Fatigue in soccer: A brief review

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Abstract
This review describes how fatigue may develop during soccer games and the potential physiological mechanisms that cause fatigue in soccer. According to time-motion analyses and performance measures during match-play, fatigue or reduced performance seems to occur at three different stages in the game: (1) after short-term intense periods in both halves; (2) in the initial phase of the second half; and (3) towards the end of the game. Temporary fatigue after periods of intense exercise in the game does not appear to be linked directly to muscle glycogen concentration, lactate accumulation, acidity or the breakdown of creatine phosphate. Instead, it may be related to disturbances in muscle ion homeostasis and an impaired excitation of the sarcolemma. Soccer players' ability to perform maximally is inhibited in the initial phase of the second half, which may be due to lower muscle temperatures compared with the end of the first half. Thus, when players perform low-intensity activities in the interval between the two halves, both muscle temperature and performance are preserved. Several studies have shown that fatigue sets in towards the end of a game, which may be caused by low glycogen concentrations in a considerable number of individual muscle fibres. In a hot and humid environment, dehydration and a reduced cerebral function may also contribute to the deterioration in performance. In conclusion, fatigue or impaired performance in soccer occurs during various phases in a game, and different physiological mechanisms appear to operate in different periods of a game.

Keywords: Time-motion analysis, high-intensity exercise, sprint performance, muscle metabolism.

Introduction
The physical aspects of soccer have been studied intensively in male participants. Using time-motion analysis, it has been demonstrated that elite players typically cover a total distance of 9–12 km during a game (Bangsbo 1994; Bangsbo, Norregaard, & Thorøe, 1991; Reilly & Thomas, 1976; Rienzi, Drust, Reilly, Carter, & Martin, 1998; Van Gool, Van Gerven, & Boutmans, 1988; Mohr, Krustrup, & Bangsbo, 2003a; Mohr, Ellingsgaard, Andersson, Bangsbo, & Krustrup, 2003b). The type of exercise performed in soccer is intermittent, with a change in activity every 4–6 s (Bangsbo, 1994; Mohr et al., 2003a,b; Reilly & Thomas, 1976). Thus, an international top-class player performs approximately 1350 activities during a game, including about 220 runs at high speed (Mohr et al., 2003a). Besides running, other game-related and energy-demanding activities, such as dribbling, tackling and heading, contribute to the overall demands on the player (Bangsbo, 1994; Reilly, 1997). On average, the aerobic loading during a game is about 75% of maximal oxygen uptake (Bangsbo, 1994; Mohr et al., 2003b; Reilly, 1994), with the anaerobic system being highly taxed during intense periods of a game (Bangsbo, 1994; Ekblom, 1986; Krustrup et al., 2003a; Reilly 1997). This review discusses fatigue during a game and the physiological mechanisms that may impair a player's physical performance. Fatigue is defined as "failure to maintain the required or expected power output" (Edwards, 1983).

Temporary fatigue during a game
Studies have demonstrated that the amount of sprinting, high-intensity running and distance covered are lower in the second half than in the first half of a game (Bangsbo, 1994; Bangsbo et al., 1991; Mohr et al., 2003a,b; Reilly & Thomas, 1976). This may indicate that performance is inhibited in the second half and fatigue occurs towards the end of a game. The question is whether the players also
experience temporary fatigue during a game. In a recent study, top-class professional male players were examined in competitive games at the highest international level by the use of time–motion video analysis (Mohr et al., 2003a). The amount of high-intensity running in the 5-min period immediately after the most intense 5-min interval recorded during the game was observed to be less than the average of the entire game (Figure 1). This phenomenon has also been found in top-class women’s soccer (unpublished observations). This finding indicates that performance was reduced after a period of intense exercise, which could have been a result of the natural variation in the intensity in games due to tactical or psychological factors. However, in another study players performed a repeated sprint test immediately after a short-term intense period during the game and at the end of each half (Krustrup et al., 2003a). It was shown that after intense periods in the first half, the players’ sprint performance was significantly reduced, whereas at the end of the first half the ability to perform repeated sprints was recovered (Figure 2). Together, these results suggest that soccer players experience fatigue temporarily during the game.

