appropriate quantity of carbohydrate (Module 1), whilst simultaneously meeting fluid needs. Both hydration and carbohydrate ingestion will require additional attention in matches where extra-time (2 x 15 min) is played. All match nutrition strategies, including hydration, should be practised in training and minor matches to allow individualised protocols to be developed and to identify potential adverse effects in players. This method also allows players the opportunity to become adapted to the nutrition strategy without impacting on important/competitive match performance.

Method to monitor player fluid balance

It is possible to measure the fluid balance of players across training and matches. By routinely adopting this method, it will help inform the individual players of their fluid needs during exercise and inform the coaches to the level of hypohydration being experienced by the player. Specifically, fluid intake and losses can be recorded and used to calculate the player's sweat rate (B. L. Baker, 2016).

It is important to note that body water gain occurs through metabolic water production via the dissociation of water from glycogen and substrate use (Unit 1). It is generally accepted that for most exercise (~2 h or less) evaporative loss of water from the lungs through respiration is negligible, as is changes in metabolic mass, and can be ignored (Cheuvront & Montain, 2017; R. J. Maughan, Shirreffs, Merson, & Horswill, 2005). For practical purposes, it is assumed that 1 kg of a player's body mass loss represents approximately 1 L of water loss (R. J. Maughan, Shirreffs, & Leiper, 2007; R. J. Maughan, Watson, Evans, Broad, & Shirreffs, 2007). Therefore, sweat loss can be calculated from the change in a player's body mass during exercise following the correction for fluid intake. The method to measure fluid balance during exercise is displayed in Figure 4 and summarised below:

1. Collect a pre-exercise (ideally first morning) urine sample from the players. These samples can be used as an indicator of the players' hydration status, either through analysis of urine specific gravity/osmolality or more simply by analysis of volume and colour.

2. Before the first BM measurement, encourage players to void their bladder. Record the players' BM (kg). This can be completed by players wearing minimal clothing (i.e. underwear) or nude if privacy is possible.

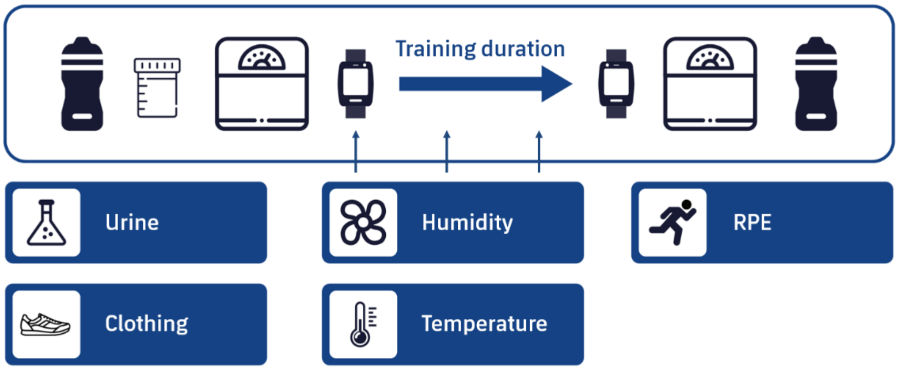
3. Allocate each player a drink bottle, which should be weighed before and after exercise. Changes in the bottle weight in grams, represents the volume of fluid ingested in ml. Advise the player to only drink from their bottle and to avoid squeezing water onto their faces for cooling purposes.

4. During exercise, record the duration of exercise and the environmental conditions and collect, measure and record any urine which maybe passed by the player.

5. After exercise, ensure the player is dry before the final body mass measurement is recorded (kg). A change in body mass of 1 kg is the equivalent of 1 L of fluid loss.

An example of how to calculate the sweat rate of a player is displayed in Figure 4. This method allows for individual sweating response to training and matches to be captured and it helps the nutritionist identify those players with "high" sweat rates, and thus at greater risk of significant hypohydration.

Figure 4: Fluid balance method overview



Source: Prepared by author.

Figure 5: Player sweat rate calculation and working example

Sweat loss (L)=

BODY MASS LOSS (kg) + FLUID INTAKE – URINE VOLUME

Sweat rate (L/h)=

SWEAT LOSS (L) / DURATION (HOUR)

Sweat loss (L)=

BODY MASS LOSS (kg) + FLUID INTAKE – URINE VOLUME = 2.0 L

1.5 500 ml / 1000 0 ml / 1000

Sweat rate (L/h)=

SWEAT LOSS (L) / DURATION (HOUR) = ~1.3 L/h

2.0 1.5 (90 mil)

Source: Prepared by author.

