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Physical and energetic demand of soccer: A brief review

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ABSTRACT

Soccer is a complex and exhaustive team-sport requiring a high level of tactical, technical and physical ability to succeed. During a competitive match, a random combination of explosive and powerful activities, together with technical and tactical gestures, are performed intermittently manner over a 90-min game. This review presents a detailed analysis and up-to-date synthesis of the literature describing activities and energy system contribution during soccer to provide to strength and conditioning coaches a clear understanding of soccer players' physical needs during competition.

Keywords: physiology; energy systems; energy contribution; aerobic fitness; endurance parameters.

INTRODUCTION

Soccer is one of the most popular team-based sports worldwide for audiences, attendance and participation (8). Official matches consist of two halves of 45-minutes each, interspersed by a 15-minute break. Soccer is characterised as an intermittent sport, requiring athletes to execute a variety of explosive technical and tactical movements repetitively (60). The performance of such an array of activities requires a complex physiological demand which highly taxes anaerobic and aerobic energy systems (28). Hence, analysis of the physical and metabolic requirements of soccer is a crucial step in the process of designing effective and appropriate strength and conditioning programmes for players.

In the recent years, the advent of sport technology tracking systems has resulted in the production of a greater amount of data aiming to capture and describe soccer activity and metabolic requirements (52, 55). While the acquisition of this data provides greater information regarding soccer physiology and match performance, it needs to be carefully analysed for validity and reliability, and to consider the implications of approaches used for data collection to appreciate what these tracking systems actually measure and what they miss. This narrative review explores and analyses the physical and energetic demands of soccer by critically discussing the available literature. This will provide strength and conditioning practitioners with an essential and comprehensive picture of soccer players' physical requirements, which is crucial to develop specific and effective training programmes.

OVERVIEW OF SOCCER MATCH TIME-MOTION PROFILE

Technological advancements in sport has led to the advent and engagement of player monitoring devices, including global positioning systems (GPS) and video motion analyses, enabling the quantification of various physical, tactical and technical activities of soccer players in training and competitive contexts (55). Data collected from these systems during soccer uniquely describes the non-rhythmical alternation of various match activities by mainly allocating the various players' movements into different speed categories such as standing, walking, jogging, and running at different intensities (10). Adopting a speed-based approach has previously shown that elite outfield soccer players typically run between 9 and 14 km during a 90-minute game (55) covering 22-24% of total match distance at speeds higher than 15 km/h (high intensity threshold; corresponding to speed above the mean speed at the second ventilator threshold in professional soccer players), 8-9% at higher than 20 km/h (very high intensity threshold - corresponding to speed above the mean maximal aerobic speed in professional soccer players), and 2-3% at higher than 25 km/h (sprinting threshold; corresponding to speed close to the maximal sprinting speed in professional soccer players) (53). However, more recent literature has reported a ~2% increase in total distance covered and a ~30% increase in high intensity runs between 2006/2007 and 2012/2013 seasons. This gives a clear indication that soccer games are continuously evolving and becoming more physically demanding (19). This data can also be affected by match specific contextual variables such as team formations. For instance, a recent study reported that 4-3-3 formations perform significantly more high intensity runs than 4-4-2 formations (5); and defensive formations (i.e. 4-5-1) can perform up to 20% more of their total high intensity runs when not in ball possession compared to other offensive formations (i.e. 4-4-2; 4-3-3) (13). Furthermore, variances in match running outputs exist between players of different playing positions, with wide players (full-backs and wide midfielders) and central midfielders usually covering more total distance and performing more high intensity runs than attackers and central backs (19, 26); and attackers and wide players usually sprinting the most (26). In contrast, goalkeepers have been shown to cover significantly lower distance than all other positions, covering between 5.6 and 6.0km per game on average, mainly by walking (~4.0km, ~70% of total distance) and jogging (~1.2km, ~20% of total distance) (62). These differences in running activities may have implications for training specificity. However, regardless of the position, match-activity data suggests with consistency that elite players tend to perform most of the soccer game at velocities below the high intensity threshold zone (at 14-16 km/h in most studies for professional soccer players, which may be lower in amateur or semi-professional soccer players.), and secondly, that above this threshold, players tend to cover shorter distances as the speed intensity increases (26). Distances covered across a soccer game at high intensities might also vary according to players' league level and age. Amateur players have been reported to perform less periods of high intensity running than professional players (51), but this is likely due to amateur players training less and having lower speed capabilities (43). When comparing different levels of professional soccer players, who train similarly, those playing at lower levels performed a higher percentage of high intensity running (27). Indeed, the lower technical indicators, such as the percentage of successful pass completions, frequency of forward and total passes, balls received and average touches per possession, associated with lower level matches have been suggested to be responsible for the increasing physical activity at lower professional standards (14). This reasoning might also be responsible for the trend to perform more high intensity activity, relative to players' physical capacity, often reported for young players compared to adults (18, 48). However, in contrast, the impact of age alone does not seem to be influential across adolescent players of different ages since few differences in match physical activity relative to a player's physical capacity have been reported between players from U12 to U16 (37).

