Energetics of high-intensity exercise (soccer) with particular reference to fatigue

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Soccer entails intermittent exercise with bouts of short, intense activity punctuating longer periods of low-level, moderate-intensity exercise. High levels of blood lactate may sometimes be observed during a match but the active recovery periods at submaximal exercise levels allow for its removal on a continual basis. While anaerobic efforts are evident in activity with the ball and shadowing fast-moving opponents, the largest strain is placed on aerobic metabolism.

On average, competitive soccer corresponds to an energy expenditure of about 75% maximal aerobic power. The energy expenditure varies with playing position, being highest among midfield players. Muscle glycogen levels can be reduced towards the end of a game, the level of reduction being reflected in a decrease in work rate. Blood glucose levels are generally well-maintained, although body temperature may rise by 2°C even in temperate conditions.

The distance covered by players tends to under-reflect the energy expended. Unorthodox modes of motion - running backwards and sideways, accelerating, decelerating and changing direction – accentuate the metabolic loading. These are compounded by the extra requirements for energy associated with dribbling the ball and contesting possession. The overall energy expended is extreme when players are required to play extra-time in tournaments. Training, nutritional and tactical strategies may be used to reduce the effects of fatigue that may occur late in the game.

Keywords: Aerobic metabolism, anaerobic metabolism, glucose, lactate, muscle glycogen.

Introduction

Soccer is probably the most popular sport worldwide, with about 120 million registered players (Ekblom, 1986). It is played in all continents and participation is especially increasing at under-age (youth and under), women’s and veteran’s levels. Its popularity is most notable at a spectator level by the huge television audiences for the major competitions. At this professional level, there are many physiological stresses associated with competitive play that call for high levels of physical fitness on the part of the players. This review is focused on the exercise intensity of playing soccer and the factors that may cause performance to fall off in the later stages of the game. This decline in performance characterizes fatigue.

The exercise intensity during soccer play can be indicated by the overall distance covered by each player (Reilly, 1996). This is a global measure of work rate, which represents a compilation of discrete actions or movements for the whole match. These activities can be classified according to type of action or movement, intensity (quality), duration (distance) and frequency. The activities may be aligned to a time-base so that average work:rest ratios can be determined. These work:rest ratios can provide models for laboratory investigations of fatigue in exercise conditions such as soccer play, and can also be included as elements in soccer players’ training programmes. The disclosure of work-rate profiles can be complemented by monitoring physiological responses to increase understanding about the stresses that competitive play entails. They also allow for identifying decrements in performance as the game progresses.

Work-rate profiles

The energy expended during soccer play is a function of the total distance covered throughout the 90 min of a match (Reilly, 1994). Methods of monitoring movements of players during competition have included tape-recorded commentaries, video-recordings, film analysis, synchronized trigonometric techniques and
computer-aided video analysis (Reilly, 1996). Whatever method is adopted, it must comply with quality control criteria and provide valid, objective and reliable observations.

There is a consensus in the literature that outfield players cover 8-12 km during a game (Reilly, 1996). This encompasses over 1000 different activities, with a change in the type or level of activity occurring about once every 6 s (Reilly and Thomas, 1976). The relative distances covered in the different positions in a team are shown for outfield players in Fig. 1. Masked within these categories are sideways and diagonal movements and skills within the game that have energetic consequences, such as jumping to win possession of the ball, kicking it, tackling, and so on. The broad movement categories neglect the frequent changes in pace that are called for - runs to follow opponents, to maintain defensive or offensive lines, as well as chase the ball.

While the total amount of work, as indicated by the distance covered, may vary from game to game for any individual player, the amount of high-intensity exercise appears to be more constant (Bangsbo, 1994a).

Cruising and sprinting may be combined to represent high-intensity activity during soccer play. This would mean that the ratio of low-intensity to high-intensity exercise is approximately 2:1 if indicated by the distance covered (Reilly and Thomas, 1976). When referred to a time-base, the calculated ratio is about 7:1. This indicates a predominant reliance on aerobic energy. Overall, the rest periods average 3 s every 2 min, although the low-activity movements (and rest periods) increase towards the end of the game when players cannot maintain their running in support of team mates or covering for them. As only about 2% of the total distance covered is in possession of the ball, the majority of activity is performed 'off-the-ball' in positional manoeuvres on the periphery of the actions 'on the ball'.

While the majority of the exercise associated with competitive soccer is at submaximal intensities, the importance of the all-out efforts should not be discounted. Sprints are noted to occur about once every 90 s and high-intensity efforts (cruises plus sprints) once every 30 s (Reilly and Thomas, 1976; Reilly, 1994). The timing and direction of these runs, whether in possession of the ball or 'off-the-ball', are more important than the velocity. These activities at high intensity constitute the anaerobic components of soccer play and often their successful execution determines the result of a game.