Sweat analysis

Sweat is hypotonic but contains electrolytes (Unit 1). The major electrolytes found in sweat are sodium (Na^+) and chloride (Cl^-); collectively, these ions form the salt (sodium chloride). Analysis of sweat composition allows for the amount of sodium chloride lost during exercise to be determined, and differences among individual players to be measured. The replenishment of sodium chloride post exercise is important for complete and rapid rehydration detailed below (Shirreffs, Taylor, Leiper, & Maughan, 1996). Full details of the sweat collection and analysis protocol have been described in detail (L. B. Baker, Stofan, Hamilton, & Horswill, 2009). In summary, absorbent patches are covered with an adhesive film that holds the patch in place and prevents sweat evaporation. The patches should be placed on the skin surface following washing with deionized water and drying with a sterile gauze swab. Patches remain in place for the duration of exercise and are removed immediately after exercise, or sooner if they become saturated.

There are different methods to analyse the sweat electrolyte composition (L. B. Baker et al., 2009). Historically this analysis has been laboratory based, relatively slow and expensive. Recently, a field method has been validated against gold standard laboratory techniques which allows rapid analysis of sweat composition (L. B. Baker et al., 2014). After removal from the skin, patches can be immediately placed inside the barrel of a 5-mL syringe using sterile tweezers. The syringe plunger is then depressed to compress the patch, and the expelled sweat is collected into a sterile tube. Sweat samples can be analysed immediately using a compact wireless analyser that uses ion-selective electrode technology (Horiba B-722) to derive measures of sodium concentration. Sweat electrolyte losses (g) should be normalised, and whole body losses should be calculated from the sweat electrolyte concentration, the molecular weight of the electrolyte and the total sweat loss of the player (L. B. Baker et al., 2016; L. B. Baker et al., 2014).

Fluid intake

To maintain water balance, fluid intake must compensate for the fluid loss that occurs during training, matches and daily living. Fluid intake is usually dependent on thirst feelings but thirst (or the lack of thirst) can also be overridden by conscious control (Sawka & Greenleaf, 1992). It is important to note, however, that thirst has been reported to be a poor indicator of fluid requirements or the degree of hypohydration during exercise (McKenna & Thompson, 1998). As discussed, even a mild degree of hypohydration can be sufficient to impair exercise performance, especially during exercise in warm conditions (Cheuvront & Kenefick, 2014). In studies investigating sweat rates in professional football, fluid has been freely available. Those studies which have reported the volume of fluid voluntarily ingested have shown that drinking was highly variable among players in the same teams and was also influenced by the environmental conditions (R. J. Maughan & Shirreffs, 2007a, 2007b). Maughan et al. (2005) tabulated results from five studies that investigated fluid loss and intake of elite male football players at temperatures ranging from 5-32°C and found *ad-libitum* fluid intake ranged from 423-1401 ml (R. J. Maughan, Watson, et al., 2007). Unfortunately, the volume of the fluid intake which was water and which was a beverage containing carbohydrate is not commonly reported. This is of interest because the routine ingestion of carbohydrate provided in combination with fluid, typically via carbohydrate-electrolyte beverages, has been reported to positively influence various aspects of football-specific performance ((I Rollo, 2014; Russell & Kingsley, 2014) and outcomes associated with team sport performance (L. B. Baker, Rollo, Stein, & Jeukendrup, 2015; Williams & Rollo, 2015).

DID YOU KNOW?
The term ad-libitum simply means self-selected or freely chosen.

Fluid loss

Sweat losses in professional footballers have been reported to vary greatly among players, even in response to the same exercise session (Aragón-Vargas, Moncada-Jiménez, Hernández-Elizondo, Barrenechea C, & Monge-Alvarado, 2009). The two main determinants of the rate at which fluid is lost as a consequence of sweating (sweat rate) are exercise intensity and environmental conditions (Hawley, Dennis, & Noakes, 1994; R. J. Maughan, Watson, et al., 2007). Sweat rate is primarily determined by metabolic heat production, which is directly proportional to absolute exercise intensity. The environmental heat stress is determined by the ambient temperature, relative humidity, wind velocity and solar radiation. Of these factors, the ambient temperature and relative humidity are considered the most important. A high ambient temperature increases skin blood flow and high humidity will severely compromise the evaporative loss of sweat. Rather than evaporate, sweat will often drip off the skin in such conditions, diminishing the effectiveness of heat loss via this route.

