S. M. Shirreffs[1]
L. F. Aragon-Vargas[2,3]
M. Chamorro[4]
R. J. Maughan[1]
L. Serratosa[4]
J. J. Zachwieja[2]

The Sweating Response of Elite Professional Soccer Players to Training in the Heat

Abstract

Sweat rate and sweat composition vary extensively between individuals, and quantification of these losses has a role to play in the individualisation of a hydration strategy to optimise training and competitive performance. Data were collected from 26 male professional football (soccer) players during one 90 min pre-season training session. This was the 2nd training session of the day, carried out between 19.30 and 21.00 h when the mean ± SD environment was 32 ± 3 °C, 20 ± 5 %rh and WBGT 22 ± 2 °C. Training consisted of interval running and 6-a-side games during which the average heart rate was 136 ± 7 bpm with a maximum rate of 178 ± 7 bpm (n = 19). Before and after training all players were weighed nude. During training all players had free access to sports drinks (Gatorade®) and mineral water (Solan de Cabras®). All drink bottles were weighed before and after training. Players were instructed to drink only from their own bottles and not to spit out any drink. No player urinated during the training session. Sweat was collected by patches from the chest, arm, back, and thigh of a subgroup of 7 players. These remained in place for the first 15 – 30 min of the training session, and sweat was analysed for sodium (Na^+) and potassium (K^+) concentration. Body mass loss was 1.23 ± 0.50 kg (ranging from 0.50 to 2.55 kg), equivalent to dehydration of 1.59 ± 0.61 % of pre-training body mass. The sweat volume lost was 2193 ± 365 ml (1672 to 3138 ml), but only 972 ± 335 ml (239 to 1724 ml) of fluid was consumed. 45 ± 16 % of the sweat volume loss was replaced, but this ranged from 9 % to 73 %. The Na^+ concentration of the subgroup's sweat was 30.2 ± 18.8 mmol/l (15.5 to 66.3 mmol/l) and Na^+ losses averaged 67 ± 37 mmol (26 to 129 mmol). The K^+ concentration of the sweat was 3.58 ± 0.56 mmol/l (2.96 to 4.50 mmol/l) and K^+ losses averaged 8 ± 2 mmol (5 to 12 mmol). The drinking employed by these players meant that only 23 ± 21 % of the sweat Na^+ losses were replaced: This ranged from replacing virtually none (when water was the only drink) to replacing 62 % when the sports drink was consumed. These elite soccer players did not drink sufficient volume to replace their sweat loss. This, however, is in accord with data in the literature from other levels of soccer players and athletes in other events. These measurements allow for an individualisation of the club's hydration strategy.

Key words
Drinking · hydration · soccer · sweat rate · sweat composition

Introduction

At the highest level, soccer is an endurance sport played by trained athletes. The average power output is reported to be about around 70 % of $\dot{V}O_{2max}$ [4], although Reilly [29] reported mean values of about 75 % of $\dot{V}O_{2max}$. Players at senior level typically cover about 8 – 12 km in the course of a game [30]. There is, however, a large variability depending on playing position, on the level of play, and on the tactics employed as well as a large inter-individual variability [25].

Affiliation
[1] Loughborough University, UK
[2] Gatorade Sports Science Institute, Barrington, USA
[3] University of Costa Rica, Costa Rica
[4] Real Madrid Football Club, Spain

Correspondence
S. M. Shirreffs · School of Sport and Exercise Sciences, Loughborough University · Leicestershire LE11 3TU · United Kingdom · Phone: 44 15 09 22 63 32 · Fax: + 44 15 09 22 63 01 · E-mail: s.shirreffs@lboro.ac.uk

Accepted after revision: April 25, 2004

Bibliography
Int J Sports Med 2005; 26: 90 – 95 © Georg Thieme Verlag KG · Stuttgart · New York ·
DOI 10.1055/s-2004-821112 · Published online September 10, 2004 ·
ISSN 0172-4622

