

Research article

Metabolic demands of match performance in young soccer players

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Abstract

The aim of the present study was to determine metabolic responses, movement patterns and distance covered at running speeds corresponding to fixed blood lactate concentrations (FBL_s) in young soccer players during a match play. A further aim of the study was to evaluate the relationships between FBL_s, maximal oxygen consumption (VO₂max) and distance covered during a game. A multistage field test was administered to 32 players to determine FBL_s and VO₂max. Blood lactate (LA), heart rate (HR) and rate of perceived exertion (RPE) responses were obtained from 36 players during tournament matches filmed using six fixed cameras. Images were transferred to a computer, for calibration and synchronization. In all players, values for LA and HR were higher and RPE lower during the 1st half compared to the 2nd half of the matches ($p < 0.01$). Players in forward positions had higher LA levels than defenders, but HR and RPE values were similar between playing positions. Total distance and distance covered in jogging, low-moderate-high intensity running and low intensity sprint were higher during the 1st half ($p < 0.01$). In the 1st half, players also ran longer distances at FBL_s [$p < 0.01$; average running speed at 2mmol·L⁻¹ (FBL₂): $3.32 \pm 0.31\text{m}\cdot\text{s}^{-1}$ and average running speed at 4mmol·L⁻¹ (FBL₄): $3.91 \pm 0.25\text{m}\cdot\text{s}^{-1}$]. There was a significant difference between playing positions in distance covered at different running speeds ($p < 0.05$). However, when distance covered was expressed as FBL_s, the players ran similar distances. In addition, relationships between FBL_s and total distance covered were significant ($r = 0.482$ to 0.570 ; $p < 0.01$). In conclusion, these findings demonstrated that young soccer players experienced higher internal load during the 1st half of a game compared to the 2nd half. Furthermore, although movement patterns of players differed between playing positions, all players experienced a similar physiological stress throughout the game. Finally, total distance covered was associated to fixed blood lactate concentrations during play.

Key words: Soccer, time motion analysis, blood lactate, heart rate, rate of perceived exertion.

Introduction

Within the sport science literature, especially during the last two decades, the metabolic demands and activity profiles of players during soccer matches have been widely studied (Bangsbo and Lindquist, 1992; Mohr et al., 2003; Rodrigues et al., 2007; Roi et al., 2004). Several reports have demonstrated that the average heart rate (HR) during a 90-minute soccer match ranges from 155 to 172 b·min⁻¹ (Ali and Farrally, 1991; Bangsbo, 1994; Eniseler, 2005; Rodrigues et al., 2007) which corresponds to approximately 85% of maximum HR (Helgerud et al., 2001). This relative work load is close to the anaerobic

threshold (Stolen et al., 2005). Measuring blood lactate (LA) concentrations is also beneficial in indicating the severity of exercise. Most studies have shown average LA values of 4 – 8 mmol·L⁻¹ during match play (Ekblom, 1986; Rohde and Espersen, 1988; Roi et al., 2004). In addition to HR and LA, there have been numerous investigations to determine type, intensity, distance and duration of running activities during match play. 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. Even without establishing any other physiological variables, time-motion analysis alone provides important information about a player's specific training needs. However, it can be criticized as being a poor indicator of individual physiological stress level, since chosen movement speeds thresholds in time-motion studies (walking, jogging, cruising and sprinting) are the same for players at different performance levels. Together with HR, fixed LA concentrations are one of the best indicators of training load during exercise (Billat, 1996; Svensson and Drust, 2005). Therefore, to indirectly determine individual physiological load using time-motion analyses, it might be better to use running speed at fixed LA concentrations (FBL_s) as a reference. This might be important, particularly when comparing player performance according to positional role.

An alternative method to assess internal load imposed on players during match play is rating of perceived exertion (RPE). A strong relationship between RPE and HR has been established (Borg, 1982). However, it is suggested that RPE is more sensitive to accumulated fatigue than HR during prolonged exercise (Martin and Andersen, 2000) and may be a more reliable measure of exercise intensity during intermittent activities like soccer training and match play (Impellizzeri et al., 2004; Coutts et al., 2009). Therefore, measuring RPE values throughout a soccer match can provide understanding of internal load imposed on players and accumulated fatigue towards the end of a game. However, it is still unclear how hard a player perceives he/she is working throughout a soccer match.

In contrast to RPE, it was reported that LA (Ekblom, 1986; Rohde and Espersen, 1988), HR (Bangsbo, 1994), amount of sprinting and high intensity efforts (Barros et al., 2007; Mohr et al., 2003; 2008; Rienzi et al., 2000) were lower in the second half of a game than in the first half. These reductions may indicate development of fatigue in the second half. However, soccer players should ideally be able to maintain high exercise intensity

throughout a game. It has been reported that enhancing maximal oxygen consumption (VO_2max) improved soccer performance, represented by distance covered, level of work intensity, number of sprints, and number of involvements with the ball during a match (Helgerud et al., 2001). In addition, several studies have indicated a significant correlation between VO_2max and total distance covered during a soccer match (Bangsbo and Lindquist, 1992; Bangsbo, 1994; Krstrup et al., 2005). It was also demonstrated that VO_2max can be improved by performing a soccer specific high intensity interval training (McMillan et al., 2005). Apart from the importance of VO_2max , it has also been suggested that fixed blood lactate levels between 2 and $4\text{mmol}\cdot\text{L}^{-1}$ may be used as an indicator of aerobic endurance performance of youth soccer players (McMillan et al., 2005). Furthermore, Edwards et al. (2003) reported that a player with a higher lactate threshold could cover more distance at a higher intensity during matches without excessive accumulation of lactate, compared with a less well aerobically trained player. However, to date, only one study has examined the relationship between oxygen consumption at $3\text{mmol}\cdot\text{L}^{-1}$ LA concentration and distance covered during a soccer match (Bangsbo and Lindquist, 1992). Therefore, it may be important to test for a relationship between FBL_s and distance covered during the soccer match.

