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FOOTBALL TASK FORCE

PHYSIOLOGICAL DEMANDS OF FOOTBALL

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KEY POINTS

- The demands on a football player during a game can be determined from match analysis and physiological measurements during match play.
- A myriad of factors influences the demands of a player, such as the player's physical capacity, technical qualities, playing position, tactical role and style of playing, as well as ball possession of the team, quality of the opponent, importance of the game, seasonal period, playing surface and environmental factors.
- It is mainly the high-intensity exercise periods which are important, with the amount of high-speed running having been shown to be a distinguishing factor between top-class players and those at a lower level.
- The aerobic energy system is highly taxed during a football game, with average and peak heart rates around 85% and 98% of maximal values, respectively, corresponding to average oxygen uptake of around 70% of maximum.
- The many intense actions (>100) during a game indicate that the rate of anaerobic energy turnover is also high during game periods, with a significant rate of utilisation of creatine phosphate and lactate accumulation.
- Careful planning of training and nutritional strategies is required in preparation for training and games.

INTRODUCTION

In recent years much research regarding match performance has been conducted, and science has to a greater extent been incorporated into training planning and nutritional strategies to prepare for training and games. Changes in both performance and physiological response throughout a game have been studied with a focus on individual differences in the physical stress to which players are exposed in games. These differences are related to the training status of the players and the specific tactical role of the individual player. This review deals with current knowledge about the demands of the game at a top-class level, with a focus on match analysis and physiological measurements during match play.

MATCH ANALYSIS

The first attempts to analyse the activity profile of football players during games were performed in Sweden in the late 1960s using video analysis on short filmed sequences of a game. This approach was further developed in England and later in Denmark, and in the early 1990s data on differences between players in different playing positions were presented in scientific journals (Bangsbo et al., 1991). Inspired by video-based match analysis systems, a large number of automatic systems were put into use by professional football clubs at the beginning of this millennium. The most successful were the multiple-camera systems developed by Amisco and Prozone, which are match analysis systems commonly used by many top-class football clubs today. The systems use several high-speed cameras installed at the stadium filming different sections of the field for post-game analysis. In addition to tactical analysis, these systems provide detailed information on characteristics of the fitness work in the game, including all the intense running bouts and also, in recent years, taking accelerations into account. The technology has led to detailed analyses of many aspects of the game, such as the importance of team tactics and the style of play of the opponent and their impact on physical demands, and a huge number of articles within this area have been published in recent years (Castellano et al., 2014). This information has provided a more detailed and nuanced picture of the demands on players, but the outline of fundamental requirements for players has not changed.

HIGH-SPEED RUNNING AND STANDARD OF PLAY

The typical distance covered by a top-level outfield male player during a match is 10–13 km (Bangsbo et al., 1991; Mohr et al., 2003; Krustrup et al., 2005; Bangsbo et al., 2006; Mascio & Bradley, 2013). However, the majority of the distance is covered by walking and low-intensity running and it is mainly the high-intensity exercise periods which are important. The amount of high-speed running is what distinguishes top-class players from those at a lower level. Computerised time-motion analysis has demonstrated that international top-class players perform 28% more high-intensity running (2.43 vs. 1.90 km) and 58% more sprinting (650 vs. 410 m) than professional players at a lower level (Mohr et al., 2003). Furthermore, Ingebrigtsen et al. (2012) found that top teams in the Danish League covered 30–40% more high-speed running distance compared to the middle and bottom teams. On the other hand, Di Salvo et al. (2013) observed that Championship players did more high-speed running and sprinting than players in the Premier League, even though the differences were small. Along the same lines, a study comparing the match performance of players in the top three competitive standards of English football found that players in the second (Championship) and third (League 1) categories performed more high-speed running (>19 km/h) than those in the Premier League (803, 881 and 681 m, respectively), which was also the case for sprinting (308, 360 and 248 m, respectively) (Bradley et al., 2013a). This accounted for all positions. In addition, a group of players (n=20) changing teams and moving down from the Premier League to the Championship League covered more distance with high-intensity running (1103 vs. 995 m), whereas no difference was observed for players moving up from Championship to Premier (945 vs. 1021 m). The differences may be related to playing style, with Premier League teams utilising possession tactics rather than the long ball tactic typically used at lower standards, demonstrating the major influence of tactics on physical performance. It is interesting that the high-speed distance covered was markedly greater for the lower level team when the ball was out of play. No difference in the Yo-Yo Intermittent Endurance Test Level 2 was observed between the various groups, suggesting that the differences were not due to differences in physical capacity. It should be noted that the performance on the Yo-Yo Test of Premier League players was about 2,300 m, which is less than observed for lower standards in Scandinavia (Heisterberg et al., 2013). Thus, the lower performance of Premier League players may also be due to the insufficient fitness level of these players. The data may not be representative for other national leagues.

