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Physical and Physiological Demand of Soccer Player Based on Scientific Research

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Abstract

Soccer is the most popular sport in the world with nearly 200 million practitioners. Match analysis of the physical demand have revealed that the game is characterized by the mix of short-duration sprints, high-intensity running, jumps, duels, tackles, directional changes, backward, and walking and standing episodes with an average game intensity ranging from 80 to 90% of maximal heart rate (HR_{max}). For instance, top-level players require developing specific physical capacities such as an elevated aerobic power and the ability to perform repeated HIR (including sprinting) with limited rest period, to be able to cope with the game demands. The utilization of glycogen stores during a football match was suggested to be 155–160 g from the muscle glycogen stores, with an estimated 600 kcal of energy provided, while blood glucose derived from the liver may account for approximately 210 kcal of energy during the game. In accordance, the endogenous CHO stores are suggested to supply ~55% of the energy requirements of match-play, and a substantial utilization of lipids and proteins must also be taken into account.

1. Introduction

Football game is the most popular sport in the world. Based on the linear HR-VO2 relationship established in laboratory treadmill tests, it was found that the average intensity of elite adult players ranged from 70 to 80% VO_{2max} during a match play (1). Strøyer and et al. 2006, reported similar values using Danish youth players (12–14 years), with the application of linear regression equations based on the individual HR-VO2 relationship calculated from submaximal and maximal treadmill tests (2). In terms of energy expenditure, a value of 1360 kcal has been reported during match play for a player weighing 75 kg and having mean oxygen consumption (VO_{2max}) of 60 $ml.kg^{-1}.min^{-1}$ (3). However, these intensities seem to be somewhat inflated because both elite adult and youth players are often stationary or walking during soccer training and/or matches (4). Both standing still and walking constitute approximately

15 and 40%, respectively, of the total playing time during a 90-minute match (5). However, high-intensity activities, (sprinting, directional changes, and tackles/duels) and short/insufficient recovery intervals between these actions, elevate the exercise intensity (EI) close to maximal values (4-6). Because the majority of soccer activities are performed at low to moderate intensities, it is described as an ‘‘intermittent aerobic sport’’ with approximately 90% of total energy expenditure provided by aerobic energy sources/ pathways (1, 7). However, 150–250 (approximately 15%) soccer actions are performed at a high intensity (8), which are sufficient to increase the blood lactate concentration to submaximal values (3–8 $mmol.L^{-1}$) (9).

Researchers examined Brazilian professional first division players during 2 friendly matches and concluded that the HR stayed below the anaerobic threshold for 56.7 ± 21.9% of total match duration (10). Physiological load with increased anaerobic characteristics was reported by Coelho 2005, in Brazilian youth elite players during competitive matches, using linear interpolation in the field tests to determine the percentage of HR corresponding to 4 $mmol.L^{-1}$ of blood lactate, showing that players remained above 85% of the HR_{max} for more than half the match, which corresponded to the anaerobic threshold (11). Using the same procedure, Eniseler 2005, confirmed these results as 49.6 ± 21.1% of the total duration of a match play was spent by elite Turkish players above the anaerobic threshold. These studies used the anaerobic threshold as a reference point to correspond to the complexity of the physiological stimuli of soccer (12). The metabolic interaction above the anaerobic threshold highlights the importance of developing aerobic capacity, expressed by VO_{2max}, which allows an elevated level of recovery, the removal of the produced lactate, and the capacity to perform repeated high-intensity actions (13). It is thus suggested that coaches should structure HR zone-based training sessions based on the results of laboratory and/or field test to individualize and optimize the physical training of the players (10).