Average blood lactate concentrations of 3–6 mmol·l⁻¹ have been observed during soccer games, with individual values above 12 mmol·l⁻¹ (Agnew, 1970; Bangsbo, 1994; Ekblom, 1986; Krustrup et al., 2003a). Such values suggest that the anaerobic energy system is highly taxed during intense periods of the game. In a recent study of muscle lactate and pH during a soccer match, muscle lactate rose fourfold compared with resting values after intense periods in both halves. In concert, muscle acidosis was markedly elevated after these intense sequences (Krustrup et al., 2003a).

Additionally, a weak but significant correlation ($r = 0.41$) was found between muscle lactate and decreased sprinting performance after an intense period (Krustrup et al., 2003a). Therefore, it could be suggested that temporary fatigue during a game may be related to high muscle lactate concentrations and/or muscle acidosis, since it has been demonstrated in vitro that high lactate and low pH impair muscle performance during intense contractions (Fitts, 1994). However, muscle lactate concentrations during the game were rather low (on average ~20 mmol·kg⁻¹ dry weight) compared with those found at exhaustion after high-intensity exercise (Bangsbo, Graham, Kiens, & Saltin, 1992a; Bangsbo et al., 1992b; Gaitanos, Williams, Boobis, & Brooks, 1993). Furthermore, in a study using the Yo-Yo intermittent recovery test, in which athletes perform intense intermittent exercise to exhaustion, muscle lactate and pH recorded 1.5 min before the point of fatigue were not different from those seen at exhaustion (Krustrup et al., 2003b). Thus, it is unlikely that elevated muscle lactate and lowered muscle pH cause fatigue during a soccer game. The development of fatigue that occurs temporarily during a game may be due to low muscle creatine phosphate concentrations, since performance in intense intermittent exercise has been demonstrated to be elevated after a period of creatine supplementation (Balsom, Seger, Sjödin, & Ekblom, 1992; Greiffenhagen, Bodin, Söderlund, & Hultman, 1994). In addition, it has been shown that after intense periods in soccer the decrease in muscle creatine phosphate is significantly correlated with impairment in sprint ability (Krustrup et al., 2003a). On the other hand, muscle creatine phosphate was only lowered by 25%, which in part could be due to the fast recovery of creatine phosphate and the approximately 20 s delay in collecting the muscle biopsy in this study. Creatine phosphate may have been significantly lower in individual muscle fibres, since the stores of creatine phosphate have been reported to be almost depleted in individual fibres at the point of fatigue after intense exercise (Soderlund & Hultman, 1991). However, during the Yo-Yo intermittent recovery test, no changes were observed in muscle creatine phosphate in the final phase of exercise (Krustrup et al., 2003b), and this fact argues against creatine phosphate having a potential inhibitory effect on performance during intense intermittent exercise. Together, these findings suggest that temporary fatigue in soccer is not causally linked to high muscle lactate, high muscle acidosis or low muscle creatine phosphate.

It has been suggested that the development of fatigue during high-intensity exercise is related to an accumulation of potassium in the muscle interstitium (Bangsbo, Madsen, Kiens, & Richter, 1996; Fitts,
metabolism. In line with this, Nordsborg et al. (2003) demonstrated that the rate of accumulation of interstitial potassium in exercising human leg muscle was significantly increased when muscle pH was lowered (Bangsbo et al., 1996) due to intense arm exercise before the leg exercise. Thus, soccer players may experience temporary fatigue as a consequence of accumulation of extracellular potassium and concomitant electrical disturbances in the muscle cell. However, at present little is known about potassium turnover in the muscle during a soccer game.

