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Physiology of Soccer: The Role of Nutrition in Performance

Abdullah F Alghannam*

Department for Health University of Bath BA2 7AY, UK

Abstract

Across all layers and entities of society, soccer participation is common practice, making it the most popular sport in the globe. Performance in soccer requires a multitude of factors including physical, technical, decision-making and psychological skills that ultimately impact competition. A substantial physical strain is associated with this activity that is not only a consequence of mere running, which may impact upon exercise tolerance and adherence. In turn, an appreciation of the activity profile and the physiological load of participating in this sport are important. Furthermore, an inherent relationship exists between physical activity and nutrition and thus manipulation of nutrition could improve training and competition. The current review aims to examine the activity profile and physiological demands of soccer. An investigation of the potential effects of carbohydrate ingestion on performance will also be discussed.

Keywords: Soccer; Intermittent exercise; Aerobic metabolism; Anaerobic metabolism

Introduction

Soccer is recognized as the most popular sport around the globe [1]. The number of participants was estimated to reach 200,000 professional and 200 million amateur players in 208 countries [1,2]. During the last 3 decades, soccer had developed progressively and a substantial volume of research was instigated to investigate match activities [3-5], physiological demands [6-9] and training methodologies [10,11] of the game. The increased research activity in the soccer domain continues to date within the multiple disciplines of sports science, and is progressively applied to the numerous aspects of professional soccer [12]. The significant body of research concerned with optimal performance over the past 2 decades was ascribed to the increased physical demands of match play [12,13]. Consequently, the integration of the scientific approach is abundant in the planning and execution of training regimes in contemporary elite soccer, with the aim to achieve a competitive edge over rivals [8,14].

Exercise training is aimed to induce adaptation to improve subsequent exercise capacity [15]. In soccer, training at an elite level requires a high level of stress imposed on the physiological systems to improve the various fitness components to enable players to match the demands of the game in all its aspects [11]. Accordingly, a typical training week encompasses 6 training sessions undertaken in 5 days in addition to a scheduled competitive game, indicating a high frequency with limited time to recover between the exercise bouts for players [8,16]. Not surprisingly, the overall congested annual schedules impose a significant load on the players' physiological and metabolic systems close to the threshold of exhaustion, from which they are required to recover rapidly in preparation for the next game [17]. Thus, the emergence of nutritional interventions in soccer was shown to be an integral factor in the further development of the sport in the last decade [8]. This was attributed to the high interrelation between training and nutrition, as the optimal adaptation to the demands of repeated training stimuli require sufficient nutrient intake to sustain muscle energy reserves [18]. As a result, the application of nutritional interventions in soccer was shown to influence the outcome of a game by reducing the detrimental attributes of fatigue and inducing optimal utilization of the player's physical and tactical skills [19].

Measurement of Performance in Soccer

The measurement of performance in soccer entails a multitude of complexities to appraise than in other individual sports [14]. Individual sports, such as track-and-field events provide an objective rank system to measure time, distance or height, which can produce an accurate measurement of competitive performance in these events [11]. The intricacy of determining the individual performance of players in soccer is attributed to the subjectivity of the means of performance analysis and the acyclical nature of the event, in addition to the absence of a clear index to measure the player's performance within a team [11,14,20]. Therefore, it was suggested that the individual contribution in soccer may be measured by the overall distance covered during a game [21]. This is regarded as a valid method of performance measurement in soccer as energy expenditure is directly associated with a given accomplished distance that provides a useful global scale of work rate averaged over the entire duration of a game. Moreover, it facilitates in the determination of the mode, duration, intensity and frequency of the action executed by a player during a game [11]. Thus, motion analysis provides an objective method for a comprehensive scale to determine performance of players [12]. Nonetheless, the limitations of the traditional manual (e.g. Reilly and Thomas, 1976) and the more recent computer aided (e.g. Di Salvo et al. 2007) methods employed to interpret the work rate profile need to be taken into consideration.