**Fatigue**

The distance covered in the second half of a game tends to be less than in the first half. This is a manifestation of fatigue, defined as a decline in performance due to the need to continue performing. An overall drop of 5% over the second half compared with the total distance covered in the first half has been reported by Bangsbo *et al.* (1991) for Danish players. The corresponding difference covered was about 450 m in Belgian university players (Van Gool *et al.*, 1988). Nevertheless, aerobic fitness does seem to allow players to continue at a high work rate, as an inverse relation between maximal aerobic power (\(\dot{V}O_2\text{max}\)) and decrement in work rate has been noted (Reilly and Thomas, 1976). Fatigue is most pronounced in centre-backs and strikers, and less apparent in midfield players and full-backs, who tend to have the higher \(\dot{V}O_2\text{max}\) values. Although midfield players cover the greatest distances among players in outfield roles, their superior aerobic

![Figure 1](image-url) Distance covered (mean ± s.d.) according to playing position in soccer matches (modified from Reilly and Thomas, 1976).
fitness levels enable them to maintain a high exercise intensity throughout the game.

The level of muscle glycogen stores pre-match is also likely to delay the onset of fatigue. Saltin (1973) filmed soccer players during a competitive game, sampling each subject's activity for 3 min at a time. He reported that the soccer players with low glycogen content in the quadriceps muscles before the match covered 25% less distance than the other players. The most striking consequence was in running speed, since the players with initially low glycogen stores covered 50% of the total distance walking and 15% at top speed, in contrast to 27% walking and 27% sprinting for players who started with high muscle glycogen concentrations. It would seem that attention to dietary means of boosting glycogen stores pre-match and avoiding hard training the day beforehand would help in delaying fatigue, especially in matches where extra-time is possible.

The occurrence of fatigue may be linked with a host of physiological factors. Bangsbo (1994a) attempted to identify the intramuscular factors causing fatigue in a series of laboratory-based investigations. It proved difficult to identify any single factor (e.g. hydrogen ions, lactic acid, potassium imbalance, ammonia or energy depletion) or precise combination of factors that would explain fatigue definitively.

The behaviour of players and match phenomena attest to the occurrence of fatigue. The distribution of goals scored during football matches shows a bias towards more goals than predicted being scored towards the end of the game (Reilly, 1996). This cannot be attributed to a fall in work rate, which should affect both teams equally. Nor can it be attributed to a fall in blood glucose, as the liver releases enough glucose during a match to maintain euglycaemia (Bangsbo, 1994a). Its explanation is likely to be accounted for by a complex of phenomena, including increased risk-taking by the team that is behind, a change in tactics due to the proximity of the end of the game, and lapses in concentration or mental fatigue. Deterioration in mental performance related to soccer-specific decision-making is evident only in less-skilled players (Marriott et al., 1993).

The style of play can influence the physiological demands on players. The 'direct method' of play, characterized by the national teams of Ireland and Norway, maintains the game at a high pace (Reilly et al., 1992). This style has a levelling effect on the work rate of outfield players, since they are all expected to work at a high intensity 'off-the-ball'. There are particular demands on forwards to pressurize defenders and thus prevent a slow, methodical attack being built up. The tactics of both these national teams were modified in the 1994 World Cup, where the hot conditions pre-

vailed against the maintenance of a consistently high work rate throughout the game.

### Physiological responses to match-play

Energy expenditure during soccer match-play may be indicated by direct means using Douglas bags or portable telemetric devices such as Cosmed K2 or Metamax. Both methods have limitations in that their use is only feasible in simulations of match-play and they inhibit full involvement in the game. Measurements of blood lactate periodically at intervals during a 'friendly' game and measurement of the rise in core temperature provide indications of the metabolic processes engaged, but lack precision for calculating energy expenditure. The most widely used strategy has been to measure heart rate during match-play and juxtapose the observations on heart rate-VO$_2$ regression lines determined during incremental running on a treadmill. The estimate of VO$_2$ from observations of heart rate is likely to overstate the actual O$_2$ consumption due to the factors (heat, emotional stress, static exercises) that cause heart rate but not VO$_2$ to rise. The error is thought to be small, since it is only for short periods that the relation between heart rate and VO$_2$ in the game differs from that obtained in laboratory conditions (Bangsbo, 1994a). The heart rate in itself provides a useful index of overall physiological strain, quite apart from its use in estimating VO$_2$ (Reilly and Thomas, 1979).

A representative sample of results from studies of heart rate during actual soccer matches is given in Table 1. Heart rates average around 165 beats min$^{-1}$, which corresponds to a relative metabolic loading of about 75% VO$_2$ max. The resultant energy expended for a player with 75 kg body mass is 70 kJ min$^{-1}$. This is in excess of the energy requirements of locomotion over 11 km because of the extra energetic demands associated with soccer activities. They include jumping, changing direction, accelerating and decelerating, tackling, performing other games skills, and so on.

