

Fluid and electrolyte balance in elite male football (soccer) players training in a cool environment

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There are few data in the published literature on sweat loss and drinking behaviour in athletes training in a cool environment. Sweat loss and fluid intake were measured in 17 first-team members of an elite soccer team training for 90 min in a cool (5°C, 81% relative humidity) environment. Sweat loss was assessed from the change in body mass after correction for the volume of fluid consumed. Sweat electrolyte content was measured from absorbent patches applied at four skin sites. Mean (\pm s) sweat loss during training was 1.69 ± 0.45 l (range 1.06–2.65 l). Mean fluid intake during training was 423 ± 215 ml (44–951 ml). There was no apparent relationship between the amount of sweat lost and the volume of fluid consumed during training ($r^2 = 0.013$, $P = 0.665$). Mean sweat sodium concentration was 42.5 ± 13.0 mmol·l⁻¹ and mean sweat potassium concentration was 4.2 ± 1.0 mmol·l⁻¹. Total salt (NaCl) loss during training was 4.3 ± 1.8 g. The sweat loss data are similar to those recorded in elite players undergoing a similar training session in warm environments, but the volume of fluid ingested is less.

Keywords: electrolyte balance, football, hydration, soccer, sweating, thermoregulation.

Introduction

There are several reports in the published literature of the sweat losses and drinking behaviours of male and female athletes training and competing in various sports and in different environments. Most of these reports have focused on sweat loss in a competitive environment, with a view to helping to formulate guidelines for fluid replacement that will help to optimize performance and minimize the risk of heat illness. It is perhaps not surprising, therefore, that most of these studies have involved measurements on athletes in a warm or hot environment, where sweat losses are generally higher and the risk of heat-related problems is much greater. The published data show a wide range in sweat rates in different environments (Rehrer and Burke, 1996). There is also a wide inter-individual variability in the sweating response, as well as a variation across time within the individual depending on physical fitness and heat acclimation status, as well as on other variables such as exercise intensity and duration and the amount and type of clothing worn.

As well as the water lost in sweat, a variety of electrolytes and other solutes are also lost. Sweat is invariably hypotonic relative to plasma, and the primary electrolyte present is sodium, the major cation present in the extracellular space (Maughan *et al.*, 2000). In the absence of fluid intake, large sweat losses lead to an increase in plasma osmolality and to hypernatraemia. When sweat sodium losses are high, there may be reasons for adding sodium to drinks consumed during exercise, but this probably only applies when the exercise period is very prolonged and sweat sodium losses are substantial. There are, however, only limited data on the extent of sodium losses in most sporting contexts. There does not seem to be evidence to support the addition of other electrolytes (Coyle, 2004).

Because maintenance of fluid balance presents a greater challenge in the heat than in cool conditions, most of the available data have been collected in warm or hot conditions, but there are some reports of measurements made in cooler conditions. Rehrer and Burke (1996) have reported mean sweat rates of 1000 ml·h⁻¹ for football players at an ambient temperature of 10°C, with a slightly higher mean sweat rate (1200 ml·h⁻¹) at 25°C. This suggests that average sweat rates in cool conditions may not be very different from those in warmer environments, perhaps because of

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differences in the exercise intensity or differences in the type and amount of insulative clothing worn. For athletes training and competing in cold environments, different priorities may apply during exercise. Sweating rates are likely to be lower in cold environments (Rehrer and Burke, 1996; Galloway and Maughan, 1997) and the effect of hypohydration on exercise performance is less marked (Coyle, 2004). It may be, therefore, that there is not the same need for provision of fluids during activities taking place in a cool environment, but there is little published information to support this.

We have recently reported data on the sweat losses and drinking behaviour of two groups of elite soccer players training in a warm environment (Maughan *et al.*, 2004; Shirreffs *et al.*, in press). These data highlighted the similarities in the mean responses of the two groups and also the wide inter-individual variability. There appear to be no data in the published literature on voluntary fluid intake of different groups of athletes engaged in similar training sessions in different climatic conditions. The aim of the present investigation, therefore, was to collect descriptive data on sweat loss and fluid intake in soccer players training in a cool environment.

Methods and materials

The participants were 17 members of the first-team squad of a Dutch Premier Division professional team. This represents the whole first team squad except for players who were unable to participate due to illness, injury or absence on international duty. All players gave written informed consent to participate after the details of the study had been explained to them. The study was approved by the Research Ethics Committee of Loughborough University. The mean (\pm s) physical characteristics of the participants were: age 24 ± 4 years, height 1.80 ± 0.07 m, body mass 78.1 ± 6.8 kg.

