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Original article

THEORETICAL ASPECTS REGARDING ENERGY COST AND PHYSICAL EXERCISE LEVEL DURING FOOTBALL MATCHES

ZAHARIA Gabriel[1], ȚIFREA Corina[2], DAMIAN George Cosmin[3]

Abstract

Objective. The purpose of this paper is to make a synthesis of the specialized literature regarding the means and methods of monitoring effort during football matches and to provide/make available to coaches the scientific data for directing and programming sports training.

Methods. Thus, evaluations of the metabolic needs during a football match were carried out by the method of collecting the body temperature. They demonstrated that the average metabolic load of a football player during a match is very close to 70% of VO2max. More recently, assessments of energy expenditure using heart rate monitoring have been performed allowing for a more detailed analysis of aerobic performance, but heart rate monitoring does not provide effective information regarding short bursts of very high intensity exercise. Overall, all these methods showed a total energy consumption between 1200 and 1500 kcal during a match. Average heart rate was observed to be 157b/min and maximum 187b/min, 5-10b/min lower than values reported during top-level matches, while average blood lactate values of 5mmol·L^{-1} were at the same level. The distance covered during the match was 9.75±0.33km 10% lower than the values reported in elite-level competitions and the total volume of high-intensity running 1.62±0.12km 20% lower than the values reported at top-level matches.

Conclusions. However, the declines in sprint performance were similar to those seen in elite-level players. Both findings indicate that the absolute intensity was somewhat lower than the intensities reported during matches played at top level, but that the relative physiological stress of the players is comparable to that of top-level players.

Keywords: effort monitoring; intermittent exertion; blood lactate; muscle lactate; exercise metabolism.

Introduction

The science of physical training, as well as the means and methods of training used in the preparation of football players, have continuously evolved. This evolution is mainly due to the increase in the area of knowledge in fields that concern the physical and mental adaptation of the human body to stress factors of training and sports competition. The contemporary top football player is monitored almost continuously, following the physiological and psychological reactions arising from the application of the means and methods of physical, technical, tactical and recovery training, in order to make the training process more efficient. The collected data are interpreted by specialists in the field, precisely to develop new ways of training and rehabilitating the modern football player.

In football, physical conditioning is certainly the most developed component of training in the last two decades. This was possible following extended study and experience acquired in the field of exercise physiology, with the support of sports medicine specialists.

Thus, in order to increase the success rate, the aim was to understand the multiple aspects of football performance, and the field of sports science is becoming a vast territory both in the area of research and in the area of applied science. Originally sports science included sub-disciplines of physiology, psychology and biomechanics, (Nevill, Atkinson, & Hughes, 2008) but since the 1990s, it has also rapidly expanded into the area of data analysis, with the aim of monitoring sports performances (Sarmento, and others, 2014).

This significant interest in the field of performance analysis in sports, and especially in football, has led to the development of a very large number of computer-operated systems built for this purpose. These analysis systems can be simple systems such as recording the frequency of a set of indicators, such as tracking physical data through GPS, or much more comprehensive systems that combine technical and physical performance analysis, through automatic player tracking (Randeers, și alții, 2010).

[1] Liceul cu Program Sportiv "Nicolae Rotaru" Constanța, România.
[2] UNEFS, București, România.
[3] Faculty of Physical Education and Sport, University Ovidius Constanta, România

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The development of automated systems has led to a significant increase in the amount of performance data available and thus very large samples of data can be provided for analysis, giving a clear advantage to sports science (Coutts, 2014).

The vast majority of analyses of physical demands in football matches played in European football leagues have been conducted in the English Premier League, (Bradley, și alții, 2009) (Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009), A Series Italy (Mohr, Krustrup, & Bangsbo, 2008), La Liga Spain (Castellano, Blanco-Villaseñor, & Alvarez, 2011).

In recreational football, especially among young players, the level of effort and physiological responses caused by the match may reflect the level of individual involvement that each player imposes on himself. For this reason, the best perspectives on stress factors specific to the game of football are evident when the intensity of the game is at the highest possible tempo. Thus, examining elite professional level matches can yield the most useful scientific information about the unique physiological demands inherent in the game (Reilly, 2016).

