Fluid and Electrolyte Intake and Loss in Elite Soccer Players During Training

R.J. Maughan, S.J. Merson, N.P. Broad, and S.M. Shirreffs

This study measured fluid balance during a 90-min preseason training session in the first team squad (24 players) of an English Premier League football team. Sweat loss was assessed from changes in body mass after correction for ingested fluids and urine passed. Sweat composition was measured by collection from patches attached to the skin at 4 sites. The weather was warm (24–29 °C), with moderate humidity (46–64%). The mean ± SD body mass loss over the training session was 1.10 ± 0.43 kg, equivalent to a level of dehydration of 1.37 ± 0.54% of the pre-training body mass. Mean fluid intake was 971 ± 303 ml. Estimated total mean sweat loss was 2033 ± 413 ml. Mean sweat electrolyte concentrations (mmol/L) were: sodium, 49 ± 12; potassium, 6.0 ± 1.3; chloride, 43 ± 10. Total sweat sodium loss of 99 ± 24 mmol corresponds to a salt (sodium chloride) loss of 5.8 ± 1.4 g. Mean urine osmolality measured on pre-training samples provided by the players was 666 ± 311 mosmol/kg (n = 21). These data indicate that sweat losses of water and solute in football players in training can be substantial but vary greatly between players even with the same exercise and environmental conditions. Voluntary fluid intake also shows wide inter-individual variability and is generally insufficient to match fluid losses.

Key Words: football, soccer, dehydration, sweating, electrolytes

Introduction

Loss of body water and the associated electrolytes can impair cardiovascular and thermoregulatory function and, if the losses are of sufficient magnitude, exercise performance is also impaired (35). Dehydration in exercise results from the need to maintain body temperature close to the normal resting value of about 37 °C. During exercise, the rate of heat production is increased above the resting level, and heat loss must increase correspondingly. 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.
Football (soccer) is an activity characterized by repeated short sprints in an endurance context, where there is a need to maintain skill levels throughout the duration of a game lasting 90 min. The total distance covered by outfield players in the course of a top class game varies considerably but has been estimated to be about 8–13 km, and the mean rate of energy expenditure is about 16 kcal/min, corresponding to an oxygen consumption of about 75% of maximum (4). The demands of training will also vary considerably, depending on the time of the season, the level of competition, and numerous other factors. Preseason training is traditionally the time when the work load is highest, as players seek to achieve match fitness after the summer layoff.

High rates of metabolic heat production are associated with elevation of body temperature and the initiation of sweating. 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-related problems (15). Post-match rectal temperatures in excess of 39 °C are common, reflecting the thermal stress of match play. In an unpublished report of a Swedish first division match quoted by Bangsbo (5), 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 (5), 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.

Athletes in training and competition are at risk of hypohydration, as fluid intake seldom matches fluid loss (8). Many published reports have described sweat losses and drinking behaviors of various groups of athletes in training and in competition. For several sports, there are data for athletes of different competition levels, and measurements have been made under varying environmental conditions. Broad et al. (7) have reported sweat rates of soccer players training in summer (985 ± 320 ml/hr; mean ± SD) and winter (746 ± 249 ml/hr), with intakes being much lower for each (429 ± 312 ml/hr in summer and 311 ± 257 ml/hr in winter). This combination of loss and intake would result in a negative fluid balance of about 500 ml/hr. It is generally accepted that the loss of exercise capacity is apparent when the fluid deficit exceeds about 1% of body mass and that the performance decrement is proportional to the fluid deficit (35). In some, but not all, sports environments, there are opportunities for ingestion of fluids to replace water and salt losses and to act as a vehicle for ingestion of carbohydrate and other nutrients.

Although the normal response to exercise is to incur a fluid deficit, some individuals, in situations where sweat losses may not be high and where there are ample opportunities for drinking, may consume volumes of fluid far in excess of losses (28). Where drinks with a low sodium content are consumed in very large volumes, there is a risk of a dilutional hyponatraemia, with potentially serious consequences (29). In a sport such as soccer, this situation may be more likely to arise in training, where frequent breaks are allowed and drinks are readily available, than in competition, where opportunities for drinking are limited.