All measurements were made on a single day during the early part of the 2003–2004 playing season. Training began at approximately 10.30 h and lasted about an hour and 40 minutes. The training was that normally carried out by the players on this day of the week and at this time of the season, and consisted of a warm-up, interval running, ball drills and a short game. All players followed the same training programme. Environmental conditions were recorded every 10 min throughout the training session: mean ambient temperature during training was $5.1 \pm 0.7^\circ\text{C}$ and mean humidity was $81 \pm 6\%$. The players were at liberty to choose the clothing they wore: most wore T-shirt, football shirt, shorts and track suit. Some players changed their clothing assembly during the course of training.

A pre-exercise urine sample was collected from all players upon arrival at the training ground. These samples were analysed for osmolality by freezing point depression (Camlab, Roebing, Cambridge, UK) to give an index of pre-training hydration status. The players were instructed to collect any urine passed during training in containers provided so that this could be taken into account in the calculation of sweat loss from the measured changes in body mass. No player passed any urine during training.

Before and after training, all players were weighed wearing only underpants. Sweat loss was calculated from the change in body mass after correction for fluid intake. The relatively small changes in mass due to substrate oxidation and other sources of water loss (primarily evaporative loss from the lungs) were ignored. Players were asked to micturate and defecate if necessary immediately before the pre-exercise measurement of body mass. During the training session, all players had free access to water in individually identified drinks bottles, and the coaching staff scheduled regular breaks in activities to allow the players to consume this, according to the normal practice of these players. Only water was provided, as this was what was normally available to the players during training.

Sweat samples were collected during the training session from each of four skin sites (chest, forearm, back and thigh) by absorbent sweat patches applied to the skin surface (Tagaderm + Pad, 3M, Loughborough, UK). The gauze patches were covered with an adhesive non-porous film that held them in place and prevented evaporation of sweat. The patches were positioned before the start of the training session and remained in place throughout the session. All patches were placed on the right-hand side of the body after preparation of the skin site by washing with deionized water and drying with a clean electrolyte-free gauze swab. The patches were removed immediately after training and placed in sealed sterile containers until they were analysed. After weighing of the patches and elution of sweat with deionized distilled water, the sweat collected was analysed for sodium (Na^+) and potassium (K^+) concentration by flame photometry (Corning Model 410C).

Statistical analysis

The data were tested for normality of distribution and are presented as the mean \pm standard deviation, with the range of data given in parentheses. The significance of the measured changes during training was assessed using a paired *t*-test. Correlation analysis between variables was performed using a least-squares regression model, and the coefficient of determination (r^2) is

reported. Where a P -value of less than 0.05 was found, statistical significance was accepted.

Results

Pre-training body mass was 78.06 ± 6.79 kg (range 65.56–93.52 kg). All players lost weight during the training session and body mass after training was 76.68 ± 6.60 kg (range 64.64–92.30 kg). There was a significant ($P < 0.001$) body mass loss over the training session of 1.27 ± 0.47 kg (range 0.62–2.26 kg). This is equivalent to dehydration of $1.62 \pm 0.55\%$ (range 0.87–2.55%) of the pre-training body mass.

Mean fluid intake during training was 423 ± 215 ml (range 44–951 ml). There was no apparent correlation between the extent of sweat loss and the volume of fluid consumed ($r^2 = 0.013$, $P = 0.657$; Fig. 1). After correction for the amount of fluid ingested, the estimated mean sweat loss was 1.69 ± 0.45 l (range 1.06–2.65 l). This corresponds to a sweat rate of 1.13 ± 0.30 l·h⁻¹ (range 0.71–1.77 l·h⁻¹). Sweat electrolyte concentration and total sweat losses are

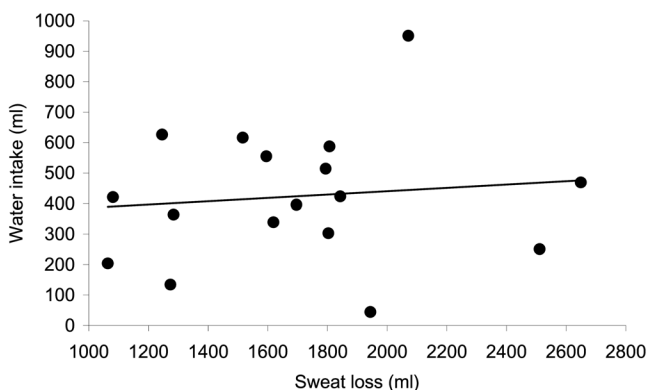


Fig. 1. Relationship between the volume of fluid consumed during training and the amount of sweat loss. There was no statistically significant association ($r^2 = 0.013$, $P = 0.665$).