Football is practiced and played in a variety of environmental conditions. In Barcelona, during the same competitive season, players train and compete in environmental conditions ranging from cool in the winter months [wet bulb globe temperature (WBGT)] 15 ± 7°C, 66 ± 6 % RH, January 2015) to very hot in the summer (WBGT $\geq$ 29 ± 1°C, 52 ± 7 RH, July 2014). The mean sweat rate of professional players training in hot (32.3 ± 3°C) ambient temperatures has been reported to be 1.46 ± 0.24 L/h (range 1.12-2.09 L/h) and the corresponding mean level of hypohydration was 1.59 ± 0.61% of pre-exercise body mass (range 0.71-3.16%) (Shirreffs et al., 2005). Although mean sweat losses have been reported to be lower (1.13 ± 0.30 L/h, range 0.71-1.77 L/h) when training in cool temperatures (5.1 ± 0.7°C), players still experience significant levels of hypohydration: 1.62 ± 0.55% (range 0.87-2.55%) (R. J. Maughan et al., 2005).

Female players will generally have lower sweat rates than their male counterparts due to a smaller body size and less muscle mass contributing to metabolic heat production during exercise (Cheuvront, Haymes, & Sawka, 2002). Because of the lower fluid and electrolyte losses in female players, some studies have suggested that hydration is unlikely to require special consideration in this group (Kilding et al., 2009). However, in our experience, female players sweat response will also vary significantly among players in response to the same training session. In addition, it is also a challenge for female players to drink large volumes of fluid prior to and in recovery from exercise. Thus, more research and insight are needed to optimise the hydration practices of this elite population.

In our experience, when fluid is readily available and players have routine access, as in training, players drink sufficient volumes to prevent body mass losses in excess of 2% pre-exercise body mass values. These observations extend to when players completed training at various intensities and different environmental conditions (I. Rollo et al., 2016). However, greater challenges to fluid balance occur during matches, especially in hot conditions, as sweat rates (water losses) may increase dramatically. High sweat rates combined with limited opportunities to drink during competitive match play, often result in players experiencing significant hypohydration (>2% BM).

Fluid intake strategies

Fluid intake during training and matches can help maintain plasma volume and prevent the adverse effects of dehydration on endurance and technical performance. When there is only little time in between two training sessions, rapid rehydration is crucial, and drinking regimes need to be employed to optimize fluid delivery. As such, strategies for fluid replacement before, during and after football exercise will be discussed in the following sections.

Fluid intake before training and matches

The aim for the player should be to begin training and games hydrated. Generally, there is sufficient time, i.e. ≥8 h between training sessions or matches, for the player to consume sufficient volumes of fluid with meals to achieve this. However, during matches, the player may incur in significant fluid losses and thus more structured hydration strategies may be required. An effective pre-exercise hydration strategy will help ensure that any previous fluid deficits that the player has experienced from exercise or travel is rectified before re-engaging in football-specific activity.

As a guide, to ensure adequate hydration prior to exercise, players are advised to drink a volume of fluid specific for their body mass. Specifically, at least four hours before exercise, players should gradually drink approximately 5-7 ml of fluid per kg body mass. On match days, this can be completed with their final meal before the match, whereas on training days, these volumes should be ingested with breakfast. Consuming fluid with meals with small amounts of sodium or sodium containing foods will help stimulate thirst and the retention of the ingested fluid (R. J. Maughan & Leiper, 1995). Drinking approximately four hours before exercise allows sufficient time for urine output to be expelled before players are expected to perform. In addition, it avoids the situation of players drinking too much fluid immediately before exercise, which increases the risk of the player feeling bloated and experiencing gastrointestinal complaints.

In a situation where the player does not produce urine, or the urine is of low volume and dark in colour, a further 3-5 ml of fluid per kg body may be advised approximately 2 h before exercise. It is important to note that fluid intake is, of course, self-regulated by the player. Therefore, adequate education programmes within the club should be in place so that the player can identify signs of hypohydration themselves and modify their drinking behaviour appropriately.

Fluid intake during training and matches

In order to avoid significant hypohydration during the match or training, fluids should be ingested. By regularly measuring body mass before and after exercise, it is possible to build a profile of fluid losses in response to specific footballing sessions, i.e. training/games, and conditions (lower or higher temperatures and humidity). Sufficient data collection over time will allow predictions of fluid losses based on exercise intensity and forecasted weather.