High intensity and multidirectional intermittent match-activities

Match analyses using the aforementioned "speed zone" approach (expressed absolute or relative) can provide an overview of soccer activity. However it inevitably underestimates the occurrence of explosive movements because it does not appropriately account for the acceleration and deceleration phases of high intensity efforts or the number of directional changes that may also occur, which are intense actions but occur at low speeds (22). Nevertheless, during the 2007/08 German top league division (German Bundesliga) it was observed that 83% of all goals in the second half of the season involved at least one powerful action (such as rotation, straight or change of direction sprint), suggesting that high intensity efforts, even if short in duration or distance, are critical in goal scoring situations (33). An overview of soccer activity profile with special reference to high intensity activities is provided in Figure 1. A recent study of professional English league outfield players reported that the mean number of high intensity efforts (speed >21 km/h) during a game ranged from 20.3 ± 6.5 (lowest values reported for central back player positions) to 38.7 ± 14.4 (highest values reported for wide midfielder player positions) (2). A similar number of high intensity efforts (17.3 ± 8.7 for central defenders and 35.8 ± 13.4 for wide midfielders) has also been reported by Di Salvo et al. (2010) during elite European matches, by just considering sprint activity (>25.2 km/h).

Recently, Ade, Fitzpatrick and Bradley (2) reported that mean duration and length of high intensity efforts > 21 km/h in European professional soccer matches did not exceed 3.1 ± 0.5 s in time and 20.3 ± 3.5 m in distance. Among the various high intensity efforts (>21 km/h), the greater percentage has been performed without ball involvement (defined as activities performed while not in possession of the ball) (2). Conversely, central backs have been found to be the players who perform less high intensity efforts with ball involvement (such as dribbling, passing, heading or intercepting a ball) (23.4 ± 10.8%), whereas wide midfielders perform a higher number of efforts with ball involvement (39.1 ± 18.2%) (2). Further, central backs and wide midfielders have been reported as the two positional categories showing the highest and lowest means of recovery periods between high intensity efforts (>21 km/h): 271.4 ± 93.7 s and 154.5 ± 49.5 s, respectively (2). While the aforementioned data suggests a low work:rest ratio between high intensity efforts, it should be acknowledged that the average work:rest ratio has been reported to be much higher when considering high intensity speed as just higher than 19.8 km/h rather than 21 km/h (25). Specifically, it has been estimated that the average work:rest ratio for high intensity efforts is equal to 1:12 over the whole match, but can drop to 1:2 during the most intense periods of playing (25). Again, such speed data may likely miss the inclusion of brief high intensity efforts (i.e. acceleration, jumps and directional changes) and therefore underestimate the real high intensity activity profile of soccer players (36).

High intensity efforts have been observed to be preceded and followed by changes of direction up to 180°and usually involve a swerve or arch run mid-efforts (2). This high occurrence of turns and multilateral movements before, during and after high intensity efforts, further support the definition of soccer as a multidirectional activity (10). Specifically, professional soccer players in matches spend 48.7 ± 9.2% of time performing in-line running movements, 20.6 ± 6.8% not moving in any direction, and 30.7 ± 2.6% of time moving in a backwards, lateral, diagonal and arched directions (10). Additionally, over the duration of a 90-minute match, soccer players can change direction more than 700 times per game (10) and make up to 1200–1400 changes in activity per match (58). Among these, change of direction at angles lower than 90º have been found to occur up to six times more frequently than change of direction at higher angles (10).

While the number of multidirectional high intensity efforts interspersed with recovery periods reported by time-zone approaches already highlight the intermittent nature of soccer, this can be further emphasised by observing specific acceleration and deceleration data produced by accelerometer devices. Specifically, in a recent study, the mean number of accelerations (an increase in speed for at least 0.5 s that exceeds a maximum acceleration of at least 0.5 m/s^2) and decelerations (a decrease in speed for at least 0.5 s that exceeds a maximum deceleration of at least 0.5 m/s^2) observed in professional European soccer players of various positions per match has been quantified to be 656 ± 57 and 612 ± 59 respectively, when pooled across positions (54). Additionally, it has been reported that professional players cover on average 18% of total match distance while accelerating or decelerating at a rate greater than 1 m/s^2 (3).