It should be noted that successful Italian teams appear to cover less (4–12%) high-intensity running distance compared to unsuccessful teams, but more distance while in possession of the ball (Rampinini et al., 2009). In addition, players cover more ground with high-intensity running when playing against higher- compared to lower-quality opponents (Castellano et al., 2011; Di Salvo et al., 2013; Rampinini et al., 2007). Playing against strong opponents has been found to be associated with lower ball possession (Bloomfield et al., 2005; Lago, 2009), and it is possible that lower-standard players have to cover greater distances in an attempt to close in on players and regain possession. It may also be that higher-standard players are more selective about their high-intensity efforts.

National differences are illustrated by a study that included 5,938 analyses of Spanish La Liga and English FA Premier League players, which revealed that high-intensity running (21–24 km/h) accounted for 3.9% of the total distance covered and sprinting (>24 km/h) 5.3%, with the FA Premier League players covering a longer distance at high speeds than the Spanish players (Dellal et al., 2011). On the other hand, such differences in high-speed running were not observed in other studies in which FA Premier League players were compared to Italian and Spanish players (Bradley et al., 2009; Rampinini et al., 2007). Nevertheless, there is no doubt that there are cultural differences; e.g., South American players covered about 1,000 fewer metres than did English FA Premier League players (Rienzi et al., 1998).

The studies described above examined male players, but female players have also been evaluated. The amount of high-intensity running in elite female football has been shown to be about 30% lower than in male elite football (Krustrup et al., 2005; Mohr et al., 2003). This has been confirmed in studies of top-class females competing in the European Champions League, showing that they cover less high-speed running distance than their male counterparts (Bradley et al., 2014). One of the major reasons is that female players possess lower physical capacity than male players across a range of aerobic and anaerobic fitness tests (Krustrup et al., 2010; Bradley et al., 2014).

In summary, it appears safe to conclude that the top-class player has to be able to perform repeated high-intensity exercise and also that innumerable factors influence the distance covered in a game, including physical capacity, technical qualities, playing position, tactical role, style of playing, ball possession of the team, quality of the opponent, importance of the game, seasonal period, playing surface and environmental factors. Some of these will be discussed further below.

POSITIONAL DIFFERENCES

The activity profile and demands on a player are determined by his/her positional role in the team. Mohr et al. (2003) studied top-class players and found that central defenders covered less total distance and engaged in less high-intensity running than players in the other positions, which is probably closely linked to their tactical roles and their lower physical capacity (Bangsbo, 1994; Mohr et al., 2003; Krustrup et al., 2003). Midfielders covered the longest distances. However, there are marked differences between players within the same position (Figure 1), which may be related to playing style and may explain why other studies found different results. This may also explain that in the study by Dellal et al. (2011), central defenders and central defensive midfield players covered the least high-speed running and sprinting distances, whereas forwards covered the longest high-speed running distances. Central defensive midfield players covered a greater distance than central attacking midfielders, especially in the English FA Premier League (Dellal et al., 2011). Other studies have shown that external midfield players cover the most high-intensity running distance (Carling et al., 2008). In addition, central attacking midfielders covered the most distance in high-speed running when their team was in possession of the ball, whereas this was the case for external midfield players in the English FA Premier League (Bradley et al., 2013b).