This activity is associated with a high level of metabolic heat production, as about 80% of the energy used appears as heat. On a hot day, when the ambient temperature is higher than skin temperature, heat is also gained from the environment, adding to the body's heat load. At high ambient temperatures, the only mechanism by which heat can be lost from the body is evaporation of water from the skin surface. This allows body temperature to be maintained, but results in dehydration and electrolyte loss. Evaporation of sweat secreted onto the skin helps to limit the rise in core temperature, but core temperature during match play typically reaches 39 – 40 °C [22]. Severe heat stress seems to be unusual in soccer, but in a single youth soccer tournament played in hot conditions in the USA, a total of 34 players were treated for heat illnesses as a consequence of heat exhaustion [15]. Post-match rectal temperatures in excess of 39 °C are common: in an unpublished report of a Swedish first division match quoted by Bangsbo [3], all players had a rectal temperature in excess of 39 °C at the end of the game. Some individual values in excess of 40 °C have been recorded [10, 32], and such high values must be a cause for concern. In the cooler conditions that are more commonly experienced in the winter game in Europe, some elevation of body temperature is normal, although in extremely cold conditions, hypothermia is also a potential problem.

Only a limited amount of information is available on the mass (sweat) loss of soccer players during competition. Ekblom [10] has reported a mass loss of 1 – 2.5 kg during games played in temperate climates, with the loss being greater in international level games and less in players performing at a lower standard. A body mass loss of 1.0 kg (1.4% of the pre-exercise body mass) was reported by Leatt [16] in a study where players consumed 1 litre of fluid during the game, indicating a total sweat loss of close to 2 litres. Much larger losses were reported by Mustafa and Mahmoud [26] to occur in some international level players playing in hot conditions. In games played in the heat, losses of almost 4 l were observed in some individual players, although the mean loss was 2.0 – 2.5 l: when players performed in cooler (13 °C) conditions, a much smaller mean sweat loss of 0.85 l was reported. Sweat losses of up to 3.5 l in some individuals were also reported by Bangsbo [3]. It is likely that such losses would seriously impair both physical and cognitive performance.

There is little published information available as to any relationship between the losses during training and those incurred during match play [5]. This is clearly going to be influenced by the type and duration of the training session in comparison to the 90 min match. Many clubs monitor sweat losses of players to establish guidelines for fluid replacement, but these data are not normally published. In pre-season training, it is common for players to complete two training sessions per day, often with incomplete recovery between sessions, and the dangers of dehydration and hyperthermia may be greater than in match play.

As well as a loss of water in sweat, a number of electrolytes and trace minerals are lost. The solute content of sweat is influenced by a number of factors, including the sweating rate and the acclimation status of the individual. Notwithstanding the large inter-individual variability, the main electrolyte present in sweat is sodium, which is also the most abundant electrolyte in the extracellular space. Literature values for sweat sodium concentration are typically about 20 – 80 mmol/l, compared with a plasma concentration of about 140 mmol/l [23]. Sweat potassium concentration is typically about 4 – 8 mmol/l, which is relatively high compared with the plasma concentration, but low relative to the concentration of potassium in the intracellular space [23]. Acute replacement of electrolyte losses during exercise is not normally a priority, except when exercise is very prolonged and sweat losses are high, as may happen in the slower competitors in ultramarathon or triathlon competition [28]. When very large volumes of sodium-free fluid are ingested, there may be a fall in the plasma sodium concentration with adverse consequences [11], but this situation is unlikely to arise during soccer training or competition.

A variety of guidelines is used to provide advice for sports people on the replacement of their sweat losses before, during and after exercise in different environmental conditions. An example is the American College of Sports Medicine's Position Stand on Exercise and Fluid Replacement [1]. These guidelines are, however, of limited use to practitioners who face the task of providing advice to individuals. One recommendation is to drink 150 – 350 ml every 15 – 20 minutes during exercise [1]: this would translate to a fluid consumption of about 600 ml over the course of a 90 min training session at the most conservative rate of drinking, but almost 2 litres at the highest rate.

These general guidelines have an important role to play in allowing sports people to exercise safely and optimally, but there are clearly situations when an individualisation of the advice given is preferable or indeed necessary. The present study was undertaken to assess individual sweat and solute loss during a training session and to establish the drinking patterns of these players during that same training session.

Methods and Materials

Subjects

Twenty-six male soccer players gave written informed consent to participate in this study, after the details of the study had been explained to them. The study was approved by the Research Ethics Committee of Loughborough University. The players comprised the entire first team squad of a successful professional club and included 17 current international players representing 7 different countries. Twenty-three of the 26 subjects were outfield players, the other three being goalkeepers. Physical characteristics (mean ± SD) of the players were: age 26 ± 4 y, height 181 ± 5 cm, body mass 77 ± 5 kg.