Based on these considerations, the aims of the present study were: (I) to determine the metabolic and psychophysiological demands imposed on young soccer players during a match; (II) to assess the movement patterns of players and distance covered at FBL_s during match play; and (III) to examine the relationship between FBL_s , VO_2max and distance covered during the game.

Methods

Subjects

This study included young soccer players from four top junior league teams. Written informed consent was obtained from each subject and their parents after a detailed description of the purpose and procedures of the study. The study received ethical approval from the human ethics committee of Hacettepe University (No: LUT 04/18-7), Ankara, Turkey. Physiological measurements and RPE responses during match play were obtained from 36 players (12 defenders, 13 midfielders and 11 forwards). The movement patterns, distance covered at FBL_s and the relationship between selected variables were obtained in 32 players (11 defenders, 15 midfielders and 6 forwards). Twenty-one players were involved in all the measurements mentioned above. Therefore, the study included a total of 47 participants. Mean age, stature, body mass and VO_2max of participants were 17.6 ± 0.58 years, $1.78 \pm 0.05\text{m}$, $68.6 \pm 5.62\text{kg}$ and $51.76 \pm 4.18\text{mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$, respectively. All players completed the entire match. They represented their teams regularly and had at least three years of training experience. At the time of the study, all players were involved in the final stage of the competitive season. They had five training sessions, each lasting for 1.5 h and one competitive match per week. No vigorous activity was allowed for two days before the competitions and the field test.

Procedures

LA, HR and RPE responses were obtained during the soccer tournament arranged by Hacettepe University and the Turkish Soccer Coach Association. The matches were played on a regular soccer field (68 – 105m) with 11 players per side and each half lasted 45 minutes. Four friendly matches were played according to UEFA rules, except for the inclusion of approximately 3 minutes rest between 15-min game periods, during which blood samples were collected. The mean temperature and relative humidity during the matches were $23.5 \pm 1.7^\circ\text{C}$ and $67.0 \pm 7.0\%$, respectively (Hanna Instruments, HI 8564, Italy). The matches were recorded by six fixed cameras. Images were then uploaded to a computer in mpeg 1 format. Thereafter, the analysis was performed using software designed especially for this study (Mathball Match Analysis Systems, Algoritma Company, Istanbul, Turkey). The field test was administered in order to determine the players' FBL_s and VO_2max values. Previous work has shown that LA, HR and VO_2 responses at sub-maximal running speeds were higher during a field compared to a treadmill test (Unpublished data). Thus, to increase the reliability of results, the field test was preferred. All the measurements were completed over three weeks during the competition period.

HR, LA and RPE measurements during matches

During the first minute of each resting period, 25- μL blood samples were taken from the ear lobe of the subjects. Blood samples were kept in protective plastic tubes (code:2315 YSI) and, once the matches were completed, analysis was performed immediately for whole LA concentration by means of an electroenzymatic method using a YSI 1500 Sport Lactate Analyzer (Yellow Springs Inst., Yellow Springs, Ohio, USA). At the time of blood sampling, RPE was assessed using the Borg 6-20 scale (Borg, 1982). All participants had been familiarized with Borg scale “7 to 9” times during their incremental test protocols. In addition, to obtain reliable feedback from the players, they were instructed in how to use the scale properly before the beginning of the matches. The HR was collected throughout the matches with a sampling frequency of 5 s using short-range radio telemetry (S610i, Polar Electro Oy, Kempele, Finland). The data was subsequently uploaded to a computer using a Polar infrared interface with the Polar precision performance software (Version 4.01.029, Polar Electro Oy, Kempele, Finland). The data was then exported to a Microsoft Excel worksheet and the time required to conduct blood sampling was excluded from the analysis in order to obtain HR data that reflects only competitive periods. Thereafter, mean HR was determined for playing positions and selected game periods. Moreover, as shown in Figure 1, HR frequencies were also calculated with a class interval width of $10\text{beats}\cdot\text{min}^{-1}$ for the 1st and the 2nd halves of the matches.

Determination of FBL_s and VO_2max

LA concentrations at various workloads were determined using a modified shuttle run test (MSRT) in a 100 m circular environment. The reliability of MSRT in assessing VO_2max (ICC: 0.90) and FBL_s (ICC: 0.82 to 0.87) has

previously been demonstrated (Güvenç et al., 2011). The participants performed the test on a soccer field marked with cones every 20m. The pace was set with audio signals (Prosport, Tumer Electronics, Turkey) throughout the test. Initial speed was set at $8 \text{ km}\cdot\text{h}^{-1}$ and was increased by $1 \text{ km}\cdot\text{h}^{-1}$ every 3 minutes until the subject felt fatigue and stopped running voluntarily, or else failed twice to reach the next cone before the allotted timing signal. There was a 1-minute rest interval at the end of each stage, during which capillary blood sample was taken from the earlobe of the subject and analyzed immediately for whole LA concentration by means of an electroenzymatic method again using the YSI 1500 Sport Lactate Analyzer (Yellow Springs Inst., Yellow Springs, Ohio, USA). At the time of blood sampling, RPE was assessed using the Borg scale (Borg, 1982). By using the LA values, LA-running velocity curves were obtained for each subject. Thereafter, the running speeds at fixed values of “2.0, 2.5, 3.0, and up to 6.5” $\text{mmol}\cdot\text{L}^{-1}$ LA concentrations were interpolated. FBL_s were assessed for two purposes: First, running speed corresponding to $< 2 \text{ mmol}\cdot\text{L}^{-1}$ (FBL_2), $2 - 4 \text{ mmol}\cdot\text{L}^{-1}$ (FBL_{2-4}), and $> 4 \text{ mmol}\cdot\text{L}^{-1}$ (FBL_4) were obtained and the distance covered during the matches by each player in each category of running speed was determined. The second purpose was to examine whether a relationship exists between FBL_s (FBL_2 , $\text{FBL}_{2.5}$, FBL_3 , and up to $\text{FBL}_{6.5}$) and the distance covered in the games.