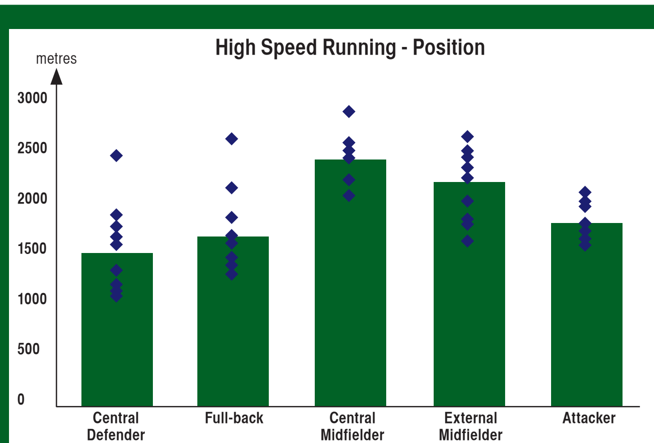

Figure 1. The distance covered with high-speed running during a game for players in different positions. Each player is represented by a symbol.

There are also differences in the types of sprints. An explosive sprint is defined as attainment of sprint speed preceded by rapid acceleration (from low or moderate speed) reaching the high-speed zone within less than 0.5 seconds. A leading sprint is characterised by gradual acceleration from low to moderate to high speed. Bloomfield et al. (2007) analysed leading and explosive sprints for different playing positions in the English Premier league and demonstrated that defenders and central midfielders performed fewer leading sprints compared to other positions.

The physical capacity of a player has a great impact on the work profile during a game and marked differences exist among top-class players even within the same position, which to some extent can explain the differences observed in high-speed running during the game (Figure 2). Such differences have been determined by the Yo-Yo Intermittent Recovery Level 1 (Yo-Yo IR1) and Level 2 (Yo-Yo IR2) Tests. On average, central defenders had lower Yo-Yo IR1 test scores than players in other positions, whereas no differences were observed in the Yo-Yo IR2 test, showing that central defenders had lower intense endurance capacity but the same ability to recover.