Methods

The physical effort in the football game has an intermittent character, and football players travel between 9 and 14 km during the entire match. The physical activities performed during a match are extremely complex and varied. Most of the time, about 85% of the total playing time, the intensity of the effort is low, such as stopping, walking, and light running. The remaining 15% of playing time consists of physically demanding actions, such as high-intensity running characterized by speeds over 14km·h$^{-1,}$, high-speed running over 20 km·h^{-1} and sprints which are defined by speeds of over 25 km·h^{-1}(Mohr, Krustrup, & Bangsbo, 2008). During a match, football players cover distances between 1500 and 3100m in the form of high-intensity running, between 300 and 1100m in the form of high-speed running and between 150m and 360m in the form of sprints. In addition, the distance covered in intense accelerations greater than 3m/s^2 and intense decelerations less than 3m·s^{-2} during a professional football game was estimated to be between 180m and 188m (Osgnach, Bernardini, Poser, & Rinaldo, 2010).

Previous assessments of metabolic demand, carried out by the method of collecting body temperature, have shown that the average metabolic load of a football player during a match is very close to 70% of VO_{2max}. (Edwards & Clark, 2006). These results have been strongly backed by the current energy consumption estimates; however, they did not lead to the development of continuous body temperature monitoring techniques for practical reasons and because of latent changes in body temperature (Osgnach, Bernardini, Poser, & Rinaldo, 2010).

Recently, assessments of energy expenditure using heart rate monitoring have been performed allowing for a more detailed analysis of aerobic performance; however, heart rate monitoring does not provide effective information regarding short bursts of very high intensity exercise. Also, direct measurements of oxygen consumption are not suitable for collecting data during very high intensity efforts and their use during training or even competition is not reliable (Kawakami, Nozaki, Matsuo, & Fukunaga, 1992).

Overall, all these methods showed an estimated total energy expenditure during a match between 1200 and 1500 kcal (Bangsbo J. , 1994).

So far, studies carried out on anaerobic energy expenditure are quite few; moreover, the current procedures are not applicable in official matches and certainly not suitable for continuous recordings.

An example of such an approach is the study by Krustrup and colleagues ((Krustrup, et al., 2006) in which the concentration of creatine phosphate was measured in the muscle tissue from the athlete's body by means of biopsy immediately after a very high intensity effort during a football match. Blood lactate concentration has also been considered as a marker of anaerobic energy consumption, with results in this study showing levels in the range of 2 and 10mmol·L^{-1} during a football match. The objective of this study was to examine muscle and blood metabolites during the football match and relate them to sprint performance during the match. Also an additional objective was to investigate how blood lactate relates to muscle lactate concentration during a football match. The participants in this study were thirty-one players from the Danish 4th division with an average age of 28 years (range 21 to 33 years).

The experimental design of the study consisted of subjects participating in three friendly games. Several physiological measurements were taken at fixed times during the match, as well as after periods of very intense exertion, from both halves of the game. The players had samples of muscle tissue taken from the vastus lateralis muscle (between 70 and 120mg) of the right leg, by the biopsy method using a biopsy needle with suction.

The biopsy was performed after periods of intense effort that included running at speeds over 18 km·h^{-1} and sprints at speeds over 25km·h^{-1}. Heart rate was also monitored throughout the match, as well as extra sports life of the players 48 hours before the match. They were restricted from drinking alcohol, smoking and consuming caffeine products.

The diet was controlled 16 hours before the match and consisted of 200g of meat, 100g of vegetables,

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300g of pasta the night before the match, 100g of cereal with milk in the morning and a light fruit snack 2 hours before the match. The values of muscle water content, muscle ATP, muscle creatine phosphate, muscle lactate, muscle pH and muscle glycogen were recorded. The data obtained in this study are presented in the table below.

Table 1 Muscle water content, ATP, IMP, CP, lactate, pH and glycogen before and after a football match and before and after periods of intense effort in the first and second half of the match. The values in the table are means ± standard deviation.