During the MSRT, breath-by-breath oxygen uptake and HR were also measured with a portable metabolic unit (K4b², Cosmed, Rome, Italy) and a Polar HR monitor, respectively. The metabolic unit and the LA analyzer were regularly calibrated according to the manufacturers’ instructions. At the end of each testing session, the data stored in the portable metabolic unit were downloaded to a computer using the manufacturers’ software (Cosmed, Data Management Software, version 7.3a) and subsequently imported into an Excel spreadsheet for further analysis. VO_2max and maximal HR were determined as the highest average values achieved during the final minute of each running stage. VO_2max was assumed to be reached when the oxygen uptake plateaued or two of the following three criteria were achieved: i) reaching at least $8 \text{ mmol}\cdot\text{L}^{-1}$ LA concentration; ii) reaching age-adjusted 90% of maximal HR; and iii) reaching at least 18 RPE (Howley et al., 1995; Park et al., 2010).

Match analysis

Match analysis protocol

All the games were recorded by six fixed cameras positioned in the stadium, parallel to the touch line. Images were later captured and stored in a computer using a video capture card. Dedicated software was used to follow movements and to determine distance covered during the games (Mathball Match Analysis Systems, Algoritma Company, Istanbul, Turkey). Before the match analyses were performed, an operator analyzed approximately 800 minutes of recording in order to ensure familiarization with the procedure. All the analyses were performed by the same operator in order to avoid any inter-individual disagreement. The 1st and the 2nd halves of the matches

were analyzed in a random order. The analyses were carried out in the following steps: First, recordings were calibrated and introduced to the system. Then, the cameras were synchronized. In the third step, each player was tracked individually from a computer screen by using a mouse, throughout the game, in order to determine the player’s real coordinates on the field. Finally, these references were used by the software to determine the movement patterns of the player.

The following locomotor categories were taken into account: (a) walking (W; 0 to $6.0 \text{ km}\cdot\text{h}^{-1}$), (b) jogging (J; 6.1 to $8 \text{ km}\cdot\text{h}^{-1}$), (c) low intensity running (LIR; 8.1 to $12 \text{ km}\cdot\text{h}^{-1}$), (d) moderate intensity running (MIR; 12.1 to $15 \text{ km}\cdot\text{h}^{-1}$), (e) high intensity running (HIR; 15.1 to $18 \text{ km}\cdot\text{h}^{-1}$), (f) low intensity sprint (LIS; 18.1 to $21 \text{ km}\cdot\text{h}^{-1}$), (g) moderate intensity sprint (MIS; 21.1 to $24 \text{ km}\cdot\text{h}^{-1}$), (h) high intensity sprint (HIS; above $24 \text{ km}\cdot\text{h}^{-1}$) and (i) total distance (TD). The movement speeds chosen in the present study were similar to those used in the literature (Mohr et al., 2003; Bangsbo et al., 1991), but sprinting-type movement was divided into three subcategories to enable more detailed analysis. In this study, distance covered at $< \text{FBL}_2$ (average for defenders: $3.32 \text{ m}\cdot\text{s}^{-1}$; midfielders: $3.41 \text{ m}\cdot\text{s}^{-1}$ and forwards: $3.10 \text{ m}\cdot\text{s}^{-1}$ respectively), distance covered at FBL_{2-4} (average for defenders: $3.32 - 3.92 \text{ m}\cdot\text{s}^{-1}$; midfielders: $3.41 - 3.97 \text{ m}\cdot\text{s}^{-1}$ and forwards: $3.10 - 3.74 \text{ m}\cdot\text{s}^{-1}$ respectively) and distance covered at $> \text{FBL}_4$ (average for defenders: $3.92 \text{ m}\cdot\text{s}^{-1}$; midfielders: $3.97 \text{ m}\cdot\text{s}^{-1}$ and forwards: $3.74 \text{ m}\cdot\text{s}^{-1}$ respectively) were also determined.

Validity and reliability assessment of the match analysis system

Before the motion analyses were performed, a validity and reliability study of the match analysis software was conducted. The validity assessment was conducted in a soccer field using one camera, which was in the same position and recorded the same dimension as in the main study. Ten players ran horizontally, vertically and diagonally to the camera position in predetermined areas and the running speed of each player was determined using photocells. The running speed of the player in each running style in predetermined areas was compared with those estimated with the match analysis system. Differences between the speeds measured with the two methods were not significant ($p>0.05$), and the smallest correlation coefficient was $r = 0.84$ ($p<0.01$). Intra individual test-retest reliability assessment was performed in ten players by repeating the analysis of the match images twice, the analyses being performed one week apart. Intraclass correlation coefficients (ICC) and coefficient of variations (CV) for TD, W, J, LIR, MIR, HIR, LIS, MIS, HIS, FBL_2 , FBL_{2-4} , and FBL_4 ranged from 0.72 to 0.98 and 1.4 to 12.4%, respectively.