All data were collected during a single 90 min pre-season training session. This was the second training session of the day for these players and it was carried out between 19.30 and 21.00 h when the mean environmental conditions were 32 ± 3 °C ambient temperature, 20 ± 5% relative humidity and WBGT 22 ± 2 °C. The first training session was completed between 9.30 am and 11 am, so players had approximately 8.5 hours to recover between sessions, during which they had unrestricted access to food and fluids. Training consisted of a warm-up, interval running and 6-a-side games followed by a warm-down. The total duration of the training session was approximately 90 min, and all outfield players followed the same training program. The three goalkeepers trained separately for part of the session. Heart rate was monitored throughout the training session on 19 of the 26 players using Polar heart rate monitors (Polar Electro Ibérica S.A., Barcelona, Spain).

Before and after training all players were weighed nude. Players were asked to micturate and defecate if necessary prior to the pre-exercise measurement. During the training session all players had free access to two flavours of the same commercially-available sports drink (Gatorade®) and also to bottled mineral water (Solan de Cabras® mineral water). Regular breaks were scheduled to allow players to consume fluids, according to the normal practice of these players when training in these conditions. The drinks provided were those that are normally available to the players during training and competition. The composition of the sports drink and mineral water are shown in Table **1**.

Each player was provided with three individually numbered drinks bottles. All drink bottles were weighed before and after training in order to establish the volume of each consumed during the training session. The players were instructed to drink only from their own numbered bottles and not to spit out any drink. Additional water was provided for players to rinse their mouth without swallowing or to cool their head and face if desired. Drinking behaviour was monitored by observers to ensure that players used only the correct bottles and that no fluid was discarded by the players.

Separate drinks bottles were provided for each player immediately after the training, as the players were leaving the field, in order that the drinks consumed after training could be determined in isolation from those consumed during training itself. Again, all drink bottles were weighed before training and after the players had been reweighed in order to establish the volume of each of the drinks consumed after the training session. The players were given the same instructions as had been in place during training namely to drink only from their own numbered bottles and not to spit out any drink.

Sweat samples were collected during the training session from a randomly selected subgroup of 7 players. Duplicate samples were collected from each of four skin sites (chest, forearm, back and thigh) by absorbent sweat patches applied to the skin surface (Sudormed Inc, CA, USA). The patches were positioned prior to the start of the training session and remained in place for the first 15 – 30 min of the training session. All patches were placed on the right hand side of the body after appropriate cleaning and preparation of the skin site. The sweat collected was analysed for sodium (Na^+) and potassium (K^+) concentration by flame photometry (Corning, 410 C). Prior to analysis, the volume of sweat collected in each patch was determined gravimetrically, by weighing the storage tube, patch and sweat and subtracting the mass of the preweighed patch and storage tube. The sweat was then diluted with deionised water, and after mixing, the electrolyte content was determined.

Statistical analysis
Data were tested for normality of distribution and are presented as mean ± SD, with the range of data given in parentheses. The significance of the measured changes during training was assessed using a paired *t*-test. The composition of the sweat collected from the 4 different sites was compared by one-way analysis of variance.

Table **1** Composition of the sports drink and mineral water

	Sports drink	*Mineral water*
Sodium concentration (mmol/l)	18	2.3
Potassium concentration (mmol/l)	3	0.3
Chloride concentration (mmol/l)	11	2.2
Carbohydrate concentration (%)	6	0

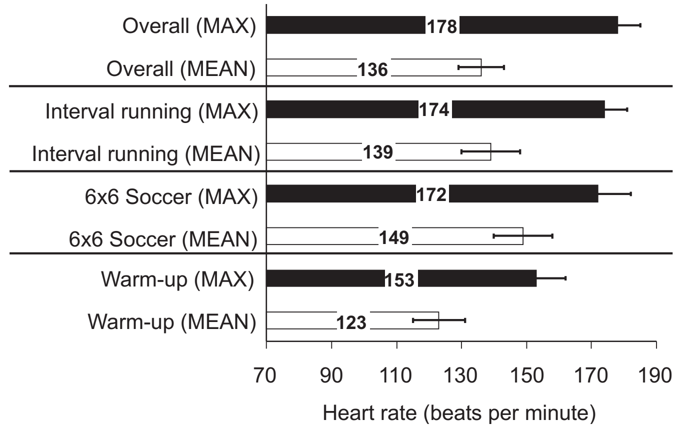

Fig. **1** The average heart rate (MEAN) and average peak heart rate (MAX) for 3 different phases of the training session (warm-up, 6 × 6 soccer, interval running) and for over the whole training session (Overall).