1.1 Exercise Intensity during the First and Second Halves of Match Play

The precise analysis of HR responses during match play according to the different halves reveals that the mean EI (exercise intensity), measured by HR, decreases in the second half with respect to the first half in elite adult (14), junior (15), University (16), recreational (17), and youth players (9). When the EI was considered as a function of time in relation to the HRmax intensity zones, Helgerud and et al. found a redistribution of the zones in the second half. They observed a reduction in the time spent within 85–90% HR_{max} and an increase of the time spent in the lower intensity zone (75–80% HR_{max}) (18). The same tendency was presented by Coelho reporting a drastic change in the time spent between 70 and 85% HR_{max} from the first half (34.5 ± 2.4%) to the second half (43.9 ± 1.1%) of the match, but it could not justify the detection of overtraining and overuse or a detraining (10).

During the second half of the match, professional players covered 5–10% less distance than during the first half, especially in the moderate (11.1–19.0 $km.h^{-1}$) and high-intensity (18.0–30.0 $km.h^{-1}$) speed categories. In the same context, blood lactate concentration, distance covered at high intensity, and number of sprints confirmed the decrease of high-intensity actions during the second half, which was described as independent of the playing level (10).

Some local physiological mechanisms could explain the lower physical activity of the players at the end of the second half. During the match play, a progressive degradation of muscle glycogen (from 40 to 90%) in muscle fibers has been observed, especially in the IIb fiber type (19). There is also a reduction in the levels of creatine phosphate, muscular pH, an increase of muscle monophosphate inosine, an accumulation of the potassium stocks (19), and a temporary decrease in the temperature of the quadriceps (20) and the body (21), in addition to dehydration (22). Despite these suggestive factors, the reason that might cause fatigue or overuse in soccer players during a match are multifactorial and still not clear and are not always associated with a reduction in the performance of sprints (19, 22).

1.2 Exercise Intensity and Heart Rate Responses According to the Playing Position

In professional (23), junior, youth (2), and university players (17), it has been shown that HR responses differed according to the playing positions, with the greatest values for the midfielders and lowest values for the central defenders. Ali and Farrally were in agreement with this observation by showing greater HR responses (176 ± 9 $b.min^{-1}$) for midfielders, in comparison with forwards (173 ± 12 $b.min^{-1}$) and central defenders (166 ± 15 $b.min^{-1}$)(17).

The midfielders' cardiovascular overload could be explained by the tactical functions of these players in the modern soccer tactical systems of play. These players presented a greater total distance covered in sprint, higher number of ball possession, and greater number of duels. Moreover, from a technical and tactical point of view, they are included both in offensive and defensive play. Midfielders usually present the best highest aerobic capacity, which allow them greater possibilities of active participation during games (10).

An interesting strategy for future studies is the adoption of HR responses to determine the precise EI according to the playing position. Researchers have studied Brazilian junior players, finding that midfielders spent more time at 85–90% and 90–95% HR_{max} than the other positions. However, the fullback presented the highest total duration spent at 95–100% HR_{max} intensity zone, and in contrast, they were also players remaining more time in the smallest EI at 70% of HR_{max}. Fullback's role is characterized by a high number of very high-intensity actions, which could explain why they require a greater period of recovery than other playing positions (10).

1.3 High-intensity intermittent in soccer

Soccer is a high-intensity intermittent sport which is normally played over 90 min, split into two 45 min halves that are separated by a 15 min half-time period (24).

The speed and accuracy with which players completed soccer-specific skills were significantly affected after a 45-min period of intermittent shuttle running replicating one half of a soccer match. Finally, soccer skill performance measured by the time taken to complete a passing test, including penalty time accrued for inaccurate passing or poor control, declined during the final 15 min of exercise within a 90-min intermittent running test (25). Changes in arousal (25), decreased neuromuscular and cognitive function (5), glycogen depletion and dehydration are possible candidate factors for impaired skill-related performance during and/or towards the end of such exercise (26). While a decline in physical performance was observed during the second half and the final third of games, this was not accompanied by a drop in skill-related performance. In addition, unlike high-speed running performance, skill-related measures were not affected in the 5-min period following the most intense 5-min period of high-speed exercise. In contrast, a reduction in the distance covered in high-speed exercise was accompanied by a drop in the frequency of some skill-related variables during the final 5 min of games. None of the physical or technical measures of performance were affected when competing in three successive matches within a short time-frame (<7 days) (26).