When sweat rates are high, significant losses of electrolytes, especially sodium will occur, but both sweating rate and sweat electrolyte content vary greatly between individuals (23). Exercise-induced muscle cramps are often thought to be linked to electrolyte disturbances, especially losses of sodium, but the evidence is not strong (20). However, a recent preliminary report has suggested that American
football players who repeatedly suffer muscle cramping in training and competition have greater sweat losses and a higher sweat sodium content than players matched for fitness and other factors but who do not suffer from muscle cramps (39). There are few published data on sweat electrolyte losses in soccer players in training, although this might be important in identifying those players at risk of potentially debilitating muscle cramps.

The aim of this study was to investigate water and electrolyte losses in a group of elite football players during a single preseason training session and to observe their fluid intakes. A measurement of pre-training hydration status was also made.

**Methods and Materials**

All measurements were made on a single day and involved the first team squad of 24 players from an English Premier League football club during preparations for the 2003–2004 competitive season. The study was approved by the Loughborough University Research Ethics Committee. The measurements to be made were described in detail to all players before they gave their written consent to participate. Physical characteristics of the subjects are shown in Table 1. Measurements were made during a morning training session, which began at 10:45 and finished at approximately 12:15. Ambient conditions during training are shown in Table 2.

**Table 1  Physical Characteristics of Subjects (N = 24)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Subjects</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>27 ± 4</td>
<td>19–32</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.81 ± 0.04</td>
<td>1.70–1.90</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>79.4 ± 4.7</td>
<td>68.9–88.0</td>
</tr>
<tr>
<td>Body Mass Index (kg/m²)</td>
<td>24.3 ± 1.4</td>
<td>20.6–26.8</td>
</tr>
</tbody>
</table>

*Note. Subject values mean ± SD.*

**Table 2  Ambient Conditions During the Training Session**

<table>
<thead>
<tr>
<th>Time</th>
<th>Temperature (°C)</th>
<th>Relative humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:45</td>
<td>24</td>
<td>64</td>
</tr>
<tr>
<td>11:15</td>
<td>25</td>
<td>53</td>
</tr>
<tr>
<td>11:45</td>
<td>26</td>
<td>56</td>
</tr>
<tr>
<td>12:15</td>
<td>29</td>
<td>55</td>
</tr>
<tr>
<td>12:45</td>
<td>29</td>
<td>46</td>
</tr>
</tbody>
</table>
On arrival at the training ground, subjects were instructed to empty their bladders as completely as possible. A sample of this void was retained for subsequent measurement of osmolality, which was used as an index of hydration status. Nude body mass was measured using a digital electronic scale readable to 0.02 kg. Subjects then sat while absorbent patches for sweat collection (3M, Loughborough, UK) were applied to four skin sites (forearm, chest, back, thigh). The skin was thoroughly cleaned with distilled, de-ionized water and dried before the patches were applied.

The players were instructed to consume no food and to drink only from the bottles provided from the time of the initial body mass measurement until the measurement period was completed. All players were under constant observation during this time to ensure compliance. Each player was provided with one 1-L bottle containing a commercial sports drink (6.4% carbohydrate, 22 mmol/L Na). Bottles were weighed before being provided to the players and again at the end of training to assess fluid intake. All drinks were available within close proximity to the players at all times, and players were encouraged by their coach to drink during breaks between phases of training. Additional bottles were available to players during training if required. Any player who passed urine during training did so into a container so that the volume could be measured.

Training consisted of 18 min of running, stretching, a 6-on-6 game, an incremental shuttle running test (34), and a warm-down. The total duration of the training session was approximately 100 min. All players trained in shirt and shorts, which were freshly laundered to minimize contamination of the sweat collection patches.

At the end of the training period, sweat patches were removed and immediately placed into sealed containers until analyzed. Subjects then toweled dry and were again weighed nude. Sweat loss was calculated from the change in body mass after correction for the mass of ingested fluid and for any urine passed during training. Mass loss due to substrate exchange and to respiratory water loss was ignored, as this would have been a small component of the total mass loss.

The amount of sweat in each patch was determined gravimetrically, and an accurately weighed amount (~2.5 ml) of distilled de-ionized water was added to each of the tubes containing the sweat patch. After thorough mixing, the tube was centrifuged and a sample removed for measurement of sodium and potassium by flame photometry (Corning 410c, Corning Ltd., Essex, UK) and chloride by coulometric titration (Jenway PCLM 3, Jenway, Essex, UK). Urine osmolality was measured by freezing point depression (Roebling Automatik, Camlab, Cambridge, UK) within 36 hr of collection.