Results

The training session was of a moderate to high intensity: the average heart rate for the whole duration of the session, including short rests and drinking breaks, was 136 ± 7 bpm with a mean maximum rate of 178 ± 7 bpm (n = 19). The mean and maximum heart rates recorded during the six-a-side practice matches were not different from those recorded during the interval running (Fig. **1**).

There was a significant (p = 0.000) body mass loss over the training session of 1.23 ± 0.50 kg (ranging from 0.50 to 2.55 kg). This is equivalent to a level of dehydration of 1.59 ± 0.61 % of the pre-training body mass, ranging from 0.71 to 3.16% dehydration.

No player urinated during the training session, so the calculated sweat volume lost was 2193 ± 365 ml (1672 to 3138 ml). The calculated mean sweat rate was 1.46 ± 0.24 (1.12 – 2.09) l/h. However, a mean of only 972 ± 335 ml (239 to 1724 ml) of fluid was consumed during the training session. On average only 45 ± 16 % of the sweat volume loss was replaced during training, but this ranged from only 9 % to 73 %. Additionally, there was no relationship ($p = 0.96$) between the sweat volume lost and the drink volume consumed during training (Fig. **2**). This mean drink intake was largely from the sports drinks which were consumed by all but 2 of the players. Water was consumed by 19 players, the mean volume consumed being 324 ± 312 ml; orange flavoured sports drink was consumed by 17 players, with the mean intake being 658 ± 367 ml; lemon-lime flavoured sports drink was consumed by 14 players, with a mean intake of 589 ± 327 ml. Fluid balance summary data are shown in Table **2**. These calculations are based solely on body mass changes and on the measured fluid intake. Water loss due to respiration has been ignored and will be included as sweat loss, and loss of mass due to substrate has also been ignored.

Fluid intake immediately after training but before the measurement of post-exercise body mass was assessed and recorded separately. Ten players consumed drinks before leaving the training field and reaching the changing room where mass was measured, and the average fluid intake was 476 ± 250 ml ranging from only 94 to 774 ml. However, there was no relationship between the drink volume consumed during training, the sweat volume lost during training, or the dehydration that occurred during training and the post-training drinking practices.

The Na^+ concentration of sweat in the sub-group of players in which it was measured was 30.2 ± 18.8 mmol/l (15.5 to 66.3 mmol/l) and Na^+ losses averaged 67 ± 37 mmol (26 to 129 mmol). The sweat K^+ concentration was 3.58 ± 0.56 mmol/l (2.96 to 4.50 mmol/l) and K^+ losses averaged 8 ± 2 mmol (5 to 12 mmol). There was no difference in the Na^+ ($p = 0.535$) or K^+ ($p = 0.301$) concentration of the sweat collected at each site. as determined by one-way analysis of variance. The fluid ingested by these players provided an average of 11 ± 8 mmol (0 to 21 mmol) Na^+ over the training session. This is equivalent to 23 ± 21 % of the sweat Na^+ losses being replaced. This ranged from replacing none (0.1 ± 0.1 mmol, 0.4 %), when water was the only drink, to replacing 62 % when the sports drink was consumed. This sub-group of players lost 2242 ± 455 (1672 to 3138) ml of sweat and replaced this during training with 944 ± 213 (658 to 1153) ml of fluid. This is equivalent to a level of dehydration of 1.72 ± 0.77 % of the pre-training body mass, ranging from 0.99 to 3.16 % dehydration. Sweat composition summary data are shown in Table **3**.