Intermittent high-intensity endurance and the ability to repeatedly sprint within relatively short time intervals (RSAs) are deemed relevant fitness prerequisites in competitive soccer players (19). Consequently, intermittent training and testing protocols have been proposed to improve soccer player’s fitness and guide talent selection (27). Recent studies reported that high-intensity intermittent endurance and RSA are both influenced by anaerobic and aerobic metabolism (28). Additionally, training studies showed that RSA training positively affects intermittent high-intensity performance (27).

Bangsbo et al. (2006) stated that the focus of training intervention, within soccer, should be on developing the capacity to perform intense exercise and on improving the ability to recover between these intense bouts. These improvements would necessitate developments in both the aerobic and anaerobic energy systems. The most efficient way to develop these capabilities may be to perform high-intensity interval type training as this medium may be able to stimulate both aerobic and anaerobic metabolism if the intensity, duration, frequency and recovery periods are sufficient (29). High-intensity aerobic training consisting of eight 2min exercise period separated by 1min recovery periods. The length of time the heart rate was 80 – 90, 90 – 95, and 95 – 100% of maximum (29).

Bloomfield et al. (2007) reported that approximately 80–90% of performance is spent in low to moderate speed running whereas the remaining 10–20% is covered in high intensity running and sprinting (30).

1.4 Metabolic demand in soccer player

Early assessments of metabolic demand, which were conducted through measurements of body temperature (31), demonstrated that the average metabolic load of a soccer player is close to 70% of VO_{2max}. In addition, HR recordings do not yield information on high-intensity bouts. Likewise, direct measurement of oxygen uptake is not suitable to provide data on high-intensity exercise, and its use during training sessions or competitions is not feasible (32). Overall, all these methods show that the total estimated energy expenditure during a match ranges from 1200 to 1500 kcal (1, 31). The studies conducted so far on anaerobic energy expenditure are rather scant; furthermore, the current procedures are not applicable to official matches and are definitely not suitable for continuous recordings. An example of this approach is the study by Krustrup and et al 2006, which measured creatine phosphate concentration on biopsies taken from muscular tissue of athletes immediately after high-intensity exercise bouts during a soccer match. Blood lactate concentration (LA) has also been considered as a marker of anaerobic energy expenditure by several researchers (19); the results of these studies show that its level during matches ranges from 2 to 10 $mmol.L^{-1}$.

In accordance, it was indicated that both the aerobic and anaerobic energy systems contribute to the physiological demands of the game (29). The total duration of active play in football is typically 90 minutes (33), indicating that the primary energy source during the game is supplied via aerobic glycolysis (1), with an average maximal oxygen uptake (VO_{2max}) of around 70 – 80% during the match (34). The mean and peak heart rates of players were estimated to be around 85 and 98, respectively (35).

The utilization of glycogen stores during a football match was suggested to be 155 – 160 g from the muscle glycogen stores, with an estimated 600 kcal of energy provided, while blood glucose derived from the liver may account for approximately 210 kcal of energy during the game (36). In accordance, the endogenous CHO stores are suggested to supply ~55% of the energy requirements of match-play, and a substantial utilization of lipids and proteins must also be taken into account (3).

It was suggested that lipid oxidation to fuel the aerobic processes of the exercising muscles during the game are derived from intramuscular triglycerides or via the blood as free fatty acids (FFA), with an estimated 40% of the total energy being met from the oxidation of FFA (3). Accordingly, it was observed that FFA concentrations increase during the game, with marked elevations during the second half (19). This was attributed to the frequent periods of rest and low-intensity exercise during match-play, that would enable sufficient perfusion of the adipose tissue and subsequently promote the release of FFA (22). The extent of protein metabolism during a football game remains unclear (36). However, it was shown that a small contribution of the total energy requirement is derived from breakdown of protein, particularly branched-chain amino acids, with an estimated supply of 2–3% of total energy metabolism (37).