Fluid intake is likely to benefit the player when exercise is longer than 30-60 minutes, but there appears little advantage during strenuous exercise of less than 30 minutes in duration. During such high-intensity exercise, gastric emptying is inhibited and the drink is more likely to cause gastro-intestinal distress with no performance benefit. Large volumes of fluid are difficult, if not impossible, to ingest, and even one litre may feel quite uncomfortable in the "untrained" stomach (Murray, 2006). Therefore, in these circumstances, it is not advised nor is it practically possible to match fluid intakes to sweat losses during exercise. Another factor that can make the ingestion of large amounts of fluid difficult is the fact that in matches the opportunities for drinking are limited to before the game, half time and during unscheduled breaks in play (L. B. Baker et al., 2016; Gleeson, 1998).

Excessive water intake should be avoided as this has been linked to hyponatremia (low plasma sodium). Although, to date and to the author's knowledge, there have been no reported cases of hyponatremia in football players, education about the right volumes of fluid to drink (based on sweat rates in combination with few drinking opportunities that exist both in training and on match days) should avoid the problem of over-drinking. Therefore, as a guide, players should aim to minimise fluid losses during exercise of an hour or more to equal to or less than 2% of starting body mass (assuming the player started in a euhydrated state).

When faced with drinking guidelines, some players may be overwhelmed by the volumes of fluid suggested. If a player's current drinking regime is in stark contrast to recommendations, it is advised to work towards fluid intake goals over time. Specifically, do not introduce large changes in one go. Drinking before exercise can be built into a daily routine, gradually increasing the volume. During exercise, it is often difficult to tolerate the volumes of fluid needed to prevent significant hypohydration. However, the volume of fluid that is tolerable can be trained and increased with frequent drinking in training (Lambert et al., 2008). Drink training will accustom the players to the feeling of exercising with fluid in the stomach, whilst helping to optimise the delivery of carbohydrate if sports drinks are chosen (A. E. Jeukendrup, 2011). It also gives the player the opportunity to experiment with different volumes and flavourings to determine the volume of fluid intake they can tolerate, and which formulations suit them best.

Type of fluid

Numerous studies have shown that "regular" water intake during prolonged exercise is effective in improving performance (for review see (Shirreffs & Sawka, 2011). However, fluid intake during exercise also offers the opportunity to provide some fuel in the form of carbohydrate (Module 1). The type and composition of drink consumed during exercise should be specific to the exercise session, as well as the goals of each individual player (Impey et al., 2016; A. Jeukendrup, 2014). Therefore, during match play, where "performance" is the objective, the addition of carbohydrate to drinks consumed will have an additive and independent effect in comparison to water on exercise performance (Below, Mora-Rodriguez, Gonzalez-Alonso, & Coyle, 1995; Nicholas, Williams, Lakomy, Phillips, & Nowitz, 1995; Williams & Rollo, 2015).

Beverages for fluid and energy replacement during exercise should: 1) taste good, 2) not cause gastrointestinal discomfort, 3) be rapidly emptied from the stomach and absorbed in the intestine, 4) provide energy in the form of carbohydrate and a source of electrolytes. It is for this reason that sports drinks are typically available in a variety of flavours (to meet player taste) and contain three main ingredients: water, carbohydrate and sodium. The water and carbohydrate provide fluid and energy respectively, while sodium is included to aid water absorption and retention (R.J. Maughan & Murray, 2001).

Both carbohydrate and fluid are important. Supply of a concentrated form of carbohydrate may slow gastric emptying and reduce water absorption. Therefore, it is usually recommended to combine the ingestion of gels, chews and other solids with water. If stomach contents are too concentrated, water may be drawn out of the interstitial fluid and plasma and into the lumen of the small intestine by osmosis, and fluid delivery will be less effective (Gisolfi, Summers, Schedl, & Bleiler, 1992). Whether this is a problem, depends on the goals for hydration and carbohydrate delivery. It must be emphasized here that the addition of sodium and other electrolytes to sports drinks is to increase palatability, maintain thirst (and therefore promote drinking), help prevent hyponatremia, and increase the rate of water uptake, rather than to replace the electrolyte losses through sweating. Replacement of the electrolytes lost in sweat during football exercise (~90 minutes) can normally wait until the post-exercise recovery period, unless the player is a particularly heavy and salty sweater and/or the exercise duration is prolonged and in warm conditions (L. B. Baker et al., 2016).