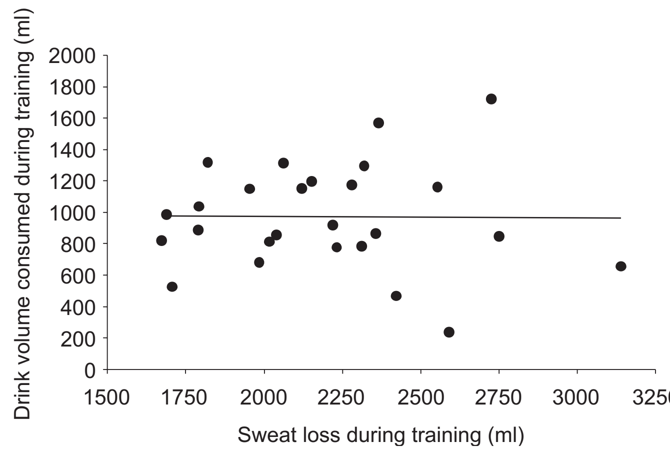

Fig. **2** The relationship between the volume of sweat lost and the volume of drink consumed during training was not significant ($p = 0.96$).

Table **2** Fluid balance summary data

Mean mass loss = 1.23 ± 0.50 (0.50 – 2.55) kg	Mean drink intake = 972 ± 335 (239 – 1724) ml
Dehydration = 1.59 ± 0.61 (0.71 – 3.16) %	– 324 ± 312 ml mineral water (n = 19)
Mean sweat loss = 2.19 ± 0.37 (1.67 – 3.14) l	– 658 ± 367 ml orange sports drink (n = 17)
Mean sweat rate = 1.46 ± 0.24 (1.12 – 2.09) l/h	– 589 ± 327 ml lemon-lime sports drink (n = 14)

24 of the 26 players drank the sports drink

Table **3** Sweat electrolyte loss and replacement summary data. Values are mean ± SD and range

	Sodium	***Potassium***
Sweat electrolyte content (mmol/l)	30.2 ± 18.8 15.5 to 66.3	3.58 ± 0.56 2.96 to 4.50
Total electrolyte loss (mmol)	67 ± 37 26 to 129	8 ± 2 5 to 12
Electrolyte replacement (mmol)	11 ± 8 0 to 21	3.1 ± 2.1 0 to 5.8
Electrolyte replacement (% of loss)	23 ± 2 0 to 62	41 ± 26 0 to 68

Discussion

The soccer players who took part in this study were all elite professional players taking part in a typical pre-season training session. Although the training session took place in the evening, the warm environmental conditions together with the intensity of training were sufficient to stimulate significant sweating. All players experienced a reduction in body mass over the course of the training session which is in accord with data in the literature from other levels of soccer players and athletes in other events [6]. However, a key finding of this study is the considerable variation in the sweating responses and drinking behaviour in the training session (Figs. **2** and **3**). These responses were not related to player position, nor were they related to the individual heart rates during training, but rather seem to reflect individual variations in the player physiology. All players were accustomed to training and playing in the heat, and there were no major differences between players in their heat exposure in the weeks prior to the study.

The level of dehydration in these players at the end of the training session ranged from 0.7 % to 3.2 % of the pre-training body mass (Fig. **3**). If, as seems likely, players had failed to completely replace the water and solute losses incurred during the morning training session, the cumulative fluid deficit would have been greater than this. At the highest measured levels of hypohydration, there is little doubt that performance would be reduced [27] and the risk of heat illness substantially increased [9]. Soc-