This is supported by measurements of core temperature, which is another indirect measurement of energy production. Core temperatures of 39°C to 40°C during a game suggest that the average aerobic loading during a game is 70% to 75% VO_{2max} (14).

The observation that elite soccer players perform 150 to 250 brief, intense actions during a game indicates that the rate of anaerobic-energy turnover is high during periods of a game (8). Even though it has not been studied directly, the intense exercise during a game would lead to a high rate of breakdown of creatine-phosphate (CP), which to a major extent is resynthesized in the subsequent periods of low-intensity exercise (19). Measurements of CP in muscle biopsies obtained after intense-exercise periods during a game have shown average levels around 75% of the level at rest. This is, however, likely to be significantly lower during the match, because these values were obtained from biopsies taken 15 to 30 seconds after-match activities in which a substantial resynthesis of CP undoubtedly has occurred (19). Using proper values for resynthesis of CP and the measured CP values, as well as the delay time in obtaining the biopsies, it can be estimated that the CP concentration during the game would have been about 60% of the resting level (19).

The CP levels might during parts of a game become low, below 30% of resting level, if a number of intense bouts are performed with only short recovery periods. More important, CP might become very low in individual muscle fibers, because the stores of CP have been reported to be almost depleted in individual fibers at the point of fatigue after intense exercise (38).

During the match studied by Krustrup and et al 2006, muscle ATP was only moderately reduced (15%) during the game, which to some extent might have been a result of the 15- to 30-second delay in obtaining the biopsies. Even during intense short-term exhaustive exercise, however, muscle ATP is not lowered more than 30%, and the resynthesis rate is rather low in recovery. Thus, the observed ATP concentrations might reflect true lowering of muscle ATP. A corresponding accumulation of muscle IMP is observed during a game (19). In addition, plasma NH3 concentration is higher, supporting the suggestions of a significant activation of muscle AMP deaminase reaction. In addition, the concentrations of hypoxanthine and uric acid in the blood were significantly higher during match play than at rest, indicating a further breakdown of IMP (3, 38).

1.5 Muscle Glycogen Utilization during a Soccer Match

Saltin observed that the muscle glycogen stores were almost depleted at halftime when the prematch levels were low (~45 mmol/kg wet weight). In that study, some players also started the game with normal muscle glycogen levels (~100 mmol/kg wet weight), and the values were still rather high at halftime but below 10 mmol/kg wet weight at the end of the game. Others have found the concentrations to be 40 to 65 mmol/kg wet weight after a game (19, 39), indicating that muscle glycogen stores are not always depleted in a soccer game. Analyses of single muscle fibers after a game, however, have revealed that a significant number of fibers are depleted or partially depleted at the end of the game (Figure 1) (19).

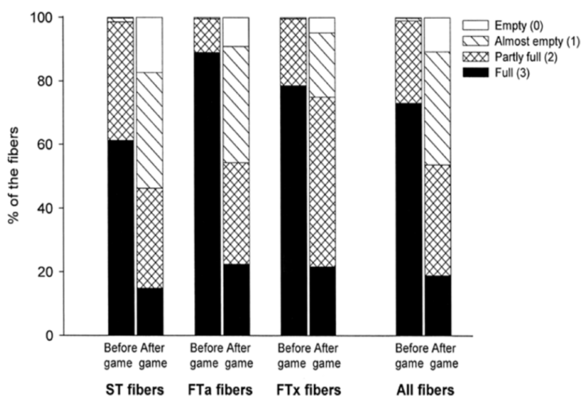

Figure 1. Relative glycogen content in slow-twitch (ST) and fast-twitch (FT) A and X fibers, as well as all fibers, before and immediately after a soccer match. Values are mean (n = 10) (Based on Mortimer, et al 2006) (20).