**Statistical Analysis**

Data were tested for normality of distribution and are presented as mean ± SD, with the range of data given in parentheses. Correlation analysis was performed by least squares regression. Differences in regional sweat electrolyte concentration were determined by one-way ANOVA and Tukey’s HSD test. The significance level was set at .05. All results are for 24 individuals unless otherwise stated.

**Results**

Summary data for sweat loss and fluid intake are shown in Table 3. The mean body mass loss over the 90-min training session was 1.10 ± 0.43 kg, with a range of values
from 0.38 to 1.98 kg. This is equivalent to a level of dehydration of 1.37 ± 0.54% of the pre-training body mass, ranging from 0.45–2.58% dehydration. Mean fluid intake was 971 ± 303 ml, with a range from 265 to 1661 ml. After correction for fluid intake and for urine output in the 3 players who passed urine, estimated total mean sweat loss was 2033 ± 413 ml, with a range from 1385 to 2382 ml, giving a mean sweat rate of 1355 ± 275 ml/hr. There was no significant relationship between the total volume of sweat lost during training and the volume of fluid consumed (Figure 1).

Sweat electrolyte concentrations at each of the four measurements sites and mean sweat electrolyte concentrations are shown in Table 4. A simple arithmetic average of electrolyte concentrations at the four different sites was used to calculate the average sweat electrolyte content, though some have suggested that differences in composition of sweat collected at different body sites mean that different weightings

Table 3  Loss of Body Mass, in Kilograms and As a Percentage of Initial Body Mass, Fluid Intake, and Sweat Loss in the 24 Players Who Participated in the Present Study

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mass loss (kg)</th>
<th>Mass loss (%)</th>
<th>Fluid intake (ml)</th>
<th>Sweat loss (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>1.10 (0.43)</td>
<td>1.37 (0.54)</td>
<td>971 (303)</td>
<td>2033 (413)</td>
</tr>
<tr>
<td>Range</td>
<td>0.38–1.98</td>
<td>0.45–2.58</td>
<td>265–1661</td>
<td>1385–2832</td>
</tr>
</tbody>
</table>

*Note.* Values are mean ± SD.

Figure 1 — Relationship between the total volume of sweat lost during training and the volume of fluid consumed (n = 24).
should be given to the values from the different sites (31). There was a close association \( R^2 = 0.92 \) between sweat sodium and chloride concentrations, but the sweat potassium concentration was not related to either the sodium \( R^2 = 0.10 \) or chloride \( R^2 = 0.07 \) concentration (Figure 2). Significant \( p < .001 \) regional differences in sweat sodium and chloride concentrations were found: Both sodium and chloride were lower in samples from the thigh than in samples from the chest and back, and lower in samples from the arm than in those from the chest (Table 4). Sweat potassium concentration also differed \( p < .001 \) in samples from the different sites and was lower in samples from the back than in samples from the arm and thigh.

There was no significant relationship between the calculated sweat rate and mean sweat sodium concentration \( R^2 = 0.15 \); sweat potassium concentration \( R^2 = 0.02 \), or sweat chloride concentration \( R^2 = -0.08 \).

Calculated sweat electrolyte losses, based on the sweat rate and the mean sweat electrolyte content indicate large sodium deficits incurred by some players. Mean sweat sodium loss was 99 ± 24 mmol (2.3 ± 0.6 g), with a range of values from 53–133 mmol (1.2 to 3.1 g). This corresponds to a salt (sodium chloride) loss of 5.8 ± 1.4 g (range, 3.1–7.8 g). Although an electrolyte-containing sports drink with a sodium concentration of 22 mmol/L was consumed during the training session, players replaced only 17 ± 5 mmol (range, 5–30 mmol) of sodium.

There was no relationship between either sweat rate \( R^2 = 0.06 \) or sweat sodium content with fitness as determined by shuttle running performance (34).