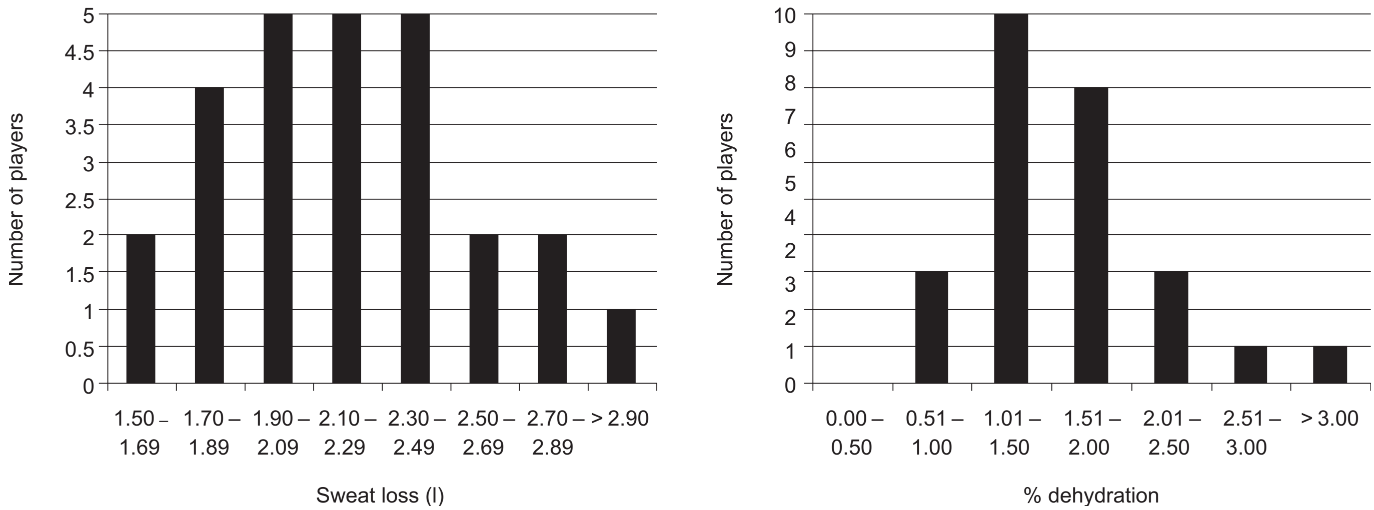

Fig. **3** The distribution of sweat loss during training and % dehydration at the end of training amongst the 26 players.

cer performance is difficult to quantify, but running and cycling studies have shown that both sprint and endurance exercise performance are adversely affected by dehydration [2, 27]. Players in multiple sprint sports such as soccer are therefore particularly likely to be affected by sweat loss. Even low levels of dehydration (about 1% of body mass) are sufficient to impair exercise performance [24]. The present data therefore suggest that some of these players are either losing only small amounts of sweat or are consuming sufficient fluid in training to limit the extent of dehydration that takes place. Others, however, might usefully be encouraged to increase their fluid intake.

The sweat sodium concentrations in the players tested were within the normal range [31], but these resulted in a large range of sweat sodium loss (ranging from 26 up to 129 mmol). Although the mineral water contains small amounts of sodium, only a tiny fraction of even the smallest sodium losses can be replaced by its sole consumption. Therefore, when sodium replacement is a concern, a sports drink is a better choice of fluid to consume in comparison to mineral water.

Cognitive performance, which is an important aspect of games such as soccer, is also impaired when severe dehydration and hyperthermia are present, but there is limited information available on the effects of more modest levels of fluid loss. However, Gopinathan and colleagues [13] showed that performance in a variety of tests of cognitive function was adversely affected when the level of dehydration, which was induced by exercise in the heat, reached 2% of the initial body mass.

Impairment of performance in a soccer-specific skill has been shown to occur at levels of hypohydration equivalent to 2.4% of body mass, while fluid ingestion sufficient to maintain a hypohydration at only 1.4% of body mass has been shown to attenuate this performance decrement [19]. Ingestion of a sports drink during a basketball training session at a rate that replaced about 50% of the mass loss on a no-drink trial (where a 2.9 ± 0.5% loss was incurred) has recently been shown to be effective in preserving free throw scoring performance [33]: ingestion of plain water was not effective. Similarly, Devlin and colleagues [8] studied cricket bowling speed and accuracy before and after 1 h of intermittent exercise with (0.5% body mass loss) or without (2.8% body mass loss) fluid replacement. While dehydration did not affect bowling speed, it had an adverse effect on accuracy of the bowl.

The decrease in blood volume which results when sweat losses are large may be a factor in the reduced work capacity: blood flow to the muscles must be maintained at a high level to supply oxygen and substrates, but a high blood flow to the skin is also necessary to convect heat to the body surface. When there is a high heat stress, and blood volume has been decreased by sweat loss during prolonged exercise, there may be difficulty in meeting the requirement for a high blood flow to both these tissues [7]. In this situation, skin blood flow is likely to be compromised, allowing central venous pressure to be maintained with only small reductions in muscle blood flow, but reducing heat loss and causing body temperature to rise. Elevated core temperatures will also contribute to fatigue [12] and dehydration is associated with an elevation of core temperature.