The intense exercise periods during a soccer game lead to high anaerobic-energy turnover with an associated accumulation of lactate and lowering of pH in the exercised muscles. These factors are probably not, however, the main factors in the temporary fatigue that occurs during a game, which is probably caused by a complex interplay between a number of factors. Recent data from human studies support an old theory about accumulation of potassium in muscle interstitium and a concomitant change in muscle membrane potential playing an important role in the development of fatigue during intense exercise (40, 41). In a study by Krustrup and et al. (2006), the muscle glycogen concentration at the end of the game was reduced to 150–350 mmol.kg dry weight (19).

1.6 The distances covered in the first and second halves of football match-play

The so-obtained data yield distances covered and relative speeds, football control, and distance from fellow players and from the other pitch areas. The results of these studies (3, 5, 23, 32) show that:

1. The total distance covered in a match (TD) ranges from 10 to 13 km, with differences related to rank and role.

2. The distance covered in the first half of the match is usually 5%–10% greater than that covered in the second half.

3. On average, players spend 70% of the total match duration performing low-intensity activities such as fast walking and jogging, whereas in the remaining 30%, they are engaged in approximately 150–250 actions of 15–20 m of high-intensity exercise.

4. ‘‘Sprinting,’’ which, in the different studies, is defined as a running speed above a lower limit ranging from 19 to 25 km.h-1, amounts to 5%–10% of the TD covered during a match, thus corresponding to 1%– 3% of the match time; average sprint duration is 2–4 s, and average sprint occurrence is 1 in 90 s.

Furthermore, the present approach allowed us to assess the metabolic power exerted by the athlete at any instant, thus redefining the concept of ‘‘high intensity.’’ The results show that top-class players covered approximately 18% of TD at high speed (exceeding 16 $km.h^{-1}$), although they spent more than 42% of the total energy at high-power output (920 $w.kg^{-1}$). Other parameters make it possible to customize the players’ evaluations. A power threshold (TP) can be defined for each player, and the energy derived above this threshold, presumably from anaerobic sources, can be assessed. The use of the same TP for the 399 players involved in one study (>20 $w.kg^{-1}$) shows that the anaerobic energy yield ranges from 11% to 27% of total energy output (33).

In the study of Aslan and et al. (2012), the average TD covered by an outfield player was 9.9±0.84km, which was within the range of 8–12 km reported in previous studies (8, 42). In line with the findings of this study, it was stated that TD covered in the 2nd half of matches decreased in top and moderate level soccer players (8). It was also consistently reported that, in the 2nd half or in the last 15- min period of matches, high-intensity distance (HID) decreased independent of playing position, level of competition and gender (6, 8).

Based on LA, HR and RPE responses, the findings of research of Aslan and et al. (2012), indicated that young soccer players experienced a higher physiological stress during the 1st half of the matches compared to the 2nd half. Even though the 2nd half of the matches was lower in terms of the volume and intensity of running compared to the 1st half, RPE values gradually increased throughout the matches (43). In addition, although, the movement patterns of players differed greatly across playing positions, the distances covered at fixed LA concentrations (FBLs) were similar, except for FBL2. Therefore, it can be concluded that the external load imposed on players differed in accordance with position players in the field, but that all players experienced a similar physiological stress during the matches, as supported by HR and RPE responses to match play. The results also demonstrated that HR was over 160 b·min-1 for approximately 70% of the total match time. Indeed, the players reached approximately 85% of their maximal HR during match play. In addition, approximately one-quarter of TD was covered at speeds that exceeded the 4 $mmol{\cdot}L^{-1}$ fixed LA threshold. This study also revealed that TD covered was influenced by FBLs in young soccer players. From a practical point of view, this result emphasizes that players should exercise at running speeds corresponding to fixed blood lactate levels to increase their distances during soccer match play (43).

Comparison of the distances covered in the first and second halves of football match-play in different leagues (44):

- Swedish 3% greater distance in the first half.
    - Brazilian 8% greater distance in the first half.
    - Danish 5% greater distance in the first half.
    - Italian 3% greater distance in the first half.
    - Euro cup 1% greater distance in the first half.
    - English 2% greater distance in the first half.
    - South American + English 4% greater distance in the first half.