Table 1. Sweat electrolyte concentration and total sweat electrolyte loss ($n = 17$)

	Mean	s	Range
Sweat [Na] (mmol·l ⁻¹)	42	13	16–66
Sweat [K] (mmol·l ⁻¹)	4.2	1.0	2.7–6.3
Total Na loss (mmol)	73	31	29–121
Total K loss (mmol)	7.1	2.8	3.4–14.3
Total NaCl loss (g)	4.3	1.8	1.7–7.0

Note: The total NaCl loss is calculated on the basis that all the sodium loss is as sodium chloride.

shown in Table 1. Sweat sodium and potassium concentrations at each of the four collection sites are shown in Table 2.

There was no apparent relationship between mean whole-body sweat rate and the mean sweat sodium ($r^2 = 0.019$, $P = 0.594$) or potassium ($r^2 = 0.016$, $P = 0.627$) concentration (Fig. 2). There was also no relationship between whole-body sweat rate and sweat electrolyte content at any of the four sites measured. The method used in the present study does not permit a reliable measure of sweat rate at each of the individual sites, so no site-specific comparisons of sweat rate and sweat composition are possible.

Table 3 shows a comparison of the data from the present study with those from other measurements made on players of a comparable playing standard. In each case, the players completed a training session of approximately 90 min involving similar activities. The difference is that the other four data sets were collected during a session that took place in a warm environment (25–32°C).

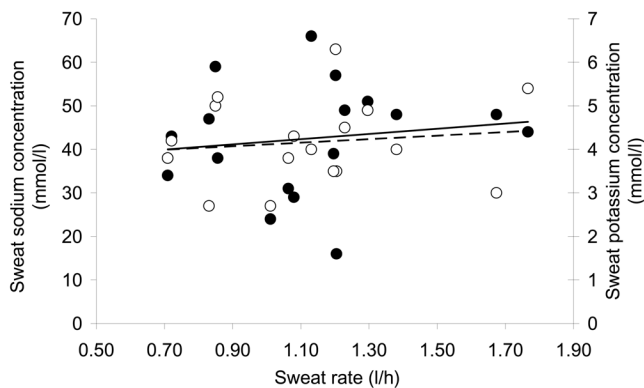
The mean osmolality of the urine samples provided by players before training was 872 ± 177 mosmol·kg⁻¹ (range 481–1228 mosmol·kg⁻¹). Six players provided samples with an osmolality of more than 900 mosmol·kg⁻¹. There was no statistically significant relationship between the pre-exercise urine osmolality and the volume of fluid consumed during training ($r^2 = 0.21$, $P = 0.062$), though there is a suggestion that those players with the highest urine osmolality values consumed the greatest amounts of fluid (Fig. 3). If the two outlying values for fluid intake are removed, a highly significant relationship is observed ($r^2 = 0.44$, $P = 0.007$). There was no association ($r^2 = 0.00$) between the pre-exercise urine osmolality and the estimated sweat rate during training.

Discussion

In spite of the rather cool conditions in which the players trained, sweat losses were not different from those of players of a comparable standard training in much warmer environments (Table 3). Environmental factors, including ambient temperature, relative humidity and wind speed, have a major influence on the sweating response and on the heat loss resulting from evaporation of sweat secreted onto the skin surface. Sweat rate is also influenced by a number of other factors, including exercise intensity, state of fitness and heat acclimation, and the amount of insulative clothing worn. There is also a large inter-individual variability in both sweating rate and sweat composition, and this is apparent even when these factors are kept constant (Greenhaff and Clough, 1989).

Table 2. Sweat cation concentration ($\text{mmol} \cdot \text{l}^{-1}$) at each of the four collection sites

	Sodium			Potassium		
	Mean	<i>s</i>	Range	Mean	<i>s</i>	Range
Forearm	36	10	18–59	5.4	1.5	2.4–7.5
Chest	45	16	11–73	3.4	0.9	1.9–5.1
Back	53	18	19–78	2.9	0.8	1.4–5.1
Thigh	34	18	12–74	4.7	1.9	1.9–8.6

**Fig. 2.** Relationship between mean whole-body sweat rate and the mean sweat sodium (\bullet , solid line, $r^2 = 0.019$, $P = 0.594$) and potassium (\circ , dashed line, $r^2 = 0.016$, $P = 0.627$) concentration.