As a result of various intermittent and multilateral movements occurring in soccer, players need to be able to repetitively perform high and low intensity activities over different directions. Hence, the ability to move efficiently and intermittently under different and unpredictable situations as well as the capacity to produce explosive efforts (such as acceleration and change of direction) appear crucial to facilitate and optimise the execution of soccer specific movement patterns and subsequently physical performance. Endurance and strength training have the potential to develop these aspects (9, 38-40, 56) and need proper consideration during soccer training.

****Insert Figure 1 near here****

Match running performance fluctuation

While data reported in the previous sections represent the mean performance over a 90-minute match, fluctuation in physical performance during games have often been observed regardless of level or age (34, 48, 51, 54, 55). Specifically, in several studies, a significant yet transient decrement in high intensity running, compared to match mean intensity, has been observed following the most intense 5-minute periods of a game (16, 25, 34). Also, significantly shorter distances covered, and less high intensity running, sprints and accelerations are completed towards the end of the first half and more markedly towards the end of the second half (16, 34, 49, 53, 54). Researchers have suggested that the higher the intensity during the first minutes of a match, the greater the decrement in physical performance observed later during the match (15, 53). Hence, while technical components and pacing strategies might play a role in intra-match performance fluctuation (16, 20), the observed decline in movement output over the course of a match has predominantly been attributed to acute fatigue induced by high physiological match demands. Thus, the ability to recover faster between high intensity periods, or ability to save energy by moving more efficiently throughout the duration of the match (which are abilities related to aerobic fitness), might be relevant factors helping to preserve soccer running performance in between crucial match periods and over the whole 90-minute game. Hence strategies to improve these physical qualities are worth consideration during soccer training and warrant investigation.

While running performance decrement is constantly observed within matches, a specific team fluctuation in running activity profile between matches (i.e. congested fixture) has not been commonly reported (21, 24, 29, 47). A recent study suggested that an individual player analysis rather than team analysis should be conducted to evaluate between match physical performance fluctuation, since multiple factors such as quality of player opponent, fitness level and tactical tasks might induce specific fatigue trends in each player (61).

ENERGETIC CONTRIBUTION TO SOCCER

Aerobic and anaerobic energy systems together represent the mechanism of the human body to produce energy available to muscles (35, 44). These two systems involve multiple and interrelated processes to provide energy (35). More specifically, the aerobic system produces energy by breaking down carbohydrates and fats in the presence of oxygen (35, 44). This energy pathway is able to produce greater amounts of adenosine triphosphate (ATP), the chemical substance that serves as the currency of energy in cells, but at a low rate, and therefore acts as the major contributor of energy during long endurance activities (35). The anaerobic system produces energy by multiple processes such as by splitting stored ATP and phosphocreatine (PCr), and the breakdown of carbohydrate to lactate in the absence of oxygen (35, 44). It provides less ATP than the aerobic system but at a higher rate and it is therefore mainly taxed during short maximal bouts of exercises or repeated high intensity efforts (35). The intermittent nature of a soccer game, which involves periods of work and recovery at various intensities (maximal and submaximal) over 90-minutes, therefore requires a complex interplay of both the aerobic and anaerobic energy systems (59). In recent years it has become popular to estimate energy expenditure in soccer by calculating metabolic power from GPS (22, 23, 41, 52). While this measure is novel and has some advantages, it should be noted that such an approach could lead to an underestimation of the real energetic cost of a match and due to the inability to accurately account for energy expenditure during recovery periods (where players stand or walk after high intensity efforts) or when performing soccer-specific activities such as jumping, moving laterally, backwards or with the ball (17). For this reason, quantification of soccer demand in this review will be based only on physiological data directly extrapolated from soccer players.

Quantification of soccer anaerobic demand

Anaerobic energy contribution is crucial during high intensity activities which non-rhythmically occur during a match (55). When associating heart rate (HR) values from matches with individually determined anaerobic thresholds (considered as the intensity when lactate starts accumulating above 4mmol/L; or where production occurs at a higher rate than clearance (32)), it has been reported that players can spend ~50% of total match duration above this threshold (31). Since lactate production is representative of energy produced through glycolysis (defined as the extraction of energy from carbohydrates (CHO) substrate in the absence of oxygen) (35), it is clear that anaerobic energy systems also supply considerable energy to players over the course of a soccer match.