Table 4 Sweat Electrolyte Content (Mean ± SD; mmol/L) At Each of the Four Sites Where Measurements Were Made and Mean Sweat Electrolyte Concentration

<table>
<thead>
<tr>
<th>Site</th>
<th>Sodium</th>
<th>Potassium</th>
<th>Chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forearm</td>
<td>43 ± 13</td>
<td>6.7 ± 2.0</td>
<td>38 ± 11</td>
</tr>
<tr>
<td>Chest</td>
<td>59 ± 17</td>
<td>5.9 ± 1.4</td>
<td>52 ± 15</td>
</tr>
<tr>
<td>Back</td>
<td>52 ± 16</td>
<td>4.7 ± 1.4</td>
<td>48 ± 15</td>
</tr>
<tr>
<td>Thigh</td>
<td>37 ± 11</td>
<td>6.5 ± 1.7</td>
<td>32 ± 9</td>
</tr>
<tr>
<td>Mean</td>
<td>49 ± 12</td>
<td>6.0 ± 1.3</td>
<td>43 ± 10</td>
</tr>
</tbody>
</table>

Discussion

Players in the present study did not consume sufficient fluid during training to match sweat losses and all players lost weight during the training session. The amounts of weight loss ranged from the insignificant (0.54 kg; 0.65%) to the substantial (1.98 kg; 0.88%)
A small loss in body mass is unlikely to have any detrimental effect on performance in a task such as soccer training or match play, and it might be suggested that fluid deficits of up to 1% of body mass may be tolerated with no adverse effects on performance (8, 23, 29, 35). Encouraging players to consume more fluid than they need to maintain physiological function may be counter-productive. Nonetheless, it is clear from these results that the large inter-individual variability in both sweating rates and drinking behavior means that advice must be targeted at players on an individual basis.

Only a limited amount of information is available on the weight (sweat) loss of soccer players during training and competition against which the present data can be compared. We have recently reported slightly higher sweat losses in players during a similar preseason training session carried out in a warmer (32 ± 3 °C, 20 ±
5% rh) environment (38). In that study of 26 players, 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 of 2193 ± 365 ml (1672 to 3138 ml) was slightly greater than in the present study (2033 ± 413 ml), but the volume of fluid ingested during training was the same in both studies [972 ± 335 ml (239 to 1724 ml) compared to 971 ± 303 ml (265 to 1661 ml)]. The training session in the present study was the first session of the day, while that reported by Shirreffs et al. (38) was the second session of the day.

More information on fluid balance in players in match play is available, and this is summarized in Table 5. In several of these studies, it is not apparent that any assessment of fluid intake was made, so the results may reveal the extent of hypohydration but may underestimate the sweat rates. This is in part due to the problems associated with obtaining accurate data in the field but more especially to the reluctance of managers to allow anything that might distract players. It is also immediately apparent from this table that most of these studies have included rather small numbers of subjects. Ekblom (11) reported a weight loss of 1.0–2.5 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. The number of subjects on which these data were based was not disclosed. A body weight loss of 1.0 kg (1.4% of body weight) was reported by Leatt (16) in a study where 7 players consumed 1 L of fluid during the game, indicating a total sweat loss of close to 2 L. Much larger losses were reported by Mustafa and Mahmoud (26) to occur in 8 international level players playing in hot conditions. In games played in the heat, losses of almost 4 L were observed, 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. Large sweat losses of up to 4.5 L in some individuals were also reported by Bangsbo (4), but details of the experimental conditions were not provided.
<table>
<thead>
<tr>
<th>Ambient temp (°C)</th>
<th>Humidity (%)</th>
<th>n</th>
<th>Sweat loss (%)</th>
<th>Fluid intake (L)</th>
<th>Rectal temp (°C)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<tr>
<td>33</td>
<td>7</td>
<td>2.00</td>
<td>1–2.5</td>
<td>2.80</td>
<td>39.5</td>
<td>11</td>
</tr>
<tr>
<td>26</td>
<td>78</td>
<td>8</td>
<td>1.00</td>
<td>2.09</td>
<td>3.08</td>
<td>16</td>
</tr>
<tr>
<td>13</td>
<td>7*</td>
<td>8</td>
<td>0.66</td>
<td>0.85</td>
<td>1.19</td>
<td>17</td>
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<tr>
<td>20–18</td>
<td>18–20</td>
<td>15</td>
<td>0.24</td>
<td>2.16</td>
<td>1.60</td>
<td>39.2</td>
</tr>
<tr>
<td>23–21</td>
<td>78–85</td>
<td>14</td>
<td>0.75</td>
<td>1.74</td>
<td>1.37</td>
<td>39.2</td>
</tr>
<tr>
<td>22–20</td>
<td>74–82</td>
<td>13</td>
<td>0.00</td>
<td>2.25</td>
<td>1.54</td>
<td>39.2</td>
</tr>
<tr>
<td>27</td>
<td>52</td>
<td>8</td>
<td>0.74</td>
<td>3.19</td>
<td>3.89</td>
<td>39.3</td>
</tr>
<tr>
<td>38</td>
<td>25</td>
<td>6</td>
<td>1.50</td>
<td>3.63</td>
<td>4.61</td>
<td>39.9</td>
</tr>
<tr>
<td>12–15</td>
<td>66–88</td>
<td>23</td>
<td>0.19</td>
<td>1.57</td>
<td>2.03</td>
<td>39.6</td>
</tr>
<tr>
<td>19</td>
<td>55</td>
<td></td>
<td>1.14</td>
<td>1.31</td>
<td>1.70</td>
<td>15</td>
</tr>
</tbody>
</table>