The traditional manual video based motion analysis was extremely labor-intensive and was restricted to analyze one player per game [12,21]. In addition, human error through the subjective nature of movement recognition [22], and the difficulties in the determination of changes in gate movements during the match [23] could be encountered in this method. The more recent computer based analysis allows for simultaneous analysis of all players during a game in a relatively short period of time [5]. However, their reliability and validity has not been satisfactorily established [12]. Therefore, work rate profiles expressed as distance covered is considered to

***Corresponding author:** Abdullah F Alghannam, Department for Health University of Bath BA2 7AY, UK, Tel: (+44) 1225 385 918; E-mail: A.F.Alghannam@gmail.com

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be the most appropriate method of monitoring a player during the game [21]. It is also important to consider that the amount of energy expended during soccer participation is greater than mere running to cover a similar distance [11]. While it has been reported that field running is more energy demanding than on a compact terrain [24], the augmented energy expenditure in soccer is largely attributed to the additional imposed physical demands during the match such as environmental influences and sport-specific movements [25,26].

Match Activity Profile

Relative discrepancies exist in the literature for the distance covered by players in soccer matches. The variations in work-rate profiles were ascribed to differences positional roles [5], environmental conditions [25] style of play [27] and nutritional status [28] of players. However, it was consistently observed that the distances covered in contemporary elite soccer to be around 10-12 km (Table 1) with midfield players covering greater distances than any other position within the team [6]. The relative distance covered in different activity patterns of outfield players was reported to be 24% walking, 36% jogging, 20% cruising, 11% sprinting and 7% backward "off the ball" movements [3]. Accordingly, the possession of the ball consisted of 2% of the total distance covered by players during the game, while sideways movement and diagonal runs are superimposed within these broad movement categories [11,29]. This coding of activity pattern was suggested to be a good representation of contemporary match play in the major national leagues in Europe [30], and was shown to be in concurrence with time-based motion analysis studies [5].

The distance covered in soccer encompasses ~1200 discrete bouts [31] changing every 4-6 seconds [9]. It was estimated that 150–250 of these bouts are intense in nature [32]. The time ratio between low-intensity and high-intensity activity is approximately 7:1 [33]. Nevertheless, recent findings suggest that contemporary elite players perform more frequent (32 ± 8), shorter (≤ 10 meters) and more explosive high-intensity bouts than earlier players [34], with an estimated recovery time of ~72 seconds within these bouts [35]. Albeit, the work-rate profiles provide a relatively consistent representation for players from game to game, it was indicated that high intensity activity was shown to be the most constant feature [7].

Physiological and Metabolic Demands of Soccer

Aerobic periods in soccer

Soccer is broadly characterized as an intermittent aerobic event interspersed with periods of high-intensity activities [9,38]. Players perform numerous different types of exercise intensities during the game and consequently both the aerobic and anaerobic energy systems contribute to the physiological demands of the game [7,8]. The total duration of active play in soccer is typically 95 minutes [11]. Thus, the primary energy source during the game was suggested to

League	n	Distance (km)	Method of analysis	Reference
English Premier League	24	10.3	Manual video	[30]
English Premier League	370	10.7	Automatic computer	[35]
Danish Premier League	23	10.8	Manual video	[36]
Champions League matches	791	11.0	Automatic computer	[37]
Italian League	18	10.9	Manual video	[32]
Spanish and Champions League matches	300	11.4	Automatic computer	[5]

Table 1: Distance covered during match play in contemporary elite soccer; n, number of players.