	Before the match	After the match	after a period of very intense effort in the first half of the match	after a period of very intense effort in the 2nd half of the match
Water content (%)	76,0 ± 0,4 (74,4 – 77,3)	78,2 ± 0,7 (75,7 – 81,1)	77,6 ± 0,2 (76,7 – 79,0)	78,8 ± 0,3 (77,7 – 80,2)
ATP muscular (mmol·kg^{-1})	26,4 ± 2,3 (24,1 – 28,8)	23,0 ± 0,4 (22,6 – 23,5)	25,6 ± 0,2 (25,3 – 25,9)	22,6 ± 1,0 (19,1 – 26,8)
IMP muscular (mmol·kg^{-1})	0,0 ± 0,0 (0,0 – 0,0)	0,3 ± 0,1 (0,0 – 0,6)	0,2 ± 0,1 (0,0 – 0,5)	0,6 ± 0,2 (0,0 – 1,1)
CP muscular (mmol·kg^{-1})	88 ± 2 (74 – 98)	79 ± 3 (68 – 95)	76 ± 3 (58 – 93)	67 ± 3 (44 – 85)
muscular lactate (mmol·kg^{-1})	4,2 ± 0,5 (2,7 – 6,1)	13,0 ± 1,8 (8,7 – 23,9)	15,9 ± 1,9 (6,4 – 29,3)	16,9 ± 2,3 (2,6 – 36,4)
muscular H^+ (mmol·kg^{-1})	57 ± 2 (54 – 68)	69 ± 2 (60 – 72)	111 ± 9 (81 – 159)	86 ± 4 (71 – 110)
muscular pH (-log h^+)	7,24 ± 0,02 (7,17 – 7,30)	7,17 ± 0,01 (7,14 – 7,22)	6,96 ± 0,03 (6,80 – 7,09)	7,07 ± 0,02 (6,96 – 7,15)
muscular Glycogen (mmol·kg^{-1})	449 ± 23 (387 – 626)	255 ± 22 (168 – 375)	296 ± 23 (199 – 403)	241 ± 16 (161 – 319)

The authors of the study highlighted that muscle ATP was 22,6 ± 1,0 mmol·kg^{-1} after a period of intense effort in the second half of the match, which was lower compared to rest time periods (26,4 ± 2,3 mmol·kg^{-1}) statistically significant ($p<0.05$). The muscle IMP was 0,6 ± 0,2 mmol·kg^{-1} after a period of intense effort in the second half, a statistically significantly higher value ($p<0.05$) compared to rest periods.

Muscle creatine phosphate was 67 ± 3 mmol·kg^{-1} after a period of intense effort in the second half, these values being statistically significantly lower ($p<0.05$) compared to the values obtained during the rest period which were of 88 ± 2 mmol·kg^{-1} but also compared to the first half in which the recorded values were 76 ± 3mmol·kg^{-1}.

The muscle lactate recorded after periods of intense effort in the first half was 15,9±1,9 mmol·kg^{-1} and in the second half 16,9±2,3 mmol·kg^{-1}, i.e., four times higher ($P<0.05$) compared to rest period. Very large variations of the muscle lactate level were observed in the same subject in the two rounds (from 14.4 to 27,8 mmol·kg^{-1}). Muscle pH being 6,96±0,03 after a high-intensity exercise sequence in the first half, lower level ($P<0.05$) compared to a high-intensity sequence in the second half, the value being of 7,07±0,02 and compared to rest (7,24±0,02). The concentration of hydrogen ions (H^+) was 111±9, 86±4 and 57±2 mmol·L (Krustrup, și alții, 2006)$^{-1}$

Muscle glycogen was 449±23mmol·kg^{-1} at rest before the match and 42±6%lower ($P<0.05$) after the match. The 10 subjects who were analyzed according to muscle fiber specificity in terms of muscle glycogen depletion during the game had 58,5±3,5%slow twitch fibers, 26,9±2,6% fast fibers type a, and 14,6±3,0% fast type b fibers. Before the game, 73±6% of the total muscle fibers were rated as having full glycogen stores, whereas this value was lower by 19±4% ($P<0.05$) after the game. After the match, 36±6% of each subject's muscle fibers had nearly depleted glycogen stores, and another 11±3% had completely depleted glycogen stores. Across muscle fiber types 54±10% of slow-twitch and 46±11% of fast-twitch a-type fibers had their glycogen stores completely depleted after the match, while in fast-twitch b-type fibers 25±10% had these stores depleted (Krustrup, și alții, 2006).