The player who became dehydrated by 3.2% over the training session was by far the heaviest sweater of the squad, losing 3.1 l of sweat over the 90 min, equivalent to an average sweat rate over the 90 min training session of 2.1 l/h. However, he drank less than 700 ml during training which was significantly less than many other players in the squad during the same training session. This suggests that some of his dehydration was voluntary, rather than due to limited opportunities to drink during the training session. An adequate fluid intake before, during and after exercise can help to avoid the negative effects of dehydration, but even where awareness exists, appropriate behaviour does not always follow. Jonnalagadda et al. [14] reported that 90% of their sample of collegiate American football players recognised the importance of maintaining hydration status, but the casualty statistics suggest that even top professional players do not put this into practice.

Replacement of water and salt losses incurred is only one of the nutritional objectives of the player during training or match play. The adverse effects of fatigue on performance can also be delayed or reduced by ingestion of carbohydrate to supplement the body's limited endogenous stores. There are good reasons, therefore, to recommend that players should ingest carbohydrate-containing drinks rather than plain water during exercise. The rates at which substrate and water can be supplied during exercise are limited by the rates of gastric emptying and intestinal absorption. It is not clear which of these processes is limiting, but it is commonly assumed that the rate of gastric emptying will determine the maximum rates of fluid and substrate availability. Many factors, including exercise, affect the rate of gastric emptying and this may become a primary limitation to the ability to replace fluids [21]. High intensity exercise (above about 70 – 75% of maximum oxygen uptake) results in a slowing of emptying, but exercise at lower intensities has no effect [20]. In studies designed to simulate the exercise pattern in soccer, where there are frequent short bursts of activity at very high intensities, it has more recently been shown that there is some slowing of the gastric emptying rate, which may limit the amount of fluid that can be replaced [17,18]. The intake of these players may therefore have been limited to avoid the discomfort associated with accumulation of fluid in the gastrointestinal tract. The solution to the problem of high fluid losses may not be as simple as just suggesting an increased fluid intake.

Conclusion

It is clear that, on average, these elite soccer players did not drink sufficient fluid during their training session to replace their sweat losses and several players incurred substantial fluid deficits. The mean values, however, hide the large inter-individual differences in both the sweating response and drinking practices of the players. These measurements allow the soccer club to individualise the advice and support it gives to players with respect to a hydration strategy to minimise reductions in match performance and training quality.

Acknowledgements

This study was supported in part by a research grant from the Gatorade Sports Science Institute®. The co-operation of the playing and support staff involved in the training session described in this study is gratefully acknowledged.

References

1 American College of Sports Medicine. Position stand on exercise and fluid replacement. Med Sci Sports Exerc 1996; 28: i – vii

2 Armstrong LE, Costill DL, Fink WJ. Influence of diuretic-induced dehydration on competitive running performance. Med Sci Sports Exerc 1985; 17: 456 – 461

3 Bangsbo J. The Physiology of Soccer – With Special Reference to Intense Intermittent Exercise. Copenhagen: University of Copenhagen, 1993

4 Bangsbo J. Energy demands in competitive soccer. J Sports Sci 1994; 12: 5 – 12

5 Broad EM, Burke LM, Cox GR, Heeley P, Riley M. Body weight changes and voluntary fluid intakes during training and competition sessions in team sports. Int J Sport Nutr 1996; 6: 307 – 320

6 Burke LM, Hawley JA. Fluid balance in team sports: Guidelines for optimal practices. Sports Med 1997; 24: 38 – 54

7 Coyle EF, Gonzalez-Alonso J. Cardiovascular drift during prolonged exercise: new perspectives. Exerc Sport Sci Rev. 2001; 29: 88 – 92

8 Devlin LH, Fraser SF, Barras NF, Hawley JH. Moderate levels of hypohydration impair bowling accuracy but not bowling velocity in skilled cricket players. J Sci Med Sport 2001; 4: 179 – 187

9 Eichner ER. Treatment of suspected heat illness. Int J Sports Med 1998; 19: 150 – 153

10 Ekblom B. Applied physiology of soccer. Sports Med 1986; 3: 50 – 60

11 Flear CTG, Gill CV, Burn J. Beer drinking and hyponatraemia. Lancet 1981; 2: 477

12 Gonzalez-Alonso J, Teller C, Andersen SL, Jensen FB, Hyldig T, Nielsen B. Influence of body temperature on the development of fatigue during prolonged exercise in the heat. J Appl Physiol 1999; 86: 1032 – 1039