Blood lactate (BLa) levels have often been proposed as a direct estimation of lactate production and in turn anaerobic contribution (35). More specifically, direct measures of BLa in soccer players have produced values of 2-10mmol/L across players of different ages and playing levels (7), with top class players exhibiting higher anaerobic energy production across level and age categories. While these values indicate high lactate production during periods of a match, anaerobic contribution might also be underestimated by these data since blood samples used for analysis mainly account for only the five minutes before blood sampling (59). Moreover, BLa clearance is likely to be higher during intermittent activities, as supported by a scarce correlation between muscle lactate and BLa during soccer matches (46), and the post-match decrease in muscle glycogen concentration (42, 57), with a significant number of fibres partly or completely depleted as found in Danish players at the end of a game (45).

Anaerobic energy production can also occur without lactate production, when energy is produced by the breakdown of phosphates already stored in the muscle (PCr) rather than producing them from carbohydrates (CHO) alone (35). Therefore, a further direct indicator of anaerobic energy contribution to consider during brief intensive activity is the PCr concentration, as a lower concentration (i.e. depletion) reflects a greater anaerobic utilisation of this substrate (35). However, PCr is complex to measure, requiring biopsies which are invasive and impractical in soccer (and indeed, most applied settings) (8). Accordingly, only one study has provided direct measurements of PCr after intense periods of a game, indicating PCr was reduced to 75% of the pre-game resting concentration (45). However, given the rate of PCr resynthesis (0.5 mmol/kgDW/s, where DW = dry weight) (11), and the time taken between exercise and biopsy (15-30 seconds), PCr concentrations reported would have been approximately 60% of resting levels during soccer matches. Furthermore, if more intense bouts of activity had been performed with short recovery in-between, PCr concentrations might have dropped below 30% of resting levels (7). Despite the anaerobic system providing a minor contribution to energy supply over the duration of a 90-minute match, in comparison to the aerobic energy system, the anaerobic energy system still appears to be highly taxed during specific periods of a game. This is evident within the movement demands and profile of soccer, involving periods of high intensity activities (mainly relying on glycolytic energy pathway) and brief explosive movements (mainly relying on PCr energy pathway) (35, 59). Therefore, the role of anaerobic energy systems in soccer should not be under-valued and should remain targeted for training prescription by strength and conditioning coaches

Quantification of soccer aerobic demand

Since oxygen is required by the aerobic system to produce energy, values of oxygen consumption (VO_2) allow the quantification of aerobic demand. Direct measures of VO_2 can only be obtained by breathing through gas analyser systems (in-lab or portable), which is unfortunately not practical during match play (59). Indeed, in previous research, players wearing the heavy and uncomfortable gas analyser system played at a lower intensity than those free of the assessment device (59). For this reason, direct values of VO_2 obtained from such study (61% and 49% maximal oxygen consumption (VO_{2max}) during the first and second half respectively) have been considered an underestimation (59). Although technology has advanced in recent years to include lighter and smaller portable gas-analysis units, routine monitoring of VO_2 during games is still not commonplace and remains both an impractical and non-feasible method to obtain precise values of aerobic system contribution directly during soccer. As a practical alternative, researchers and practitioners have adopted surrogate measures of exercise intensity, such as core temperature and HR measurements, which provide indirect estimations of oxygen consumption during matches (8). However, use of these measures in a predictive capacity assumes that a stable linear relationship exists between oxygen consumption and these parameters. In particular, core temperatures of 39°C to 40°C in soccer players corresponded to 70-75% of VO_{2max} (30, 50). Similarly, 80–90% maximum heart rate (HR_{max}) reported during both competitive and recreational matches independently of players' level and age, have been converted to an average of 70–80% of VO_{2max} (4, 8). It should be acknowledged that other physiological factors might lead to both an overestimation (dehydration, hyperthermia, and mental stress) (8) or underestimation (HR lag, for example) (1, 12) of oxygen consumption during part of the match when using these indirect approaches. However, regardless of estimation variability using indirect approaches, the consensus is that aerobic metabolism clearly provides the greatest energy supply during a game as the estimated oxygen consumption accounts for approximately 90% of total energy required from match activity (6, 8).