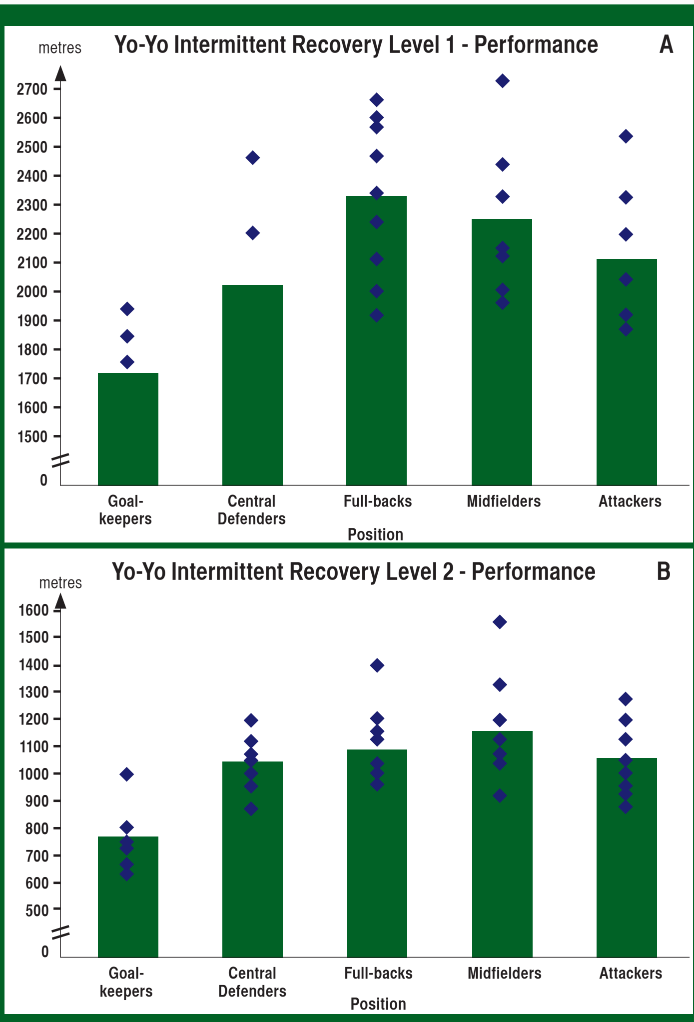

Figure 2. Yo-Yo intermittent recovery level 1 (Yo-Yo IR1; A) and level 2 (Yo-Yo IR2; B) in relation to playing position. Each player is represented by a symbol.

OTHER DEMANDING MATCH ACTIVITIES

The data on high-intensity running do not include a number of energy-intensive activities, such as short accelerations, turns, actions with the ball, tackles and jumps. For example, most maximal accelerations do not result in speeds associated with high-intensity running but are still metabolically taxing (Osgnach et al., 2010). Furthermore, it has been demonstrated that players in the FA Premier League make about 700 turns in a game, with around 600 of them being 0–90 degrees (Bloomfield et al., 2007). Players were involved in about 110 actions with the ball with marked variations. The number of tackles and jumps depends on the individual playing style and position in the team and at the top level has been shown to vary from 3–27 and 1–36, respectively (Mohr et al., 2003). There also appears to be national differences. In all positions the number of headings for Spanish League players was lower than for players in the English FA Premier League (Dellal et al., 2011). For example, the number of headings for the central defender in the Spanish League and FA was 5 and 15, respectively. Likewise, the total number of ground duels by the full-back was lower in the Spanish League compared to the FA (7 vs. 24).

INFLUENCE OF TEAM TACTICS ON PHYSICAL DEMANDS

The style of play and the team system play a role in the demands on the individual players. In a recent study the effect of playing formation on high-intensity running and technical performance of English FA Premier League teams was analysed (Bradley et al., 2011). No differences were observed in total distance covered or high-intensity running between the 4-4-2, 4-3-3 and 4-5-1 formations, but players in a 4-5-1 formation performed less very-high-intensity running when their team was in possession and more when their team was not in possession compared to the 4-4-2 and 4-3-3 formations. These differences may be related to the attacking and defensive characteristics inherent to these playing formations. A 4-5-1 is a more defensive system than a 4-4-2 and 4-3-3 due to the reinforcement of the midfield zones at the expense of forward players. Not much difference, however, was observed in the individual positions, except that attackers in a 4-3-3 performed about 30% more high-intensity running than attackers in the 4-4-2 and 4-5-1 formations. It was also observed that the attacker in a 4-5-1 had a significant decline in high-intensity running in the second half, which was not observed in the other systems. It may be that the 4-5-1 formation requires marked physical work on the attacker, as he is often isolated and in the defence and has to put pressure on the back line. Overall ball possession did not differ between the 4-4-2, 4-3-3 and 4-5-1 formations, but the number of passes and the fraction of successful passes were highest in a 4-4-2 compared with the 4-3-3 and 4-5-1 formations. Generally, the results suggest that playing formation does not influence the overall activity profiles of players, except for attackers, but does have an impact on very-high-intensity running activity, with and without ball possession, and some technical elements of performance.