1.7 Recovery in soccer player

In practice, several recovery strategies are used: low-intensity training, active warm-down, massage, stretching, resistance training, deep-water running, and contrast-temperature water immersion (45). These strategies are designed to minimize the stress induced by matches and accelerate the recovery (45). The theoretical overall advantage of active recovery would be to allow the players to tolerate higher training loads (intensity, volume, and frequency) and to ultimately enhance performance (45, 46). Active recovery training may include submaximal cycling and low-intensity resistance training.

There is only one scientific report evaluating the effects of an active recovery program after a soccer match (47). The study was on male players who performed acute warm-down for 12 min immediately after the match. The active warm-down had a positive effect on the recovery of jump and sprint performance and perceived muscle soreness (48).

In conclusion of the study of Anderson and coworker (2007) clearly demonstrates the existence of differences in the recovery pattern of the various neuromuscular and some biochemical parameters in response to a female soccer match. This study also shows that the time course of recovery of the neuromuscular and biochemical parameters is not affected by active recovery. Finally, the performance of players during the game, expressed as mean heart rate value and amount of high intensity running, is not impaired when two matches are interspersed by 2 d of active or passive recovery (48).

Bangsbo and Mohr (2005) examined fluctuations in high-intensity exercise, running speeds, and recovery time from sprints during several top-class soccer matches. They found that sprinting speed in games reached peak values of around 32km. h-1 and that sprints over more than 30m demanded markedly longer recovery than the average sprints (10–15m) during a game (49).

Mohr et al. (2003) showed that the attackers had a more marked decline in sprinting distance than the defenders and midfield players. In addition, the performance of the attackers on the Yo-Yo intermittent recovery test was not as good as that of the full-backs and midfield players. Thus, it would appear that the modern top-class attacker needs to be able to perform high-intensity actions repeatedly throughout a game (8).

1.8 Training protocol

Aerobic interval training, consisting of 4 × 4-minute bouts at 92–95% of maximal heart rate with 3-minute rest periods in between, performed twice weekly for 4 weeks, was reported to increase maximum oxygen consumption (VO_{2max}) by 10.8%. This improvement was accompanied by an increase in distance covered in a match by 20%, allowing players to cover greater distances at a higher intensity (18).

Ekblom (1986) calculated that the distance covered in high-intensity running during a match amounted to 500 m when the environmental temperature was 30°C compared with 900 m when the temperature was 20°C (50).

It has been proven previously that interval training enhances aerobic endurance in soccer players by increasing distance covered, enhancing work intensity, and increasing the number of sprints and involvements with the ball during a match (18). The players spend 1–11% of the game sprinting (15, 51), which represents 0.5–3.0% of effective time with ball in play (51). For example, a midfielder player sprints more than 1.1 km of total 10.9 km distance covered during the match. For this reason, it is extremely important to incorporate anaerobic training into overall conditioning training protocols (52).

The midfield players performed as many tackles and headers as defenders and attackers. They covered a total distance and distance at a high intensity similar to the full-backs and attackers, but sprinted less (29). 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 (53).

Therefore, according to the above mentioned, we can design this protocol for improving physical performance of top-class soccer players (Figure 2).

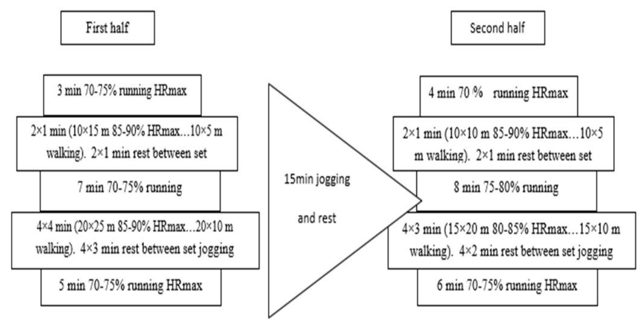

Figure 2. Protocol designed for soccer players according to scientific researches.

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