Table 2 Levels of blood lactate, blood glucose, glycerol, plasma ammonia, K, insulin, at rest, in the first half, before and after the second half, and after intense exercise sequences in the first and second half in following the playing of three friendly matches in the fourth Danish league (Krustrup, și alții, 2006)

	Rest	During the first half	After the first half	Before the 2nd half	During the 2nd half	After the 2nd half
Blood lactate (mM)	1.3 ± 0.1 (0.7 – 2.2)	6,0 ± 0,4 (3,8 – 9,6)	4,1 ± 0,4 (1,3 – 6,0)	2,1 ± 0,2 (0,9 – 3,5)	5,0 ± 0,4 (2,3 – 8,6)	3,9 ± 0,4 (2,1 – 5,9)
Glucoza sangvină (mM)	4.5 ± 0.1 (3.2 – 5.8)	6,1 ± 0,3 (4,0 – 8,2)	5,4 ± 0,4 (2,8 – 8,9)	4,1 ± 0,2 (2,9 – 5,6)	5,3 ± 0,3 (4,0 – 6,6)	4,9 ± 0,2 (4,0 – 6,3)
Free fatty acids (∝M)	390 ± 57 (174 – 1008)	555 ± 74 (186 – 1265)	671 ± 95 (185 – 1693)	1066±193 (248 – 2845)	740 ± 75 (401 – 1417)	1365 ± 111 (831 – 2276)
Plasma glycerol (∝M)	81±29 (35 – 136)	185 ± 29 (97 – 251)	–	–	234 ± 40 (82 ± 310)	–
Plasma ammonia (∝M)	59±7 (27–136)	203 ± 16 (97 – 310)	193 ± 19 (78 – 283)	128 ± 15 (50 – 240)	217 ± 20 (68 – 342)	199 ± 21 (71 – 350)
Plasma K^+ (mM)	3.9 ± 0.0 (3.6–4.3)	4,9 ± 0,1 (4,4 – 5,5)	4,6 ± 0,1 (3,6 – 5,4)	4,2 ± 0,1 3,9 – 4,6	4,8 ± 0,1 4,2 – 5,6	4,3 ± 0,1 3,9 – 5,0
Plasma insulin (∝M)	3.9 ± 0.0 (3.6–4.3)	7,4 ± 0,5 (5,3 – 11,3)	–	–	6,0 ± 0,9 3,0 ± 11,9	–

Blood lactate was 0,9 ± 0,2 mmol·L^{-1} at rest and increased ($P<0.05$) to 6,7 ± 0,9 mmol·L^{-1} after 5min of play, being higher than at the end of the match ($P<0.05$), the peak lactate level reached during the match was 7,9 ± 0,7 (4,2 – 11,9) mmol·L^{-1}.

A

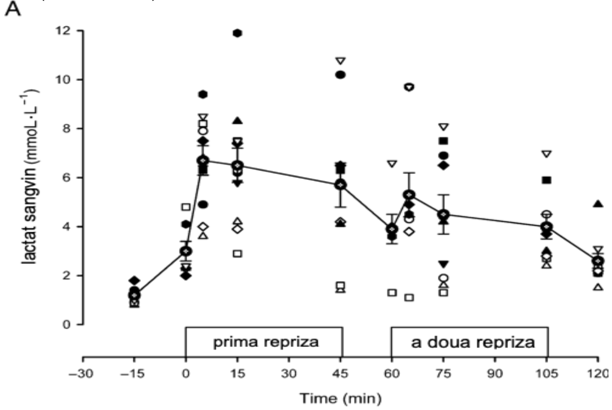

Figure 1 Blood lactate concentration before, during and after a Danish 4th league football match (Krustrup, și alții, 2006)

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Blood lactate after intense exercise episodes in the first and second half was 6,0 ± 0,4 mmol·L^{-1} and 5,0 ± 0,4 mmol·L^{-1} (table 2).

No correlation was observed between muscle and blood lactate in either the first or second half (r^2 = 0.25 in the first half and r^2 = 0.06 in the second half (P<0.05) (fig. 2).