Statistical analysis

Mean values and standard deviations were calculated for all variables. The validity assessment was conducted using Pearson correlation coefficients and student’s paired t-test. The reliability assessment was conducted using ICC, and typical error as a CV (%) was also calculated

Table 1. LA, HR and RPE responses during the soccer matches. Values are means (\pm SD).

| Variable | 15 (1) | 30 (2) | 45 (3) | 60 (4) | 75 (5) | 90 (6) |
|----------------------------|---------------------------------|---------------------------------|-------------------------------|-------------------------------|---------------------------------|---------------------------------|
| LA (mmol·L ⁻¹) | 4.96 (2.27) ^{3,4,5,6} | 4.44 (2.30) ^{1,4,5,6} | 4.14 (1.96) ^{1,4,5} | 3.40 (1.57) ^{1,2,3} | 3.63 (1.31) ^{1,2,3} | 3.09 (1.30) ^{1,2,3} |
| HR (b·min ⁻¹) | 167 (11) ^{4,5,6} | 169 (10) ^{3,4,5,6} | 165 (12) ^{1,2,6} | 162 (8) ^{1,2} | 161 (10) ^{1,2} | 161 (9) ^{1,2,3} |
| RPE | 10.4 (1.8) ^{2,3,4,5,6} | 11.5 (1.6) ^{1,3,4,5,6} | 12.6 (1.3) ^{1,2,5,6} | 12.7 (1.3) ^{1,2,5,6} | 13.7 (1.7) ^{1,2,3,4,6} | 14.5 (1.6) ^{1,2,3,4,5} |

LA: blood lactate, HR: heart rate, RPE: rate of perceived exertion. Superscripts denote significantly ($p < 0.01$) differences among the game periods.

(Hopkins, 2000). The repeated measure of analysis of variance (ANOVA), with the LSD post hoc test was applied to test the differences between the six 15-min game periods. The dependent sample t-test was used to determine differences between the 1st and the 2nd halves. Differences between playing positions in terms of LA, HR and RPE were tested using the one-way ANOVA with the LSD post hoc test. Since, there were fewer forwards compared with other playing positions in the movement patterns variable, differences between the playing positions were compared with the Kruskal-Wallis test. In case of a significant difference between groups, the Mann-Whitney U test was used to identify the points of differences. Cohen's *d* effect size was also calculated for each significant comparison. Cohen (1988) applied qualitative description for the effect sizes with ratios of 0.2, 0.5 and 0.8 indicating small, moderate and large changes, respectively. Pearson's product moment correlation coefficient was used to determine the relationship between selected variables. The scale for correlation coefficients is 0-3, 0.3-0.7 and 0.7-1.0 indicating low, moderate and high correlations, respectively (Morrow et al., 1995). The alpha level of statistical significance was set at $p < 0.05$ for all statistical tests.

Results

LA, HR and RPE responses during match play and the pairwise comparison of match periods are presented in Table 1, respectively. Mean LA concentration and HR during the 1st half of the matches were significantly higher than in the 2nd half (4.52 ± 1.88 vs 3.38 ± 1.15 mmol·L⁻¹; $p < 0.01$; $d = 1.25$; 166.9 ± 9.18 vs 161.7 ± 8.31 ; $p < 0.01$; $d = 1.43$, respectively). As shown in Figure 1, the players spent more time at higher HR intervals (above 180 b·min⁻¹) and less time at lower HR intervals

(below 180 b·min⁻¹) in the 1st half of the game when compared to the 2nd half. In addition, when HR values were expressed as a percentage of maximal HR, the players reached 87% and 84% of their maximum values in the 1st and the 2nd halves, respectively. In contrast to LA and HR results, RPE values in the 2nd half were significantly higher than in the 1st half (13.64 ± 1.28 vs 11.48 ± 1.28 ; $p < 0.01$; $d = 2.24$).

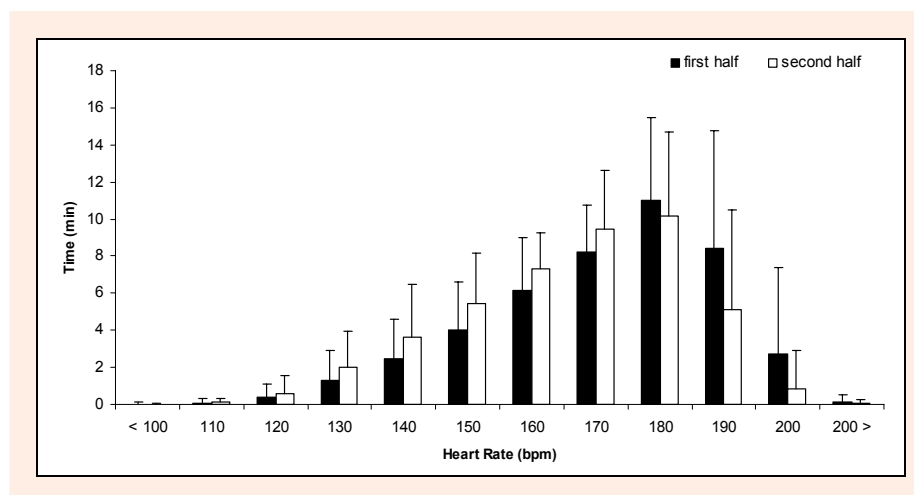
LA concentrations in forwards were significantly higher in comparison to defenders (4.62 ± 1.55 vs 3.24 ± 0.98 ; $p < 0.05$; $d = 1.13$). No significant difference was observed in mean LA concentrations between midfielders and forwards ($p > 0.05$). Although, the HR responses of defenders were 4.7 and 3.9 b·min⁻¹ lower than midfielders and forwards, respectively, there were no significant differences between playing positions ($p > 0.05$). Similarly, RPE was higher in midfielders and forwards compared with defenders, but the difference was not significant ($p > 0.05$; Table 2). However, irrespective of playing position, in the progressive periods of the match time, LA and HR values tended to decrease whereas RPE values tended to increase (Figure 2).

Table 2. LA, HR and RPE responses according to playing positions during the soccer matches. Values are means (\pm SD).

| Variables | Defenders | Midfielders | Forwards |
|----------------------------|------------|-------------|---------------|
| LA (mmol·L ⁻¹) | 3.24 (.98) | 4.02 (1.31) | 4.62 (1.55) * |
| HR (b·min ⁻¹) | 161 (8) | 166 (11) | 165 (5) |
| RPE | 12.2 (1.1) | 12.7 (1.2) | 12.9 (.9) |

LA: blood lactate, HR: heart rate, RPE: rate of perceived exertion
* significantly higher than defenders ($p < 0.05$).