13 Gopinathan PM, Pichan G, Sharma VN. Role of dehydration in heat stress-induced variations in mental performance. Arch Environ Health 1988; 43: 15 – 17

14 Jonnalagadda SS, Rosenbloom CA, Skinner R. Dietary practices, attitudes and physiological status of collegiate freshman football players. J Strength Condit Res 2001; 15: 507 – 513

15 Kirkendall DT. Effects of nutrition on performance in soccer. Med Sci Sports Exerc 1993; 25: 1370 – 1374

16 Leatt P. The Effect of Glucose Polymer Ingestion on Skeletal Muscle Glycogen Depletion During Soccer Match Play and its Resynthesis Following a Match. University of Toronto: MSc Thesis, 1986

17 Leiper JB, Broad NP, Maughan RJ. The effect of intermittent high intensity exercise on gastric emptying in man. Med Sci Sports Exerc 2001; 33: 1270 – 1278

18 Leiper JB, Prentice AS, Wrightson C, Maughan RJ. Gastric emptying of a carbohydrate-electrolyte drink during a soccer match. Med Sci Sports Exerc 2001; 33: 1932 – 1938

19 McGregor SJ, Nicholas CW, Lakomy HKA, Williams C. The influence of intermittent high-intensity shuttle running and fluid ingestion on the performance of a soccer skill. J Sports Sci 1997; 17: 895 – 903

20 Maughan RJ. Effects of CHO-electrolyte solution on prolonged exercise. In: Lamb DR, Williams MH (eds). Perspectives in Exercise Science and Sports Medicine. Carmel: Benchmark Press, 1992: 35 – 85

21 Maughan RJ. Water and electrolyte loss and replacement in exercise. In: Maughan RJ (ed). Nutrition in Sport. Oxford: Blackwell, 2000: 226 – 240

22 Maughan RJ, Leiper LB. Fluid replacement requirements in soccer. J Sports Sci 1994; 12: 29 – 34

23 Maughan RJ, Shirreffs SM. Fluid and electrolyte loss and replacement in exercise. In: Harries M, Williams C, Stanish WD, Micheli LL (eds). Oxford Textbook of Sports Medicine. 2nd Ed. New York: Oxford University Press, 1998: 97 – 113

24 Maughan RJ, Leiper JB, Shirreffs SM. Fluids and electrolytes during exercise. In: Garrett WE (ed). Textbook of Sports Medicine. Baltimore: Williams and Wilkins, 2000: 413 – 424

25 Mohr M, Krustrup P, Bangsbo J. Match performance of high-standard soccer players with special reference to development of fatigue. J Sports Sci 2003; 21: 519 – 528

26 Mustafa KY, Mahmoud NEA. Evaporative water loss in African soccer players. J Sports Med Phys Fitn 1979; 19: 181 – 183

27 Nielsen B, Kubica R, Bonnesen A, Rasmussen I, Stoklosa J, Wilk B. Physical work capacity after dehydration and hypethermia: a comparison of the effect of exercise versus passive heating and sauna and diuretic dehydration. Scand J Sports Sci 1981; 3: 2 – 10

28 Noakes TD, Goodwin N, Rayner BL, Branken T, Taylor RKN. Water intoxication: a possible complication during endurance exercise. Med Sci Sports Exerc 1985; 17: 370 – 375

29 Reilly T. Football. In: Reilly T, Secher N, Snell P, Williams C (eds). Physiology of Sports. London: E and FN Spon, 1990: 371 – 426

30 Shephard RJ. Biology and medicine of soccer: An update. J Sport Sci 1999; 17: 757 – 786

31 Shirreffs SM, Maughan RJ. Whole body sweat collection in man: an improved method with some preliminary data on electrolyte content. J Appl Physiol 1997; 82: 336 – 371

32 Smodlaka VJ. Cardiovascular aspects of soccer. The Physician and Sportsmedicine 1978; 18: 66 – 70

33 Solera A, Salazar W. Influence of dehydration and rehydration on basketball free throw accuracy. Med Sci Sports Exerc 2003; 35s: 29