League/level	n	VO_{2max} (ml.kg^{-1}.min^{-1})	Reference
Saudi/national team	23	58.0 ± 4.9	[42]
English/professional	12	63.3 ± 5.8	[43]
Senegal+Tunisia/elite under 19	34	61.1 ± 4.6	[44]
Spanish/elite under 17	32	62.0 ± 2.0	[45]

Table 2: VO_{2max} values of elite soccer players ; n, number of players.

be supplied via aerobic glycolysis [9]. The average maximum oxygen uptake (VO_{2max}) during match play was reported to be around 75-80% [6,7]. The mean and peak heart rate (HR) of players were estimated to be around 85 and 98% respectively [38]. Nonetheless, VO_{2max} values for soccer players were shown to vary noticeably, with current high-level soccer players are suggested to acquire maximal oxygen uptakes between 60-70 ml.kg^{-1}.min^{-1}, with an estimated minimum of 65 ml.kg^{-1}.min^{-1} to be found in elite soccer players [9, 39]. The variability in maximal oxygen uptake according to position is relatively small with higher VO_{2max} values observed in midfield and wider defensive players than other outfield players [39,40].

However, the absence of accurate and valid direct measurements of oxygen consumption (VO_2) during match play should be noted and that the values obtained through direct measurement are likely to be underestimated as the result of the interference of the testing modalities with performance [9]. Consequently, the majority of the methods conducted to estimate the VO_{2max} in soccer were calculated and converted by a relationship between the HR and VO_2 during treadmill running [41]. This was suggested to allow accurate indirect measurement of VO_2 during soccer matches without any restrictions on performance, and therefore represents a valid method for estimating the aerobic capacity in soccer [7]. Nevertheless, HR during a game could become overestimated, and consequently ascribe to a subsequent overestimation of VO_{2max} with numerous factors contributing to these elevations *in situ* such as hyperthermia, mental stress and dehydration [8]. As a result, the average VO_{2max} during a soccer match subsequent to the consideration of these factors was shown to be around 70% of the maximal oxygen uptake [8] (Table 2).

Anaerobic periods in soccer

The energy delivery during a soccer game is predominantly supplied by the aerobic metabolism. However, high-intensity anaerobic bouts were indicated to be an essential component of performance in soccer, as they comprise the most crucial events during the game [9,32]. Thus, the anaerobic effort is a determinant in repeated sprint bouts, jumping, tackling and duel play [29,46]. The ability to tax the anaerobic system to higher degree was shown to increases with the level of competition [9]. Indeed, high-intensity anaerobic activity was reported to distinguish between the different standard of players [32], higher and lower levels of competition [7], training status [38], the tactical role of players within a team [27] and the overall the success of a team [34].

The anaerobic contribution to the overall energy demand becomes emphasized when direct involvement in play takes place, such as position contention and ball possession [11]. This is evident by means of blood lactate concentrations of 2-10 mmol.l^{-1} during competitive soccer play [7,47]. However, it was observed that blood lactate measurements are variable between players, with a wide range of values that may reach 12 mmol.l^{-1} in some participants [7,9,47]. The fluctuations in the blood lactate measurements in the literature were attributed to the varying collection times, which could be taken following low-intensity activity or high-intensity bouts [39]. This was supported by findings that a high rate of anaerobic glycolysis was observed at short but frequent periods of time during the game, and therefore the high blood lactate concentrations observed in soccer may be a reflection of an accumulative effect that corresponds to the numerous high-intensity bouts [7,8,47].

Metabolic stress of soccer

A comprehensive view regarding substrate utilization and the onset of fatigue in soccer is beyond the scope of this review. The reader is referred a recent publication detailing the metabolic limitations of performance and fatigue development in this event [48]. Briefly, soccer participation requires energy turnover from both aerobic and anaerobic metabolism to support the demands of activity, which is associated with a large consumption of substrates [7]. A substantial oxidation of endogenous carbohydrate (CHO) stores is apparent in soccer competition, particularly from glycogen depots within the skeletal muscle [31,49,50]. The contribution from glycogen breakdown declines with a simultaneous elevation in extra-muscular blood glucose levels from the liver, that ensures the maintenance of euglycemia during the match [40,49,51,52]. CHO metabolism is suggested to supply ~55% of the energetic requirements of match play and therefore other substrates must be taken into account [7]. An appreciable contribution (~40%) from fat metabolism, especially from free fatty acids released from adipose tissue, was indicated to occur [7]; a mechanism by which hepatic blood glucose concentrations can be maintained throughout the game [8]. With an increased physiological strain, protein metabolism my contribute 2-3% to total energetic demands of soccer arising mainly from branched-chain amino acid oxidation [53,54], although the extent of protein metabolism remain unclear [40]