Observations on blood lactate responses to exercise are used to indicate anaerobic glycolysis. The data are variable, possibly being an artefact of the timing of the sample. Values are generally not high, although concentrations approaching 10 mmol l$^{-1}$ may be noted. Blood lactate concentrations tend to be higher at the more intense levels of competition (Ekblom, 1986) and in samples obtained at the end of the first half compared to the end of the second half. While lactate concentration in blood underestimates muscle lactate production, it is likely that the overall anaerobic energy yield from this source during a game is small. This is because the total duration of high-intensity exercise during a match (including cruising and sprinting) accounts for
only about 8% of game time and the average sprint is for a distance of about 14 m. The vast majority of effort is at low to moderate intensity and engages aerobic processes.

Bangsbo (1994a) reported that the free fatty acid concentrations in the blood increased during a soccer match and more so during the second half of the match. As glycerol showed only a minor increase, this was deemed to represent a significant gluconeogenic precursor during soccer play. Intramuscular lipolysis probably also occurs and overall the contribution of fat to total energy metabolism is likely to be about 20% (Bangsbo, 1994b). It will exceed this when a match runs the full course of extra-time.

The energy expended during soccer play contributes to a rise in body core temperature and leads to sweating to lose heat by evaporation to the environment. The elevation in body temperature may be greater during intermittent exercise than during continuous exercise of similar overall work output (Cable and Bullock, 1996). Ekblom (1986) reported average rectal temperatures of 39.5°C in players at the end of a Swedish First Division soccer match. The corresponding average for players of lower standard was 39.1°C, reflecting a lower overall pace of play. Soccer players can lose 3 litres or more of fluid during 90 min of a competition in the heat. This figure is an average and varies with the climatic conditions as well as between individuals (Reilly, 1996). Those who sweat profusely are likely to become dehydrated near the end of the game and experience fatigue. A fluid loss of 3.1% body mass has been reported during a match at 33°C and 40% relative humidity. A similar amount of fluid was lost when the ambient temperature was 26.3°C but humidity was 78% (Mustafa and Mahmood, 1979). Acclimatization helps to maintain a desirable work rate during contests in hot conditions: this may be an influential factor in dictating the overall pace at which the game is played.

### Table 1: Mean heart rate during soccer matches

<table>
<thead>
<tr>
<th>Match situations</th>
<th>Heart rate (beats min⁻¹)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 10 min game</td>
<td>160</td>
<td>Seliger (1968a)</td>
</tr>
<tr>
<td>Sample 10 min game</td>
<td>165</td>
<td>Seliger (1968b)</td>
</tr>
<tr>
<td>Friendly 90 min match</td>
<td>161</td>
<td>Ogushi et al. (1993)</td>
</tr>
<tr>
<td>Friendly 90 min match</td>
<td>169</td>
<td>Ali and Farrally (1991)</td>
</tr>
<tr>
<td>Competitive 90 min game</td>
<td>161</td>
<td>Florida-James and Reilly (1995)</td>
</tr>
<tr>
<td>Competitive 90 min game</td>
<td>171</td>
<td>Bangsbo (1994b)</td>
</tr>
</tbody>
</table>

employing the heart rate–\(\dot{V}O_2\) relationship is due largely to the energetic demands of game-related activities not accounted for in a crude measure of locomotion such as overall distance. Some attempts have been made to assess the magnitude of the physiological demands of game skills in excess of the energy cost of motion. Dribbling the ball is an example of one skill that has been isolated for study.

Reilly and Ball (1984) investigated the additional energetic cost of dribbling a ball on a motor-driven treadmill at speeds of 9, 10.5, 12 and 13.5 km h⁻¹. Their protocol allowed players to control the ball, playing it against a rebound box at the front of the treadmill belt at a dictated rate. The added cost of dribbling was 5.2 kJ min⁻¹ irrespective of the speed of motion (Fig. 2). The elevation in metabolism was paralleled by an increase in rating of perceived exertion and in blood lactate. The increased energy cost is partly attributable to the extra muscular activity required to control the ball and propel it forward. There is also likely to be a contribution due to the departure from an optimal stride rate, which is increased in dribbling. A variation in stride length occurs in a game when the player is directly engaged in play or seeks to use this alteration in stride pattern to outwit an opponent. Kawakami et al. (1992) demonstrated the high oxygen cost of dribbling in a field setting; values ranged from 2.0 and 4.0 litres min⁻¹ for drills such as 1 vs 1 and 3 vs 1 practices.