As shown in Table 3, the players covered more distance in J, LIR, MIR, HIR, and LIS during the 1st compared to the 2nd half ($p < 0.01$). The distances covered in

**Figure 1.** Time spend at various HR intervals during the soccer matches (means \pm SD).

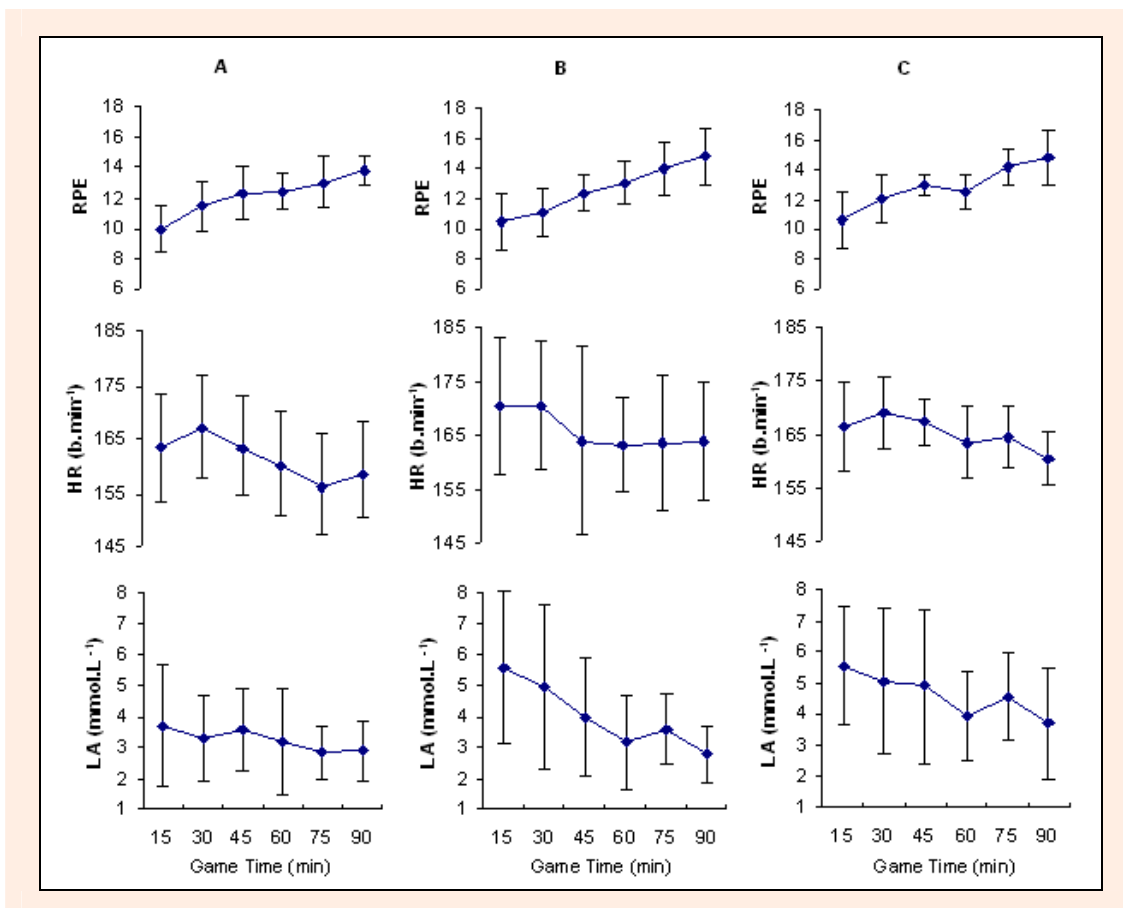


Figure 2. LA, HR and RPE responses during the soccer matches (means \pm SD). A: defenders, B: midfielders, C: forwards.

MIS and HIS were also greater in the 1st half than in the 2nd half, but the differences between the two halves were not significant ($p > 0.05$). In addition, distances covered at running speeds corresponding to FBL₂, FBL₂₋₄, and FBL₄ were significantly higher in the 1st half than in the 2nd half ($p < 0.01$). Players covered longer distance in W during the 2nd half compared to the 1st half ($p < 0.01$).

Table 3. Distance covered at different speeds during the 1st and the 2nd halves. Values are means (\pm SD).

| Activity | First Half (m) | Second Half (m) |
|--------------------|----------------|-----------------|
| TD | 5146 (445)** | 4754 (456) |
| W | 1443 (166)** | 1528 (161) |
| J | 671 (144)** | 596 (144) |
| LIR | 1263 (209)** | 1076 (238) |
| MIR | 724 (180)** | 630 (166) |
| HIR | 454 (118)** | 395 (93) |
| LIS | 277 (79)** | 230 (82) |
| MIS | 146 (55) | 142 (57) |
| HIS | 168 (72) | 157 (72) |
| FBL ₂ | 3377 (452)** | 3206 (412) |
| FBL ₂₋₄ | 549 (179)** | 478 (158) |
| FBL ₄ | 1220 (303)** | 1070 (292) |

TD: total distance, W: walking, J: jogging, LIR: low intensity running, MIR: moderate intensity running, HIR: high intensity running, LIS: low intensity sprint, MIS: moderate intensity sprint and HIS: high intensity sprint, FBL₂: running speed at 2 mmol.L⁻¹ lactate concentration and lower paces, FBL₂₋₄: running speed at 2-4 mmol.L⁻¹ lactate concentrations, FBL₄: running speed at 4 mmol.L⁻¹ lactate concentration and faster paces. ** significantly different from the second half ($p < 0.01$).

Although, there were significant differences be-

tween playing positions in terms of W, J, LIR, MIR, HIR, MIS, HIS and TD ($p < 0.05$), the distance covered in LIS was observed to be similar across playing positions ($p > 0.05$, Figure 3). The defenders and midfielders covered longer distances than forwards at running speeds corresponding to FBL₂ ($p < 0.05$). However, no significant difference was observed between playing positions at FBL₂₋₄ and FBL₄ ($p > 0.05$; Figure 4).