Rehydration after training and matches

Rehydration is an important part of the post-exercise recovery process. In the post exercise occasion, the ingestion of carbohydrate, fluid and electrolytes are required for replenishing depleted glycogen stores and rehydration respectively (Shirreffs et al., 1996). If players have accrued a body mass deficit (i.e. hypohydrated), they should aim to completely replace fluid and electrolyte losses prior to the start of the next training session or match. In most cases, players can just drink according to thirst, as there is plenty of time to restore fluid balance before the next training session.

If hypohydration is severe (>5% of BM) or rapid rehydration is needed (e.g. < 24 h before next training or match or pre-season double training sessions), the replacement of fluid and electrolytes in the post-exercise period takes on greater importance. The main factors influencing the effectiveness of post-exercise rehydration are the volume and composition of the fluid consumed.

The recommendation is to drink ~1.5 L of fluid for each 1 kg of body mass deficit (Shirreffs & Sawka, 2011). This is because some of the ingested fluid will be excreted in urine, and studies indicate that ingestion of 150% or more of weight loss is required to achieve normal hydration within 6 hours following exercise (Shirreffs & Maughan, 2000). In most other situations, water and sodium can be consumed with normal eating and drinking practices with no urgency.

Drinking plain water is not the ideal post-exercise rehydration beverage when rapid and complete restoration of body fluid balance is necessary and where all intake is in liquid form (Snell, Ward, Kandaswami, & Stohs, 2010).

Ingestion of water alone in the post-exercise period results in a rapid fall of the plasma sodium concentration and the plasma osmolality. These changes have the effect of reducing the stimulation to drink and increasing the urine output, both of which will delay the rehydration process. Plasma volume is more rapidly and completely restored in the post-exercise period if sodium chloride (77 mmol/L or 450 mg/L) is added to the water consumed (R. J. Maughan & Leiper, 1995; Snell et al., 2010). This sodium concentration is similar to the upper limit of the sodium concentration found in sweat but is considerably higher than the sodium concentration of many commercially available sports drinks, which usually contain 10-25 mmol/L (60-150 mg/L). Thus, drinking a beverage containing sodium or eating sodium-containing foods with fluids is recommended during the post-exercise occasion (R. J. Maughan, Leiper, & Shirreffs, 1996; Shirreffs & Sawka, 2011).

The inclusion of potassium in the beverage consumed after exercise would be expected to enhance the replacement of intracellular water and thus promote rehydration. However, there is little experimental evidence to support this. The rehydration drink should also contain carbohydrate (glucose or glucose polymers) because the presence of glucose will also stimulate fluid absorption in the gut and improve beverage taste. Following exercise, the uptake of glucose into the muscle for glycogen re-synthesis should also promote intracellular rehydration (Gisolfi, Lambert, & Summers, 2001; Gisolfi et al., 1992). Therefore, fluid in the post-exercise occasion can be combined with the ingestion of protein and carbohydrate, which are also required for the player's recovery and adaptation (Hobson & James, 2015; Ivy, 2001; James, Clayton, & Evans, 2011; James et al., 2013).

Table 2: Fluid guidelines

Occasion	Targets	Principle
Daily intake	Adjust to daily levels of physical activity	Fluid can be ingested via beverages, fruits and vegetable
Prior to exercise	5-7 ml / kg BM	Drink 3-4 before exercise
During exercise	Routine ingestion of fluid	Base intake on individual fluid losses and adjust for exercise intensity and environmental conditions
Post exercise	If rapid rehydration is required drink 150% of BM losses in the 5 h after the match Avoid alcohol (no more tan 1 unit)	Replace fluid losses as a consequence of sweating during exercise. The addition of sodium to the recovery beverage will help with fluid retention and maintain the drive to drink

Source: Prepared by author.

Fluid recommendations should be refined with individual sweat rates, specific training intensities and environmental conditions. Feedback from training/competition performance is required. Fluid needs will increase during training and matches in warmer environments.

Summary

- Players should aim to commence training and matches euhydrated.
- Player’s fluid loss during training and matches can be monitored and recorded.
- There is a large range in sweat rates among individual players, even in response to the same training session or match.
- Fluid intake should be modified depending on the individual player, the intensity or exercise, and the environmental conditions.
- Players should be educated on fluid needs and how to monitor their hydration status.

Disclaimer: Ian Rollo is an employee of the Gatorade Sports Science Institute, a division of PepsiCo, Inc. The views expressed in this course are those of the authors and do not necessarily reflect the position or policy of PepsiCo, Inc.

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