**Fatigue at the end of a game**

The amount of high-intensity exercise declines towards the end of a match (Bangsbo, 1994; Bangsbo et al., 1991; Mohr et al., 2003a; Reilly & Thomas, 1976; Rienzi et al., 1998) (Figure 3a). Thus, Mohr et al. (2003a) observed that for both top-class players and professional players of a lower standard, the amount of high-intensity running was reduced in the last 15 min of a game. This was seen in both groups of players despite the fact that the top-class players exercised at a much higher intensity. Furthermore, only 3% of the players had their most intense exercise period in the last 15 min of the game, and more than 40% of the players had their least intense exercise period in the last 15 min (Figure 3b). This study only included top-class male players; however, it has also been shown in top-class female players that the exercise intensity declines in the final phase of a game (Mohr et al., 2003b). Apparently, most players experience fatigue towards the end of the game. Accordingly, the ability to perform repeated sprints was reduced after compared with before a game (Krustrup et al., 2003a; Mohr, Krustrup, Nybo, Nielsen, & Bangsbo, 2004a; Rebele, Krustrup, Soares, & Bangsbo, 1998) (see Figure 3). Furthermore, it was observed that substitutes who came on in the second half sprinted and ran at a high intensity (63 and 25% more, respectively) than players who played the entire game (Figure 4). Thus, the reduction in exercise intensity and sprint performance in the final phase of games is independent of playing position, level of competition and gender, indicating that most players utilize their physical potential during a game.

Blood samples taken during soccer games have shown that blood lactate concentration declines in the later stages of a game, whereas plasma free fatty acids are increased (Bangsbo, 1994; Krustrup et al., 2003a). This trend is a result of reduced exercise intensity and a change in substrate utilization towards the end of a game. An increasing lipid turnover during the game may be induced by low muscle glycogen concentrations together with ele-
vated concentrations of catecholamine (Bangsbo, 1994; Galbo, 1983). The results of studies using dietary manipulation indicate that lowered muscle glycogen contributes to the development of fatigue during long-term intermittent exercise (Balsom, Gaintanos, Söderlund, & Ekblom, 1999; Bangsbo, Norregaard, & Thorsoe, 1992c). In a number of studies, muscle glycogen has been determined before, during and after a game. In a study by Saltin (1973), the muscle glycogen stores were almost depleted at half time when the pre-match levels were low (≈200 mmol·kg⁻¹ dry weight). When the players started the game with normal muscle glycogen concentrations (≈400 mmol·kg⁻¹ dry weight), the values were still rather high at half time, but below 50 mmol·kg⁻¹ dry weight at the end of the game. Others obtained muscle biopsies before and after a game and found the glycogen concentrations to be ≈200 mmol·kg⁻¹ dry weight after the game (Jacobs, Westin, Karlsson, Rasmusson, & Houghton, 1982; Smaros, 1980), indicating that muscle glycogen stores are not always depleted during a soccer game. Recently, muscle tissue obtained before and after a soccer game was analysed for muscle fibre type specific glycogen depletion, using the PAS-staining technique (Krstrup et al., 2003a). It was shown that after the game about half of the type I and type IIA fibres were almost or completely depleted of muscle glycogen. Thus, fatigue at the end of soccer games may be caused by glycogen depletion of individual muscle fibres. Hypoglycaemia has also been suggested to cause fatigue during long-term exercise (Fitts, 1994), but the blood glucose concentration does not reach critical values during a soccer game (Bangsbo, 1994; Ekblom, 1986; Krstrup et al., 2003a). Other factors such as dehydration and hyperthermia have also been suggested as agents responsible for the development of fatigue in the later stages of a soccer game (Reilly, 1997). During a soccer game played in a normal thermal environment, many players lose more than 3 litres of fluid (Bangsbo, 1994; Reilly, 1997), which may have a negative effect on performance towards the end of the match (Saltin, 1964). It has been demonstrated that a loss in body mass of only 1–2% contributes to an elevation in core temperature as well as cardiovascular strain (Hoffman et al., 1994). In soccer, the average core temperature ranges from 39.0 to 39.5 °C (Ekblom, 1986; Mohr et al., 2004a; Smørdal, 1978). In these studies, individual values were above 40 °C, which may be high enough to induce central fatigue due to a deterioration in cerebral function (Nybo & Nielsen, 2001). However, Mohr et al. (2004a) found no differences in core temperature between the end of the first and the second halves. In a hot and humid environment, a decrease in body fluid of 4–5 litres (Mustafa & Mahmoud, 1979) can occur and hyperthermia may become a key factor in the development of fatigue in the final stage of the game.