As presented in Table 4, significant moderate positive relationships were observed between FBL_s and TD covered during the games ($r = 0.48$ to 0.57 ; $p < 0.01$). Moreover, the magnitude of the coefficients gradually increased, starting from the FBL₄ and reached its highest level at the FBL_{6.5}. However, the relationship between FBL_s and high intensity distance (HID: distance covered faster than $18\text{km}\cdot\text{h}^{-1}$) was not significant ($p > 0.05$). In addition, no significant relationships were observed between VO₂max and TD or between VO₂max and HID (Table 4).

Discussion

The present study examined the metabolic and psychophysiological loads imposed on young soccer players during match play. To our knowledge, no study has examined the distance covered at running speeds corresponding to fixed blood lactate concentrations, and its relationship to distance covered during a game. Moreover, to our knowledge, this study also provides the first report on players' perception of activity intensity at 15-min

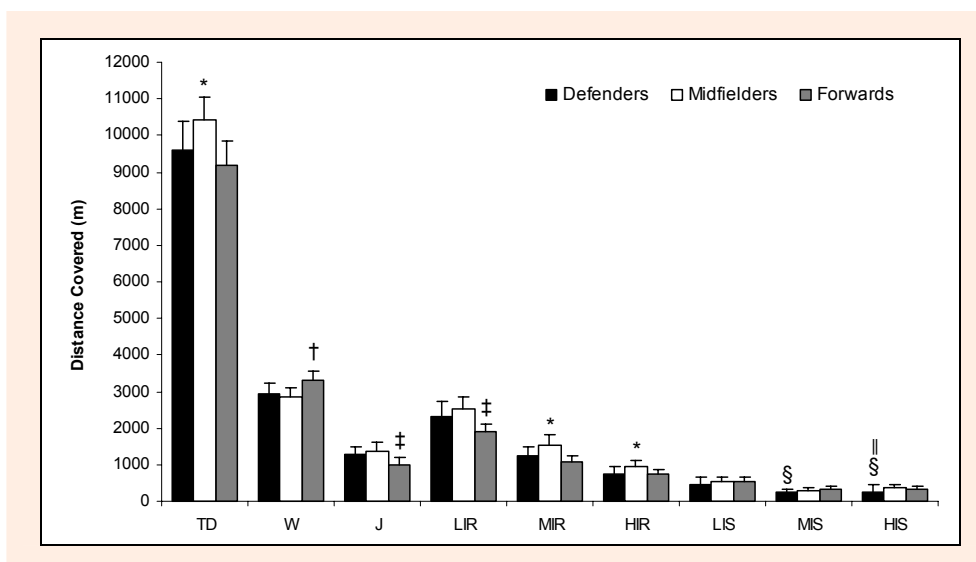


Figure 3. Movement patterns of players according to playing positions (means ± SD). TD: total distance, W: walking, J: jogging, LIR: low intensity running, MIR: moderate intensity running, HIR: high intensity running, LIS: low intensity sprint, MIS: moderate intensity sprint and HIS: high intensity sprint, * significantly higher than defenders ($p < 0.05$, $d = 1.24$, 1.18 and 1.03 for TD, MIR and HIR, respectively) and forwards ($p < 0.05$, $d = 2.03$, 2.05 and 1.16 for TD, MIR and HIR, respectively), † significantly higher than defenders ($p < 0.05$, $d = 1.30$ for W) and midfielders ($p < 0.05$, $d = 2.05$ for W), ‡ significantly lower than defenders ($p < 0.05$, $d = 1.53$ and 1.25 for J and LIR, respectively) and midfielders ($p < 0.05$, $d = 1.52$ and 2.17 for J and LIR, respectively), § significantly lower than forwards ($p < 0.05$, $d = 1.02$ and 0.44 for MIS and HIS, respectively), || significantly lower than midfielders ($p < 0.05$, $d = 0.68$ for HIS).

intervals during a game. Thus, the main contribution of this study is that it provides additional information on the internal work loads experienced by players during soccer match play.

Metabolic responses and movement patterns of players were determined from a series of non-official soccer tournament matches. This method allowed the collection of blood samples and RPE values at 15-min intervals in a large number of subjects. Previously, it was reported that higher metabolic responses were obtained during official matches (Rodrigues et al., 2007), probably due to the incentive value of the competitive environment. However, LA and HR responses obtained in this study were within the range of the results acquired in official matches (Ali and Farrally, 1991; Bangsbo, 1991; 1994; Rodrigues et al., 2007; Rohde and Espersen, 1988). These results can be interpreted as indicating that tournament matches had a motivating effect on the players.

Average LA response to match play obtained in

this study ($3.95 \pm 1.92 \text{ mmol}\cdot\text{L}^{-1}$) was approximately at the $4 \text{ mmol}\cdot\text{L}^{-1}$ fixed LA threshold while individual values throughout the match showed a large range, between 1.55 and $11.88 \text{ mmol}\cdot\text{L}^{-1}$. These results implied that anaerobic energy contribution was high in the certain periods of matches. However, there are problems associated with the use of LA measurements as an indicator of lactate production during a soccer match (Bangsbo, 1994). Lactate, produced during the high intensity exercise is simultaneously oxidized or transported from the production sites to various tissues such as heart, liver, kidney and oxidative muscle fibers for subsequent oxidation (Powers and Howley, 1997). The rate of oxidation is increased if low intensity activities are performed in between the periods of intense exercise during match play. Thus, LA concentration measured during a soccer match may reflect, but underestimate, the contribution of anaerobic glycolysis to energy supply (Bangsbo, 1994). In fact, although LA concentration might be a good reflection of