The sweat electrolyte composition and total salt losses of these players were also similar to those reported for players training in the heat (Maughan *et al.*, 2004; Shirreffs *et al.*, in press). These losses must be replaced, even though there is no evidence that complete replacement of electrolyte losses during exercise is a priority. Replacement can take place during the recovery period, and restoration of electrolyte, especially sodium, losses is a pre-requisite for restoration of fluid balance (Shirreffs and Maughan, 2000). Where exercise sessions are separated by several days, this will easily be achieved by ingestion of normal foods in adequate amounts, and it is not clear that special attention to salt replacement is warranted. However, the situation is different when two, or perhaps even more, training sessions are carried out on the same day. If losses at the higher end of the range observed in this study are sustained, it is unlikely that the normal diet will adequately replace losses. The typical British diet provides a daily dietary sodium chloride intake for 95% of the young male UK population of between 3.8 and 14.3 g, with a mean of 8.4 g; the corresponding values for young women are 2.8–9.4 g, with a mean of

6.0 g (Gregory *et al.*, 1990). For the same population, mean urinary sodium losses were reported to amount to about $175 \text{ mmol} \cdot \text{day}^{-1}$ (Gregory *et al.*, 1990), which is equivalent to about 10.2 g of sodium chloride. Even allowing for a higher total food intake among professional football players (Maughan, 1997), there may be a need for those players with exceptionally high losses to be careful to ensure an adequate intake. Although it is clear that high salt losses are a factor in the aetiology of muscle cramps and heat illness in industrial settings and that these may be alleviated by the ingestion of salt-containing drinks (Oswald, 1925; Brockbank, 1929), it is less clear that this applies to the generally smaller losses that occur in the sporting environment. There is some limited evidence that American football players who have high sweat sodium concentrations may be especially susceptible to muscle cramps (Stofan *et al.*, 2003). Bergeron has also published reports and case studies suggesting that a failure to replace sweat salt losses predisposes tennis players to muscle cramps and that these can be prevented by ensuring an adequate salt intake (Bergeron, 1996, 2003)

Almost one-third (6/17) of the players provided a pre-training urine sample with an osmolality above $900 \text{ mosmol} \cdot \text{kg}^{-1}$. These values may be indicative of a state of mild hypohydration before training began (Shirreffs and Maughan, 1998). If the pre-exercise urine osmolality is accepted as a marker of hydration status, the data do suggest that those players who begin training in a dehydrated state are likely to consume the greatest volumes of fluid during training. While pre-exercise hypohydration may be considered a predisposing factor for heat illness when prolonged strenuous exercise is performed at high ambient temperatures, the risk is greatly reduced when exercise takes place in cool conditions (Coyle, 2004). There may, therefore, be no good reason to advise these players to increase fluid intake in the hours before training.

The major difference between the results obtained for the players in the present study and those for other groups of players lies in the smaller volume of fluid consumed by the present players during training. It is

Table 3. Summary of data from this study, from two published studies (Maughan *et al.*, in press; Shirreffs *et al.*, in press) and unpublished data collected from first-team squad players of two other elite soccer teams

Temp. (°C)	RH (%)	<i>n</i>	Sweat loss (ml)	Fluid intake (ml)	Dehydration (%)	Sweat Na (mmol·l ⁻¹)	Salt loss (g)
32	20	26	2193	972	1.59	30*	3.8*
27	55	24	2033	971	1.37	49	5.7
28	56	20	2221	1401	1.15	44	5.7
25	60	24	1827	834	1.22	44	4.7
5	81	17	1690	423	1.62	43	4.3

Note: All values are the mean values for the whole data set, except for the sweat data indicated by an asterisk. Sweat composition data are available for only 7 of the 26 players tested at this club.

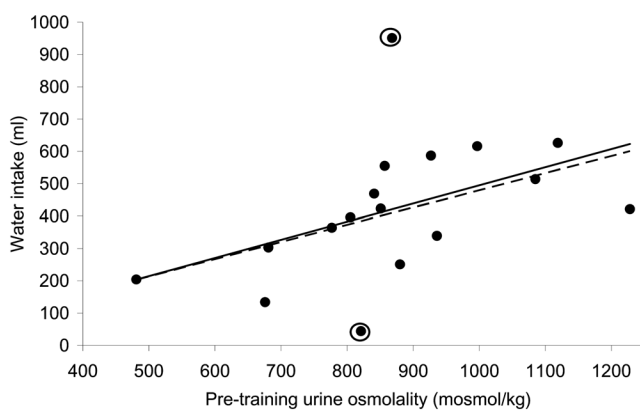


Fig. 3. Relationship between the measured pre-training urine osmolality and measured fluid intake during training. If all data are included, the relationship is not statistically significant ($n = 17$, indicated by a solid line; $P = 0.062$), but removal of the data for the two outliers (indicated with a circle) with the highest and lowest fluid intakes results in a statistically significant association ($n = 15$, indicated by a dashed line; $P = 0.007$).