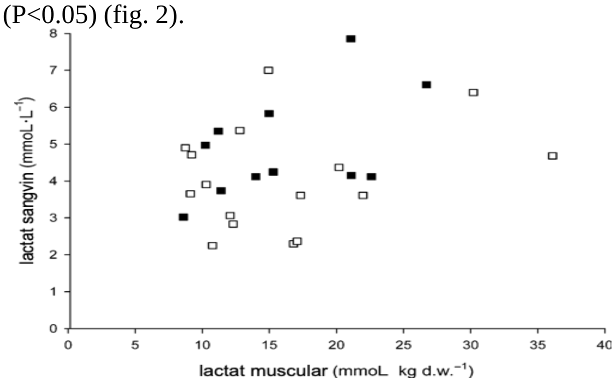

Figure 2 Correlation between muscle lactate concentration and blood lactate after intense exercise sequences in the first and second half of a football match, filled squares and empty squares represent the measurements taken in the first half (r^2=0.25, P< 0.05) and in the second half (r^2 =0.06, P<0.05)

Blood glucose was 4,3 ± 0,1 mmol·L^{-1} at rest and higher (P<0.05) after 5min of playing (5,2 ± 0,2 mmol·L^{-1}), after which remained unchanged throughout the game (90min: 4,9 ± 0,4 mmol·L^{-1}).

(Stolen, Chamari, Castagna, & Wisloff, 2005) Free fatty acids in blood plasma had a concentration of 433 ± 77μmol·L^{-1} at rest and about 1.5 – 3 times higher (P<0.05) after the first and second half respectively. (Fig. 3)

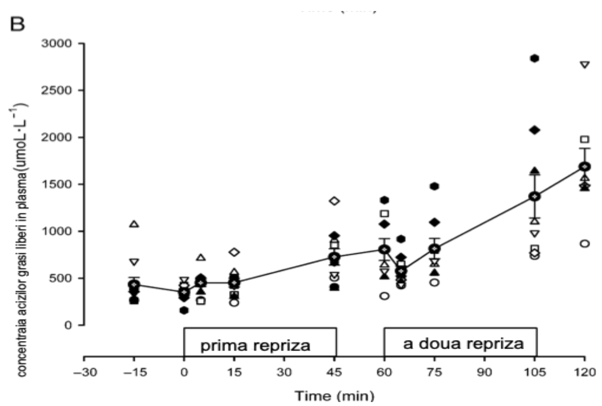

Figure 3 Plasma free fatty acid concentration level after intense exercise sequences in the first and second half of a football match (Krustrup, și alții, 2006)

Plasma glycerol was 185 ± 28μmol·L^{-1} and 234 ± 40μmol·L^{-1} after intense exercise sequences in both the first and second half, the reported values being significantly higher (P<0.05) compared to the rest period where the values were 81±29μmol·L^{-1} (Table 2.).

Plasma insulin was 11,8±1,5μmol·L^{-1}at rest and was significantly (P<0.05) lower after the first (7,3±0,8μmol·L^{-1}) and after the second half (5,2±0,6μmol·L^{-1}).

Plasma ammonia was 38±6μmol·L^{-1} at rest and almost 6 times higher (P<0.05) after 5 minutes of play, after which it remained unchanged (Fig. 4) (Krustrup, și alții, 2006).

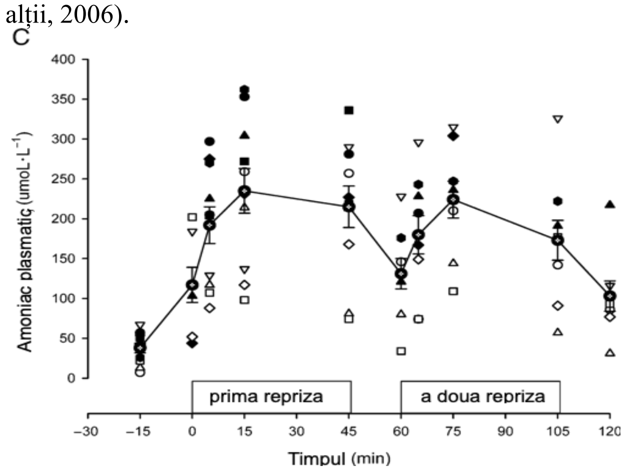

Figure 4 Level of plasma ammonia concentration in the first and second half of a football match

The plasma ammonia level was 203±16μmol·L^{-1} and 217±20μmol·L^{-1} after an intense exercise sequence in both the first and second half (Table 2).