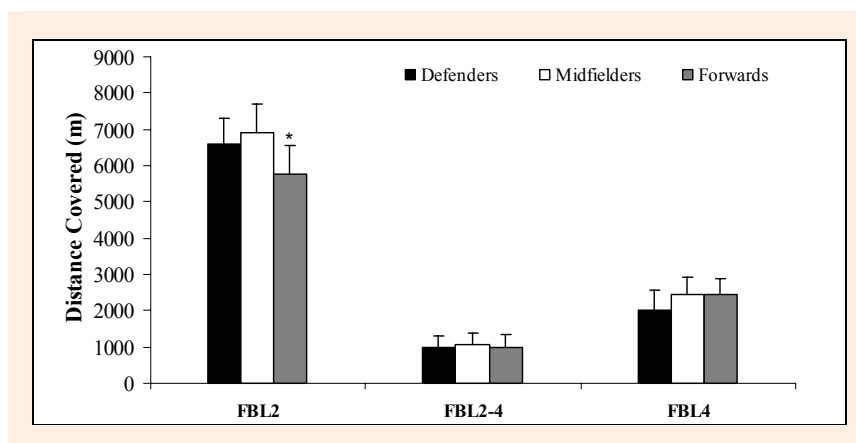


Figure 4. Distance covered at FBL₂, according to playing positions (means ± SD). FBL₂: running speed at $2 \text{ mmol}\cdot\text{L}^{-1}$ lactate concentration and lower paces, FBL₂₋₄: running speed at $2-4 \text{ mmol}\cdot\text{L}^{-1}$ lactate concentrations, FBL₄: running speed at $4 \text{ mmol}\cdot\text{L}^{-1}$ lactate concentration and faster paces. * significantly lower than defenders ($p < 0.05$, $d = 1.21$) and midfielders ($p < 0.05$, $d = 1.47$).

Table 4. Relationship between FBL_s, VO₂max and distance covered during the games.

| Distance Covered | FBL ₂ | FBL _{2,5} | FBL ₃ | FBL _{3,5} | FBL ₄ | FBL _{4,5} | FBL ₅ | FBL _{5,5} | FBL ₆ | FBL _{6,5} | VO ₂ max |
|------------------|------------------|--------------------|------------------|--------------------|------------------|--------------------|------------------|--------------------|------------------|--------------------|---------------------|
| TD | .482** | .501** | .501** | .498** | .494** | .496** | .502** | .516** | .546** | .570** | .029 |
| HID | .210 | .186 | .164 | .153 | .155 | .165 | .177 | .194 | .206 | .203 | .317 |

FBL_s: running speeds at fixed lactate concentrations, TD: total distance, HID: high intensity distance (> 18 km.h⁻¹), ** p< 0.01.

muscle lactate concentration during continuous exercise, it was reported that LA and muscle lactate was not correlated during soccer match play (Bangsbo et al., 2006). It is also essential to note that LA concentration measured in soccer largely depends on the activity pattern of the player in the 5 minutes preceding blood sampling (Stolen et al., 2005). Nonetheless, in this study, LA concentrations were used as an indicator of players' physiological stress level throughout a game. As reported in previous studies (Capranica et al., 2001; Ekblom, 1986; Rohde and Espersen, 1988; Roi et al., 2004), current results demonstrated that internal load imposed on players was high at certain moments during match play. On the other hand, the average post-match LA concentration was 3.09 ± 1.30 mmol·L⁻¹ (Table 1), which was considerably lower than the values obtained from top Italian players (6.3 ± 2.4 mmol·L⁻¹, Roi et al., 2004). In a recent literature review, Stolen et al. (2005) stated that top soccer players showed a higher LA response to match play than lower level players. A possible explanation of this result could be more intensive efforts performed by top class players (Bangsbo, 1994; Mohr et al., 2003). In line with the literature (Ekblom, 1986; Rohde and Espersen, 1988), the present results confirmed that LA responses in the 2nd half of the matches were lower than those in the 1st half. This result could be largely explained as being due to the greater distance covered by the players in MIR, HIR, LIS and FBL₄ during the first half of the match (Table 3). The current results also showed that LA concentrations of forwards were higher than those of defenders (Table 2). In fact, it was not unexpected that forwards performed more intensive movements, resulting in an increased LA values, whereas defenders performed more low intensity movements, resulting in enhanced elimination of LA (Figures 3 and 4).

Alvares and Castagna (2007) reported that TD, HID and average speed were not related to HR during a soccer match. Therefore, HR alone remains an inadequate measure of intensity in soccer matches. However, it can be used when assessing variations in physiological stress imposed on players throughout the matches. The present results showed that mean HR in the first half was 5.2 b·min⁻¹ higher than in the 2nd half, as a reflection of high HR responses observed in the first and the second 15-min periods of the matches (Table 1). In line with this result, Bangsbo (1994) reported that HR decreased 10 b·min⁻¹ during the second half in elite soccer players. Furthermore, in accordance with previous report of Capranica et al. (2001), the current results showed that players spent more time at higher HR intervals and less time at lower HR intervals during the first half when compared to the second half of games (Figure 1). Indeed, when HR values were expressed as a percentage of individual maximal

HR, the players reached 87% and 84% of their maximum values in the 1st and the 2nd halves, respectively. Helgerud et al. (2001), in a study of 18-year old elite soccer players, also reported similar findings, in that the percentage of maximal HR in the first half (86.3%) was higher than in the second half (85%). Taken together, these results also confirm that the players experienced high exercise intensity in certain periods of the game, and the average internal load imposed on players was higher in the first compared to the second half.

In addition to LA and HR, RPE is accepted as a valid measure of internal load during exercise (Impellizzeri, 2004). The results of the present study demonstrated that, although LA, HR and distance covered tended to decrease in the progressive periods of the match time, RPE values gradually increased (Table 1 and Figure 2). The current results indicated that the players perceived the progressive periods of the game as being harder, although they were less active. This implies that RPE values might be used when assessing the accumulated fatigue during intermittent prolonged exercise. This suggestion was supported by the findings of Martin et al (2000), who reported that RPE for a given HR increased during over-reaching.