The direction of movement also influences the energy cost of exercise. Around 16% of the distance covered by players is in moving backwards, sideways or ‘jockeying’ for position (Reilly, 1996). This percentage is highest in defenders. Running backwards and running sideways are similar in terms of energy expenditure but are elevated compared to the energy used in running normally (Table 2). The extra cost of the unorthodox modes of motion increases disproportionately with the speed of motion (Reilly and Bowen, 1984).

Clearly, an improvement in movement economy in running backwards and sideways would be of benefit to the player and should be incorporated into training drills.

### Game-related activities

The mismatch in energy calculations based on values of distance covered in a game and values obtained from
Strategies to reduce fatigue

Players who are aerobically well trained are better able to maintain their work rates towards the end of the game than those of poorer aerobic fitness (Smaros, 1980; Reilly, 1994). A programme of aerobic training also speeds recovery following high-intensity efforts. Active recovery at low to moderate intensity accelerates removal of lactate from the blood compared to standing still (Gollnich and Hermansen, 1973).

Nutritional strategies can also be effective in decreasing the effects of fatigue. Saltin (1973) had demonstrated the importance of pre-start muscle glycogen levels in players’ performance. Kirkendall (1993) investigated the effects of a glucose polymer supplement on work rate during soccer matches. Players were fed either 400 ml of the polymer or a placebo pre-game and at half-time. No effect was evident in the first half but distance covered in the second half was 25% greater and the distance covered at speed 40% greater for the glucose polymer condition. Similarly, Foster et al. (1986) examined the effects of a glucose polymer solution on performance in successive matches of an indoor tournament. Players competed in a 50 min game, rested for 60 min and then played again. In the intermission, they consumed either a glucose polymer solution or a placebo. Players supplemented with the glucose polymer ran further and faster in the second game than players who were given the placebo.

The energy provided in the glucose drinks delays fatigue, partly by saving muscle glycogen stores. Leatt and Jacobs (1989) examined players who were given either 500 ml glucose polymer solution or placebo 10 min pre-game and at half-time. Glycogen reduction was greater in the placebo group than in those subjects given the glucose polymer, demonstrating that glucose ingestion decreased the net muscle glycogen utilization during soccer.

The beneficial effects of carbohydrate ingestion may not be manifest in the execution of soccer skills late in the game. Zeederberg et al. (1996) failed to show any influence of ingesting a glucose polymer solution on motor skills such as tackling, heading, dribbling and shooting during a game. Nevertheless, youth professional soccer players have reported positive subjective effects of consuming a maltodextrin solution during a long training session where performance decrements would otherwise be expected (Miles et al., 1992).

Table 2 Mean (± s.d.) blood lactate concentrations (mmol l⁻¹) during soccer

<table>
<thead>
<tr>
<th>Source</th>
<th>First-half</th>
<th>Second-half</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rohde and Espersen (1988)</td>
<td>5.1±1.6</td>
<td>3.9±1.6</td>
</tr>
<tr>
<td>Gerisch et al. (1988)</td>
<td>5.6±2.0</td>
<td>4.7±2.2</td>
</tr>
<tr>
<td>Smaros (1980)</td>
<td>4.9±1.9</td>
<td>4.1±1.3</td>
</tr>
<tr>
<td>Bangsbo et al. (1991)</td>
<td>4.9</td>
<td>3.7</td>
</tr>
<tr>
<td>Florida-James and Reilly (1995)</td>
<td>4.4±1.2</td>
<td>4.5±2.1</td>
</tr>
</tbody>
</table>

Figure 2 The added energy cost and elevation in blood lactate with dribbling a ball at different velocities of movement (modified from Reilly and Ball, 1984)
Dehydration can contribute towards fatigue, particularly when matches are played in the heat. A strategy for rehydration for soccer players has been outlined elsewhere (Maughan and Leiper, 1994). The ameliorative effects of rehydration at half-time, and since the 1994 World Cup in the USA at the sidelines when breaks in play permit, have been demonstrated mainly in laboratory studies of 90 min exercise (Reilly and Lewis, 1985), rather than in soccer matches where conditions are more difficult to control.

A team with the superior tactical ability can dictate the pace of the game so that the performance capabilities of outfield players are not overtaxed. Alternatively, players may share high-intensity bouts in turn so that the overall pace of play is maintained. In environmental conditions such as at altitude, the ability to pace the total team effort economically is especially important.

**Overview**

The game of soccer can be played at an intensity that taxes both aerobic and anaerobic parameters. The aerobic capacities determine the degree to which a high work rate can be sustained throughout the entire game.

Game-related activities impose additional energetic demands on players above those associated with running. Players have to be capable of optimal performance in these activities to contribute to a successful match outcome. Training and dietary strategies may be used to minimize the effects of fatigue, particularly those experienced in the late stages of a game.

**References**