CONCLUSION

Soccer matches require players to perform multiple and unpredictable explosive movements, including accelerations, decelerations, jumps and change of directions. The performance of these movements can differ between players of different positions, with central midfielders and wide-field players usually observed to perform greater and more strenuous activity (greater total distance covered and high-speed runs; shorter recovery in between efforts). Nonetheless, running performance decrement during a match is constantly observed regardless of the position. This can be attributed to the high physiological demand and in turn, the great energy contribution required by both anaerobic and aerobic energy systems over a game, with the latter supplying the greater amount of total energy required over a game.

PRACTICAL APPLICATIONS

Data analyzed in the current review clearly highlights the importance of developing specific physical abilities unique to player position to efficiently compete in the complex scenario of a soccer game and to counteract the running performance decrement which occurs over a match. Specifically, wide-field players and midfielders might better benefit from intense endurance training, to speed up recovery between high intensity efforts and be able to cover greater distances over a match. Strikers and defenders, while still requiring a good level of endurance, might take greater advantage from the development of soccer specific power. In this regard, strength and conditioning coaches should specifically balance development of specific physical abilities according to players positions 1) the training for maximal performance of acceleration, deceleration, change of direction and any context-specific maximal efforts over short distances (<20m); and 2) the training for maximizing the ability of repeating such activities intermittently and continuously by giving specific importance to the main energy system contributing to this, which is the aerobic energy system.

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Conflict of Interest

The authors do not have any conflict of interest to declare.

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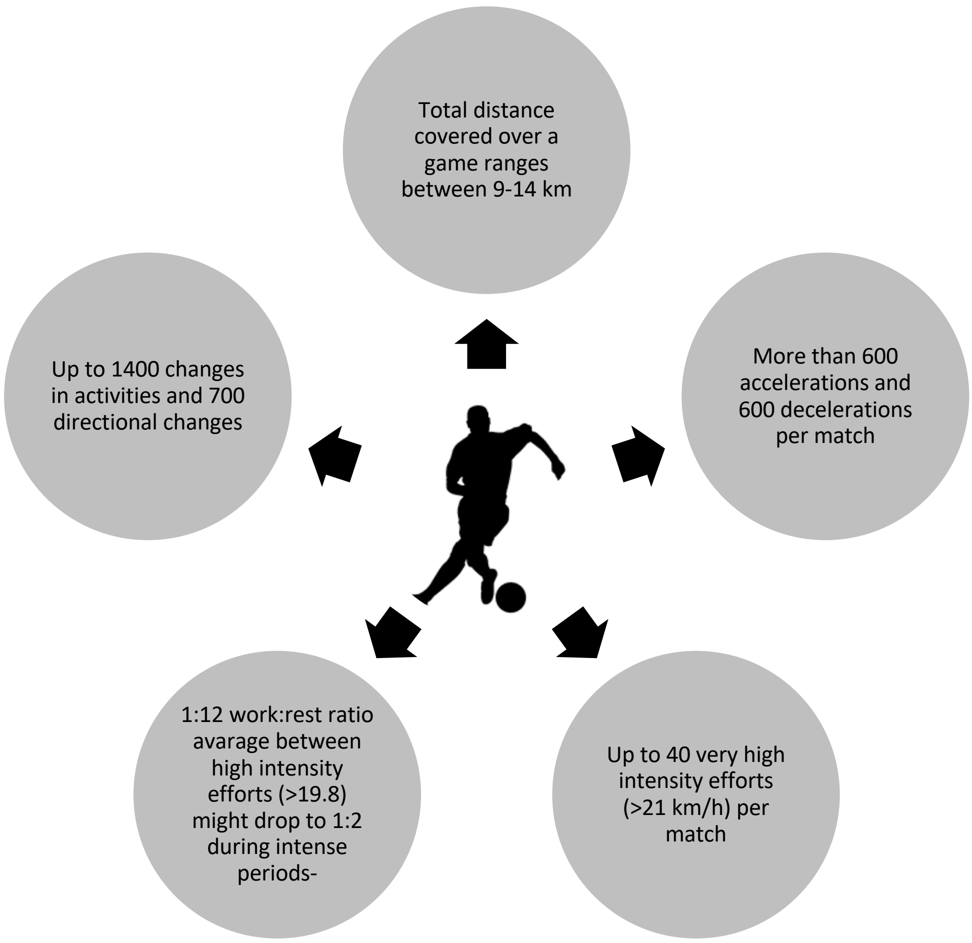

Figure 1. *Overview of professional soccer players' activity during 90-minutes game, with special reference to high intensity activities profile (2, 10, 25, 54, 55).*