In the present study, the average TD covered by an outfield player was 9.9 ± 0.84 km, which was within the range of 8–12 km reported in previous studies (Reilly, 1997; Rienzi et al., 2000; Helgerud et al., 2001; Mohr et al., 2003; Barros et al., 2007; Carling, 2010). 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 (Barros et al., 2007; Mohr et al., 2003; Mohr et al., 2008; Rienzi et al., 2000). It was also consistently reported that, in the 2nd half or in the last 15-min period of matches, HID decreased independent of playing position, level of competition and gender (Mohr et al., 2003; Mohr et al., 2008; Bradley et al., 2009). However, as in the current study (Table 3), Da Silva et al. (2007) and Castagna et al. (2003) in young players and Barros et al. (2007) in adult players reported that the distance at high intensities was maintained throughout the game. On the other hand, the present study indicated that movement patterns of players differed greatly across playing positions as reported in previous studies (Bangsbo et al., 1991; Da Silva et al., 2007; Di Salvo et al., 2007; Thatcher and Batterham, 2004; Rienzi et al., 2000; Mohr et al., 2003; Verheijen, 1998).

The distance covered by players at FBL_s was also determined in this study. These data provides additional information in understanding the metabolic demands of soccer. For example, as illustrated in Figure 4, for mid-field players, 66.2% (6894m) of TD was covered at FBL₂ (running speeds below the aerobic threshold), 10.4%

(1080m) of TD was covered at FBL_{2-4} (running speeds between the aerobic threshold and $4 \text{ mmol}\cdot\text{L}^{-1}$ fixed LA thresholds), and 23.4% (2438m) of TD was covered at FBL_4 (running speeds above the $4 \text{ mmol}\cdot\text{L}^{-1}$ fixed LA thresholds). To our knowledge, no other time-motion study has reported data in this manner. However, Eniseler (2005) reported that the time spent below, between and above the 2 and $4 \text{ mmol}\cdot\text{L}^{-1}$ heart rate reference lines corresponded to 13.9%, 36.5% and 49.6% of the total match time, respectively. Although, Eniseler examined the same physiological stress levels as done here, it was not possible to compare the two studies directly, as Eniseler determined the time spent at FBL_s from HR, whereas the present study determined distance covered at FBL_s . In addition, HR can be affected by several factors, which can influence the results by causing the heart rate after high intensity activities to remain high even during subsequent low intensity activities. Even though standing steadily and very low intensity activities constitute an important proportion of total match time (Mohr et al., 2003; Thatcher and Batterham, 2004), Bangsbo et al. (2006) reported that HR rarely drops below 65% of maximal HR during soccer matches.

Interestingly, the current results showed that, although the movement patterns of players differed greatly across playing positions (Figure 3), the distances covered at FBL_s were similar, except for FBL_2 (Figure 4). These results demonstrated that, even though the external load imposed on players differed according to playing positions, the internal load was almost similar. The current results were also supported due to the similarity between playing positions in terms of HR and RPE responses to match play.

In contrast to some previous reports (Bangsbo and Lindquist, 1992; Bangsbo, 1994; Helgerud et al., 2001; Krstrup et al., 2005), no significant relationship was found between $VO_{2\text{max}}$ and TD or between $VO_{2\text{max}}$ and HID in this study. These conflicting findings may be partly explained by the methodology used in this study, in which matches were paused in order to collect blood samples. This may provide a recovery period for players with lower $VO_{2\text{max}}$ values, allowing them to cover similar distances as players with a higher $VO_{2\text{max}}$. On the other hand, FBL_s were related to the TD covered in soccer matches ($r = 0.482$ to 0.570 ; Table 4). This result might support the suggestion of McMilan et al. (2005) who reported that fixed LA levels between 2 and $4 \text{ mmol}\cdot\text{L}^{-1}$ may be used as an indicator of aerobic endurance performance of soccer players. However, FBL_s were not related to the HID (Table 4). It was expected that no relationship was observed between these variables, because the highest FBL_s chosen in this study ($FBL_{6.5}$: $15.6 \text{ km}\cdot\text{h}^{-1}$), were relatively low compared to running speed at HID ($>18 \text{ km}\cdot\text{h}^{-1}$). In accordance with the findings of the current study, Bangsbo and Lindquist (1992) reported that TD covered was moderately related to work load corresponding to $3 \text{ mmol}\cdot\text{L}^{-1}$ LA concentration in elite soccer players ($r = 0.58$). In a study conducted on top soccer referees, Castagna et al (2002) stated that TD covered was also related to FBL_4 ($r = 0.73$). Both of these previous studies (Bangsbo and Lindquist, 1992; Castagna et al., 2002) indicated that these variables were not related to

HID as in this study. Indeed, it has been recommended that HID is a valid measure of physical performance in soccer (Bangsbo et al., 1991). Thus, it can be suggested that FBL_s is not a valid predictor of physical performance in match play.

Conclusion

In conclusion, based on LA, HR and RPE responses, the present findings 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. In addition, although, the movement patterns of players differed greatly across playing positions, the distances covered at FBL_s were similar, except for FBL_2 . Therefore, it can be concluded that the external load imposed on players differed in accordance with position played 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 $160 \text{ b}\cdot\text{min}^{-1}$ 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 $4 \text{ mmol}\cdot\text{L}^{-1}$ fixed LA threshold. This study also revealed that TD covered was influenced by FBL_s 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.

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Key points

- Based on LA, HR and RPE responses, young top soccer players experienced a higher physiological stress during the 1st half of the matches compared to the 2nd half.
- Movement patterns differed in accordance with the players' positions but that all players experienced a similar physiological stress during match play.
- Approximately one quarter of total distance was covered at speeds that exceeded the 4 mmol·L⁻¹ fixed LA threshold.
- Total distance covered was influenced by running speeds at fixed lactate concentrations in young soccer players during match play

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