*Note.* The sweat loss shown is the loss calculated from the reduction in body mass after correction for fluid intake; actual body mass reduction can be calculated by subtracting the fluid intake from the calculated sweat loss. Sweat loss is shown as an actual loss and as a percentage reduction in body mass. *The authors describe this as a cold humid environment but indicate a relative humidity of 7%.*
Even low levels of dehydration (1–2% of body mass) may impair exercise performance (22, 35), though there are no reports to suggest that it is necessary to fully replace sweat losses incurred during exercise. These effects have been seen in exercise of short duration and high intensity, where dehydration was induced prior to the beginning of exercise (3, 27). Maxwell et al. (24) also reported that performance of a high intensity intermittent running test was impaired by prior hypohydration. Reductions in exercise performance have also been seen in a variety of endurance exercise models, where sweat losses have not been replaced or only partially replaced during exercise, including both continuous and high intensity intermittent exercise. Cognitive performance, which is an important aspect of games such as football, may also be impaired when dehydration and hyperthermia are present, but there is limited information available. However, Gopinathan et al. (14) 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 weight.

There are a few publications showing deleterious effects of exercise-induced dehydration on a variety of task-specific skills. McGregor et al. (25) showed that performance of a soccer-specific skill decreased by 5% after a 90-min intermittent running task designed to simulate the demands of match play. When flavored water was ingested during the 90 min of running in an amount sufficient to prevent dehydration, performance of the skill test did not deteriorate. In a more recent publication, it was shown that modest levels of dehydration (about 2.7% of initial body mass) resulted in a significant slowing of sprint times in 5-m and 10-m sprints (19). This may be particularly relevant to soccer, as match analysis suggests that, in a typical game, each player will make an average of about 20 sprints, each lasting only 2 s and covering about 10–20 m. Some fast running will take place on average every 60–90 s (5). In a study of the effects of dehydration on cricket bowling, Devlin et al. (10) looked at bowling velocity and bowling accuracy before and after 1 hr of intermittent exercise, where fluid intake was restricted (mean body mass loss of 2.8%) or where fluid was ingested at a rate almost sufficient to match sweat losses (mean body mass loss of 0.5%). There was no effect of dehydration on bowling velocity, but there was a significant loss of line and length in the dehydrated condition.

Football performance is difficult to quantify, but players in multiple sprint sports such as football are therefore likely to be adversely affected by dehydration. Where skill deteriorates, not only will performance suffer, but loss of coordination will increase the risk of injury due to intrinsic or extrinsic factors. The FA Medical Department has shown, in an extensive survey of injuries in competition, involving more than 6000 injuries over two competitive seasons, that the risk of injury increases in the later stages of games, when players are suffering from fatigue and dehydration. Both dehydration and depletion of muscle glycogen may be factors in the fatigue and loss of performance that accompany prolonged intermittent high intensity running, but Abt et al. (1) reported that muscle glycogen depletion did not appear to result in a loss of dribbling and shooting skills in soccer players.

Sweat electrolyte concentration in these players was within the normally reported physiological range of about 20–80 mmol/L for sodium, 4–8 mmol/L for potassium, and 20–60 mmol/L for chloride (36). There was no apparent association between sweat electrolyte concentration and sweating rate, although it has been reported that sweat solute concentration normally increases as the sweat rate increases.
Costill (9) reported an increased concentration of sodium and chloride in sweat content with increased flow. This was attributed to a reduced opportunity for reabsorption in the sweat duct. Verde et al. (40), however, found that the sweat concentration of these ions was unrelated to the sweat flow rate. It must be recognized that the extent of sweat loss, as well as the rate of sweat secretion, is likely to affect the results obtained. The methodology used to collect sweat samples may also influence the results obtained, further complicating comparisons between studies.