The level of plasma K^+ ions was 4,9±0,1mmol·L^{-1} and 4,8±0,1 mmol·L^{-1} after periods of intense effort in the first and second half, being significantly higher (P<0.05) compared to rest (3,9±0,0mmol·L^{-1}) (Table 2). The maximum level of plasma ammonia concentration and plasma K reached during the match was 283μmol·L^{-1} for ammonia and 5,1 mmol·L^{-1} for K^+.

Discussions

As shown in this paper, Peter Krustrup, Jens Bangsbo and collaborators have provided information on changes in performance as well as alterations in muscle and blood metabolic balance during a football match, taking notes on temporal declines in sprint speed performance during the match and at the end. Muscle lactate and H concentration were only slightly increased during play and did not correlate with decreased match performance. At the end of the game nearly half of the muscle fibers were depleted or nearly depleted of glycogen, which contributed to reduced end-game performance. The lack of correlation between muscle lactate and blood lactate was also observed indicating that more attention should be paid to the interpretation of blood lactate levels during the match. Blood glucose remained elevated throughout the game because there was a progressive increase in the concentration of free fatty acids.

The matches examined by the authors were friendly matches, in which players from the Danish 4th league performed, and the level of representation of elite games should be taken into account. Average heart rate was observed to be 157b/min and maximum 187b/min, 5-10b/min lower than values reported during elite level matches (Bangsbo, Graham, & Saltin, 1992) while average blood lactate values of 5mmol·L^{-1} were at the same level. In the case of seven players from those who were tested by biopsy samples, space-time analyses (time-motion) were also performed, these analyses showed that the distance covered during the match was 9,75±0,33km 10% lower than top level reported values and total high intensity running volume 1,62±0,12km 20% lower than top level reported values (Bangsbo & Nørregaard, 1991).

In addition, it was observed that the volume of high-intensity running 5 min before the collection of the muscle sample was 145±23m, being 25% lower values compared to the most intense 5 min of an elite player (Mohr, Krustrup, & Bangsbo 2003). However, the declines in sprint performance were similar to those seen in elite players. Both findings indicate that the absolute intensity was somewhat lower than the intensities reported during matches played at the elite level, but that the relative physiological demand of the players is comparable to that of elite players (Rebelo, 1999).

Conclusions and suggestions

In order to optimize the process of developing motor skills, it is necessary to pay more attention to the metabolism of effort, especially in terms of the energy substrate (orientation of effort) and its size in terms of intensity of effort, duration of effort, duration of recovery after effort, type of recovery, total workload per session/workout/weekly cycle.

An important role in the dosage of effort is played by the purpose or theme of the training lesson, so if the training theme aims to develop the power of an energetic process, it is recommended to use over-maximal intensities, the duration being below the upper limit in which the respective process can energetically support muscle contraction and finally the effort at the imposed level, and if the training theme aims to develop the capacity of an energetic process, sub-maximal intensities of the respective process will be established, instead the duration will be longer (Teodorescu, 2009).

Football fitness has certainly been the component that has developed the most over the past two decades in terms of training components. This was due to research, experience gained in the field of exercise physiology, with the help of sports medicine, the improvement and increase in the number of recovery methods, and the increase in the quality of training as a process as a whole.

The ability to sprint is reduced both during and towards the end of the match, the studies presented explain this fact by reducing the amount of muscle glycogen in the muscle fibers involved in the effort, blood lactate being, however, an insignificant indicator of muscle lactate concentration during the soccer match.

Currently, when working on effort capacity in training, the ball should be used as much as possible, since it is the "essential" tool of the footballer. This principle is recommended to be applied both at the beginner level and at the high-performance level. However, depending on the training goals, we will see that it is important to establish a correct balance between integrated physical training (with the ball) and separate physical training (without the ball) (Bénézet & Hasler, 2019).

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