Macronutrient ingestion in soccer

CHO is the most metabolized fuel in soccer [55]. However, in contrast to continuous exercise, the effect of CHO ingestion on intermittent multiple-sprint activities is limited [56]. Nevertheless, the relatively small number of studies has demonstrated the significance of CHO ingestion in both field and laboratory based investigations in prolonged intermittent exercise similar to soccer [57]. The effect of a 48-hour prior diet manipulation consisting of a high (~8 $g.kg^{-1}.day^{-1}$) versus normal (~4.5 $g.kg^{-1}.day^{-1}$) CHO intake was investigated in professional soccer players [58]. The protocol involved an intermittent high-intensity field and treadmill running for approximately 90 minutes. The study reported an increase of 5.5% in the distance covered during intermittent running to fatigue by the high CHO group at the end of the protocol when compared to a normal diet. Thus, CHO intake appears to improve intermittent endurance performance. Nonetheless, the performance enhancement was not observed in all participants in that study [58].

The effects of endogenous CHO availability on high-intensity intermittent performance were subsequently investigated in another study [59]. The participants in the study were instructed to follow a 48-hour nutritional intervention that consisted of a high CHO (67% of the total energy intake) to enhance muscle glycogen stores, and a low CHO diet (4% of the total energy intake) to maintain low glycogen levels. The protocol included 6-second high-intensity bouts performed during short-term (<10 minutes) and prolonged (>30 minutes) duration at 30-second intervals. The study showed a marked reduction in high-intensity work in both protocol durations by the low CHO group when compared to high CHO participants and thus indicating that muscle glycogen availability may influence intermittent exercise. Accordingly, a further investigation looked into the effects of increased endogenous CHO availability during a 90-minute indoor soccer match [60]. The study confirmed previous studies by observing a 38% increase in glycogen content and a concomitant 33% increase in high-intensity work by the high CHO (65% of total energy intake) when compared to a control group (30% of total energy intake).

Other investigations supported the previous findings by observing that CHO consumption improved intermittent running capacity [61,62], soccer skill performance [63] and the distance covered during the second half of the game [64] when compared to a placebo beverage. The beneficial effects of CHO ingestion were associated with the maintenance of glycogen levels [61,65]. However, other factors may be a consequence of the ergogenic effect of CHO ingestion. One explanation was associated to the enhanced fuel availability to the active muscles and Central Nervous System (CNS) as the result of the elevated plasma glucose concentrations [62]. Another mechanism could be ascribed to the lowered free fatty acid concentrations as the result of CHO ingestion. This was suggested to delay serotonin formation and consequently attenuate central fatigue [66]. Irrespective of the possible mechanism of this enhancement in endurance capacity, the overall literature supports the value of adequate refueling through CHO ingestion for activities requiring high-intensity intermittent exercise [16]. As a result, availability of CHO was shown to influence soccer performance by enhancing the capacity to perform intermittent activity and may become a limiting factor in performance when depleted [16,67].

There is some evidence to suggest that the inclusion of protein with CHO may be beneficial from a performance perspective in intermittent exercise similar to soccer. It was recently shown that adding protein to a CHO supplement increases endurance running capacity towards the end of a simulated soccer match by 43% when compared to a CHO solution with equal energy content [68]. Similarly, co-ingestion of protein-CHO may also attenuate the decrements of performance towards the end of the game to a greater magnitude than with CHO ingestion alone [69]. The mechanism behind these effects remains largely unknown, however an improved central drive originating from the CNS (through a reduction of central fatigue mediated by branched-chain amino acids; [70]) may be a candidate, as evidenced by a reduced perceived exertion during exercise [68]. Nevertheless, this topic is still debatable and further research centered upon the precise nutrient type/amount to optimize training and competition in soccer is warranted.

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