FATIGUE DURING A FOOTBALL GAME

A relevant question is whether fatigue occurs toward the end of a football game and what causes the fatigue. It is a common finding 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 (Reilly & Thomas, 1979; Bangsbo et al., 1991; Bangsbo, 1994; Mohr et al., 2003; Carling & Dupont, 2011). It appears that high-speed running in the second half is affected by the activities of the first half, and full-backs, central and external midfield players in the Premier League, having the most physically demanding playing positions, were shown to have a reduction in match performance in the second half (Bradley et al., 2013b). Furthermore, several studies have provided evidence that both elite and sub-elite football players' ability to perform high-intensity exercise is reduced toward the end of games (Reilly & Thomas, 1979; Mohr et al., 2003, 2004, 2005; Krustrup et al., 2006; Carling & Dupont, 2011). In any case, technical abilities may not be affected by the reduced work capacity. One study showed that French elite players were generally able to maintain their skill-related performance throughout a game (Carling & Dupont, 2011). The reductions in match running performance could be due to players employing conscious or subconscious pacing strategies to enable successful completion of the match, thus not representing true fatigue. However, jump, sprint and intermittent exercise performance, when evaluated after a game, was significantly lowered compared with before a game (Mohr et al., 2004, 2005; Krustrup et al., 2006). Another relevant question is what occurs when players compete in multiple important games within a short time. In a study of French League players no differences in either skill or physical performance were observed when three matches within seven days, as often is the case, were played (Carling & Dupont, 2011).

Players may also experience temporary fatigue during a game. Male elite football players have on a number of occasions been shown to engage in reduced high-intensity exercise, below game average, in the five-minute period following the most intense period of the match (Mohr et al., 2003; Mascio & Bradley, 2013). These reductions in performance after a period of intense exercise could result from the natural variation in game intensity due to tactical or psychological factors. However, in another study, players performed a repeated sprint test immediately after an intense period during each half and also at the end of each half (Krustrup et al., 2006). It was shown that after intense periods in the first half, players' sprint performance was significantly reduced, whereas by the end of the first half, the ability to perform repeated sprints had been recovered. Together, these results suggest that football players experience fatigue temporarily during the game.

ENERGY DEMANDS DURING A GAME

While a huge number of studies analysing match activities has been conducted over the past five years, measurements estimating the physiological demands during match play are scarce.

Football is an intermittent sport in which the aerobic energy system is highly taxed with average and peak heart rates around 85% and 98% of maximal values, respectively (Reilly & Thomas, 1979; Ekblom, 1986; Ali & Farally, 1991; Bangsbo, 1994; Krustrup et al., 2005), corresponding to average oxygen uptake (VO_2) around 70% of maximum oxygen uptake (VO_2Max). This suggestion is supported by the finding of core temperatures in the range of 39–40°C during a game (Ekblom, 1986; Mohr et al., 2004).

More important for performance than average oxygen uptake during a game may be the rise in the rate of oxygen uptake during many short intense actions. A player's heart rate during a game is rarely below 65% of HRmax, suggesting that blood flow to the exercising leg muscles is continuously higher than at rest, which means that oxygen delivery is high. However, the oxygen kinetics during changes from low- to high-intensity exercise during the game appear to be limited by local factors and depend on, among other factors, the oxidative capacity of the contracting muscles (Bangsbo et al., 2001; Krustrup et al., 2004; Nyberg et al., 2010). The rate of increase in oxygen uptake can be changed by intense interval training (Krustrup et al., 2004).

The observation that elite football players perform 150–250 brief, intense actions during a game (Mohr et al., 2003) indicates that the rate of anaerobic energy turnover is high during periods of a game. Even though this has not been studied directly, intense exercise during a game would lead to a high rate of creatine phosphate (CP) breakdown, which to a great extent is re-synthesised in the following low-intensity exercise periods (Bangsbo, 1994). Measurements of CP in muscle biopsies obtained after intense exercise periods during a game have shown values around 75% of the level at rest. This figure is, however, likely to be significantly lower during the match, as these values were obtained from biopsies taken 15–30 seconds after match activities, during which a substantial re-synthesis of CP had undoubtedly occurred (Krustrup et al., 2006). Using proper values for re-synthesis of CP, it may be expected that during parts of a game, when a number of intense bouts are performed with only short recovery periods between, CP levels are below 30% of resting level.