The sodium losses of some players were high, reaching 3.1 g, equivalent to 7.8 g of sodium chloride, and it must be remembered that this was the first of two trainings sessions to be carried out on the same day. Similar high salt losses have previously been reported in football players in training in similar environmental conditions (38), with the highest individual value in that study of 129 mmol of sodium (7.5 g of sodium chloride). Bergeron (6) has recently stressed the need for electrolyte replacement in athletes losing substantial amounts of salt but who may be inappropriately restricting salt intake due to concerns over possible adverse effects on blood pressure. It seems unlikely that the large salt losses incurred by some players would be replaced by food and fluid consumed at lunch, so the cumulative salt deficit by the end of the afternoon training session may have been considerably greater than the loss in the morning session alone.

Fluid replacement during both training and competition is recommended to provide carbohydrate, water and electrolytes, but the requirements of individuals for these three different components can vary greatly. The American College of Sports Medicine recommendations for fluid replacement during distance running recognize this inter-individual variation in requirements and set wide limits: Between 100–200 ml every 10–20 min is recommended, corresponding to 300–1200 ml/h, or 450–1800 ml over a 90-min training session (2). Players in the present study consumed between about 500 and 1700 ml, which shows a range of behavior that is not very different from the recommendation. 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 individualization of the advice given is preferable or indeed necessary. This is illustrated by the fact that 3 of the players in this study incurred a fluid deficit of more than 2% of body mass, while 4 of the players were dehydrated by less than 1% of body mass. There was no relationship between sweating rate and the rate of fluid ingestion in these players (Figure 1), suggesting that the players’ perception of the need to replace fluid was not reliable.

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 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 (12). In this situation, skin blood flow is likely to be compromised, allowing central venous pressure and muscle blood flow to be maintained but reducing heat loss and causing body temperature to rise. The values for post-match rectal temperature quoted above indicated that a marked elevation of body temperature is a normal occurrence in competitive football.

Exercise performance can be improved by provision of carbohydrate to supplement liver and muscle glycogen stores, and also by ingestion of water to offset the effects of dehydration. 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 (22). 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 (21). In a study designed to simulate the exercise pattern in football, 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). A subsequent study confirmed this finding, with measurements made during an actual football game (18).

The mean fluid intake of the players in the present study was higher than that commonly reported for athletes during competition in different team sports (8). This may reflect a number of different factors. It was warmer than usual during the training session, where these measurements were made, so both coaching staff and players may have been especially vigilant in encouraging a high fluid intake. The fact that players and the support staff were aware of the measurements being made may also have contributed to a higher than normal fluid intake. Nonetheless, some individuals incurred a substantial fluid deficit by the end of the training session. Recommending a general increase in fluid intake to all players may not have affected the behavior of these individuals and would not have been appropriate for those who incurred only a small fluid deficit.

Opportunities for fluid intake during the game are limited, and the ability to empty ingested fluid from the stomach and to absorb it in the small intestine may be compromised, so it would seem appropriate for players to ensure that they are fully hydrated before beginning either training or match play. The measurements of urine osmolality made on samples obtained when the players reported for training indicate that some players may have been mildly hypohydrated when they began training and, in the case of 1 player, whose urine osmolality was 1254 mosmol/kg, there was the probability of more severe hypohydration. A number of studies have shown the urine osmolality, measured on samples collected at rest prior to exercise, can be used in athletes as an index of hydration status, and urine osmolality is normally less than about 600–900 mosmol/kg in individuals who are well hydrated (30, 37). The high levels of urine osmolality observed in some players in the present study suggest that they began training in a hypohydrated state. These players were due to train again the same day after only about 2 hr of recovery, so it seems unlikely that those who incurred the largest fluid deficits would have fully replaced this before resuming training. The possible cumulative effects of repeated training sessions in warm weather with incomplete restoration of fluid balance must give rise to some concerns.

References

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**Acknowledgments**

The authors gratefully acknowledge the assistance and cooperation of the players and staff of Birmingham City Football Club. We also thank Spencer Newport, Andy Stephenson, Cath Fordham, Andy Foskett, and Sam Erith for their assistance with data collection.