Figure 3. Distance covered by sprinting during 15-min periods throughout competitive soccer games at the highest international level (A, n = 18) and distribution of 15-min intervals with the most (■) and least (□) intense running for elite players during competitive matches (B, n = 93). * Significant difference from the first four 15-min periods of the game (modified from Mohr et al., 2003a).

Figure 4. High-intensity running and sprinting during the final 15 min of a game by players participating in the entire game (■) and substitutes only participating in the second half (□). * Significant difference between substitutes and players participating in the entire game (data from Mohr et al., 2003a).
Impaired performance in the initial phase of the second half

It has been shown that top-class male soccer players perform less high-intensity running in the first 5 min of the second half compared with the first half (see Figure 5). In the following two 5-min periods, no differences were found between the two halves (Mohr et al., 2003a). This pattern is also seen in the women’s game (unpublished observations) and in match officials (Krustrup & Bangsbo, 2001; Krustrup, Mohr, & Bangsbo, 2002). Such findings lead to the proposal that the normal routines of resting during the entire 15-min half-time interval in soccer is not an optimal preparation for the second half, which has been suggested to relate to a decline in muscle temperature (Bangsbo, 1995).

Several studies have found a close relationship between muscle temperature and high-intensity exercise performance (Asmussen & Boje, 1945; Bergh & Ekblom, 1979; Houmnd et al., 1991; Sargeant, 1987; Stewart & Sleivert, 1998). In a recent study, it was shown that muscle temperature was higher than 39°C after a proper warm-up before a soccer match and that it remained at this level throughout the first half (Mohr et al., 2004a). However, during the half-time break, muscle temperature declined by around 2°C when the players carried out their normal routines (Figure 6). The players also performed a sprint test before as well as after each half; the ability to sprint repeatedly was unchanged at the end of the first half, but after the half-time break sprint performance had deteriorated (Mohr et al., 2004a). Another group of players in the same game carried out a re-warm-up period, consisting of low- to moderate-intensity aerobic activities, in the final 7–8 min of the half-time interval. These players were able to maintain both muscle temperature and sprint performance during the half-time break (Figure 7). Moreover, a significant negative correlation ($r = -0.62$) was observed between the decrease in sprint performance and the decrease in muscle temperature at half-time (Mohr et al., 2004a). These results indicate that soccer players perform better physically when they prepare for the second half by re-warming at half-time, which appears to be related to a high maintained muscle temperature. However, the high sprint performance after a re-warm-up period at half-time may also be related to physiological mechanisms independent of muscle temperature (e.g., muscle oxygen uptake kinetics are accelerated by previous exercise without a coherent change in muscle temperature) (Krustrup, González-Alonso, Quistorff, & Bangsbo, 2001; McDonald, Pedersen, & Hughson, 1997).

Figure 5. High-intensity running by elite soccer players during the initial phase of the first (■) and second (□) halves of competitive games ($n = 42$). * Significant difference between the two halves (data from Mohr et al., 2003a).

Figure 6. Muscle temperature measured repeatedly during a friendly soccer game ($n = 8$). * Significant difference between the same point in the two halves (data from Mohr et al., 2004a).

Figure 7. Sprint performance before and after each half with (□) and without (■) a period of active re-warm-up at half-time ($n = 16$). * Significant difference from pre-match sprint performance (data from Mohr et al., 2004a).
Summary

The exercise intensity of top-class soccer players declines in periods during a game, most likely due to fatigue. These critical parts of the game may be immediately after short-term intense periods (temporary fatigue) in the initial phase of the second half and towards the end of the game. The physiological mechanisms responsible for fatigue appear to change during different periods of a match. Temporary fatigue may be related to disturbed muscle ion homeostasis. Impaired exercise ability in the first few minutes after half-time could be explained by a markedly lowered muscle temperature at the start of the second half. The decrement in the last stage of a game may be caused by a depletion of muscle glycogen in individual fibres, and under thermal stress conditions also dehydration and the concomitant hyperthermia.

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References