well recognized that individuals exercising in the heat with an elevated core temperature show a preference for cool fluids and will choose to ingest greater volumes of cool fluids (Hubbard *et al.*, 1984). The low fluid intakes observed in the present study may be a consequence of a reduced sensation of thirst while training in the cold, even though the extent of dehydration incurred was the same. Alternatively, they may simply reflect a reluctance to ingest cold fluids in cold weather. As with other playing squads where similar measurements have been made, there was no apparent relationship between the amount of sweat lost and the volume of fluid consumed ($r^2 = 0.013$; Fig. 1).

Several studies in the last few years have looked at effects of carbohydrate and/or fluid ingestion during exercise on aspects of skilled task performance. The major challenge to this type of study is the difficulty in

finding a relevant skilled task that can be performed with sufficient reliability to allow the effects of the intervention to be measured. Such tasks can only be performed with an acceptable degree of reliability when well-trained and skilful performers are used as participants, and access to such individuals is limited. Williams and colleagues at Loughborough University have shown that 90 min of running in the Loughborough Intermittent Shuttle-run Test leads to a reduction in soccer skill performance and mental concentration, and the ingestion of carbohydrates can reduce the decrement that occurs (Nicholas *et al.*, 1995, 1999; McGregor *et al.*, 1999). Vergauwen *et al.* (1998) showed that carbohydrate ($0.7 \text{ g} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ of an unspecified carbohydrate) ingestion during a 2 h strenuous training session prevented the deterioration in performance of a variety of tennis-specific skills that was observed to occur when a carbohydrate-free placebo drink was consumed.

It is important to note, however, that these studies were conducted in a warmer environment than that of the present study and it is not certain that similar responses would be observed in a cool environment. It is also likely that at least part of this effect can be attributed to the provision of an exogenous carbohydrate fuel source rather than to the provision of water. There are separate and additive effects of providing carbohydrate and water on exercise performance (Below *et al.*, 1995) and it is likely that similar considerations apply to the performance of skilled tasks.

It is not at present altogether clear what recommendations can usefully be made with regard to fluid intake for football players during training and competition. The aim should be to minimize any risk to health through dehydration and hyperthermia while maximizing performance. There is clearly a low risk of heat illness during football training in a cold environment, so the focus should be on performance issues. Given the variation in fluid and electrolyte loss between individuals and in different situations, and given also the

varying needs for rehydration and carbohydrate provision, there is unlikely to be a single set of simple guidelines that will meet the needs of all individuals in all situations. In 2000, the National Athletic Trainers Association published a position statement which suggested that fluid replacement should approximate sweat and urine losses and should aim to ensure that the body mass lost does not exceed about 2% of the pre-exercise body mass (Casa, 2000). More recently, Coyle (2004) has argued that the tolerable level of dehydration will depend on a number of variables, including the environmental conditions, the exercise duration and intensity, and the aerobic fitness and state of heat acclimation of the individual. From his review of the literature, Coyle concluded that dehydration of 1–2% may be tolerable in temperate environments and losses in excess of 2% of body mass may be tolerable in cold environments. This is not an entirely new idea, having previously been proposed, although perhaps less precisely, by Sawka and Montain (2000). At a much earlier date, Adolph *et al.* (1948) also suggested that complete replacement of fluid losses was not essential and that greater levels of dehydration were acceptable when the thermal environment was less challenging. It is important to recognize, though, that a loss of fluid equal to 1–2% of pre-exercise body mass may not be well tolerated by the athlete who begins exercise in a hypohydrated state.

The present results suggest that sweat losses may be substantial in football players training in a cool environment. We might speculate that adjustments in clothing, and perhaps also in activity levels, mean that the total sweat and electrolyte losses may be similar to those experienced when training in the heat. Nonetheless, there remains a substantial individual variability in sweating rate that is not easily accounted for. Fluid intake appears to be less in this group of players training in the cold than in other groups training in the heat. However, in spite of the significant body water deficits incurred by some players, it is not clear that a recommendation to increase fluid intake to reduce the extent of dehydration incurred would have any beneficial effect on the players in the present study.

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