Average blood lactate concentrations of 2–10 mM have been observed during football games, with individual values above 12 mM (Krustrup et al., 2006). These findings indicate that the rate of muscle lactate production is high during match play, but muscle lactate has only been measured in a single study. In a friendly game between non-professional teams, muscle lactate rose fourfold (to around 15 mmol/kg d.w.) compared to resting values after intense periods in both halves, with the highest value being 35 mmol/kg d.w. (Krustrup et al., 2006). Such values are less than one-third of the concentrations observed during short-term intermittent exhaustive exercise (Krustrup et al., 2003). The rather high blood lactate concentration often seen in football (Bangsbo, 1994; Ekblom, 1986; Krustrup et al., 2006) may not represent high lactate production in a single action during the game, but rather an accumulated/balanced response to a number of high-intensity activities. This is important to take into account when interpreting blood lactate concentrations as a measure of muscle lactate concentrations. Nevertheless, based on numerous studies using short-term maximal exercise performed in the laboratory, and the finding of high blood lactate and moderate muscle lactate concentrations during match play, it can be concluded that the rate of glycolysis is high for short periods of time during a game.

SUBSTRATE UTILISATION DURING A FOOTBALL GAME

Muscle glycogen is an important substrate for the football player as evident from the various studies where glycogen has been measured. Saltin (1973) observed that muscle glycogen stores were almost depleted at halftime when pre-match levels were low (~45 mmol/kg w.w.). In that study, some players who started the game with normal muscle glycogen levels (~100 mmol/kg w.w.) still had rather high values at halftime, but were below 10 mmol/kg w.w. at the end of the game. Others have found the concentrations to be 40–65 mmol/kg w.w. after the game (Smaros, 1980; Jacobs et al., 1982; Krustrup et al., 2006), indicating that muscle glycogen stores are not always depleted by the end of a football game. However, analyses of single muscle fibres after a game have revealed that a significant number of fibres are depleted or partly depleted by that time, which may be one of the reasons why fatigue appears to occur toward the end of a game (Krustrup et al., 2006).

Free fatty acid (FFA) concentration in the blood increases during a game, more so during the second half (Bangsbo, 1994; Krustrup et al., 2006). Frequent rest and low-intensity periods of a game allow for significant blood flow to adipose tissue, which promotes release of FFA. This effect is also illustrated by the finding of high FFA concentrations at halftime and after the game. The suggestion of a high rate of lipolysis during a game is supported by observations of elevated levels of glycerol, even though the increases are smaller than during continuous exercise, which probably reflects a high turnover of glycerol, e.g., as a gluconeogenic precursor in the liver (Bangsbo, 1994). Hormonal changes may play a major role in the progressive increase in the FFA level. Insulin concentrations are lowered and catecholamine levels are progressively elevated during a match (Bangsbo, 1994), stimulating a high rate of lipolysis and thus release of FFA into the blood (Galbo, 1983). The effect is reinforced by lowered lactate levels toward the end of a game, leading to less suppression of fatty acid mobilisation from adipose tissue (Bülow & Madsen, 1981; Galbo, 1992; Bangsbo, 1994; Krustrup et al., 2006). The changes in FFA during a match may cause higher uptake and oxidation of FFA by contracting muscles, especially during recovery periods in a game (Turcotte et al., 1991). In addition, higher utilisation of muscle triglycerides might occur in the second half due to elevated catecholamine concentrations. Both processes may be compensatory mechanisms for the progressive lowering of muscle glycogen and are favourable in maintaining the blood glucose concentration.

SUMMARY

The tactical role and situational effect associated with individual playing position and level of competition affect the high-intensity work done in a game. Nevertheless, although players perform low-intensity activities for more than 70% of the game, heart rate and body temperature measurements suggest that average oxygen uptake for elite football players is around 70% of VO_2Max. This may be partly explained by the 150–250 brief intense actions a top-class player performs during a game, which also suggest that the rates of CP utilisation and glycolysis are frequently high during a game. Muscle glycogen is probably the most important substrate for energy production, and fatigue toward the end of a game may be related to depletion of glycogen in some muscle fibres. The oxidation of fat appears to increase progressively during a game, partially compensating for the progressive lowering of muscle glycogen. Fatigue may also occur temporarily during a game.

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