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Faculty of Physical Education and Sport

BACHELOR THESIS

PHYSIOLOGICAL ASSESSMENTS OF SOCCER PLAYERS IN DIFFERENT DIVISIONS

Mandroukas Athanasios

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Author: Mandroukas Athanasios **Supervisor: doc. MUDr. Jan Heller CSc.**

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Abstract

Aim. The aim of this study was to examine and compare the maximal oxygen uptake (VO_{2max}) and isokinetic strength of quadriceps and hamstrings muscle groups in soccer players of three different divisions.

Subjects. Twenty four professional players from Division I (mean aged 22.6±5.1 years and training experience 13.0±4.4 years, group A), twenty four players from Division II (mean aged 23.6±5.2 years and training experience 12.7±4.7 years, Group B), and twenty five players from Division III (mean aged 25.4±5.8 years and training experience 14.3±4.7 years, Group C) participated in this study.

Methods. All participants underwent anthropometric measurements, body fat assessments and performed a maximal exercise testing on treadmill to determine maximal oxygen uptake (VO_{2max}) and cardiorespiratory indices. Blood lactate concentrations were drawn at 4min and 6min after the end of exercise and mean value was used. Peak torque values were measured of the hamstrings (H) and quadriceps (Q) on isokinetic dynamometer (CSMI, Humac Norm) at three different angular velocities of 60,180, and 300°· sec^{-1} and the ratio H/Q percentage was recorded.

Results. VO_{2max} was significantly higher in division I compared to division II and III ($p<0.001$). Heart rate (HR) at rest was significantly lower in division I compared to division III ($p<0.001$). Blood lactate concentration was significantly higher in division III in comparison to division I and II at the recovery period ($p<0.001$). Peak torque values of quadriceps at angular velocity of 60°· sec^{-1} was significantly higher in division I compared to division III ($p<0.05$). At the same angular velocity the muscular strength of hamstrings was significantly higher in division I compared to division III ($p<0.001$) and division II showed significantly higher values compared to division III ($p<0.05$).

Conclusion. The results of the present study suggest that the higher values in VO_{2max} and in the isokinetic muscle strength of soccer players of division I may be due to the higher intensity they perform in training and match activities.

Key worlds: soccer, maximal oxygen uptake, isokinetic muscle strength, exercise testing, performance.

Statutory Declaration

“I declare that I have developed and written the enclosed thesis entirely by myself and have not used sources or means without declaration in the text. Any thoughts or quotations which were inferred from these sources are clearly marked as such. This thesis was not submitted in the same or in a substantially similar version, not even partially, to any other authority to achieve an academic grading and was not published elsewhere“.

Prague, January 17th 2011

Athanasios Mandroukas

AM

Dedication

I dedicate this thesis to my family in appreciation of their continuous highly significant love and support.

To my supervisor doc. MUDr. Jan Heller CSc for his generous support.

To all the great professor of the faculty for never ended patience with my questions and make their best effort to pass on their knowledge to us.

I would like to thank all the staff of Laboratory of Ergophysiology- Ergometry of Aristotle University in Thessaloniki department of Physical Education and Sport Science.

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1. INTRODUCTION

Soccer is the word's most popular sport, being played in every nation without exception. In recent years, there has been a remarkable expansion of sport science. Coaches and soccer players are more open to contemporary scientific approaches to prepare for competitions.

Modern soccer incorporates periods of high intensity exercise interspersed with periods of lower intensity exercise. The physiological demands of soccer require players to be competent in several aspects of fitness, which include aerobic and anaerobic power, muscle strength, flexibility and agility (Ekblom, 1986; Reilly and Doran, 2003; Reilly and Thomas, 1976). These fitness components often vary according to the individual player, the positional role in the team and the team's style of play (Bangsbo, 1994; Ekblom, 1986; Reilly, 2003).

1.1 Physiological demands

Cardiorespiratory endurance together with muscular strength and power are important in term of basic physiological capacities in soccer. Soccer performance is determined by the player's technical, tactical, physiological and psychological – social characteristics. These elements are closely linked to each other, e.g. the technical quality of a player may not be utilized if the player's tactical knowledge is low. The physiological factors can be divided into several match performance abilities. These are dependent on variables which in part can be evaluated separately.

Cardiovascular capacity, neural factors and muscle characteristics comprise basic components of physiological performance that are determined by both intrinsic biological make-up and training status (Bangsbo, 1993; Ekblom, 1986; Reilly and Gildourne, 2003). The physiological demands are closely related to the players' physical capacity as the ability to perform prolonged intermittent exercise, the ability to exercise at high intensity and to develop a high power output (force). The success of a soccer team depends on its ability to choose a playing strategy that fits the physical capacity of the available players.

Top-class soccer players, in most cases, have a very high capacity only within some of the physical categories. A player with low endurance capacity can compensate this weakness by having good capabilities in other areas relevant to soccer, e.g. a high technical standards or good sprinting ability. It is important that the player and the coach obtain objective information about the player's physical performance in order to design a training plan able to provide useful feedback and motivate the player to train (Bangsbo, 1994; Metaxas et al., 2006).

1.2 Match activities – Activity profile

The activity pattern during a soccer match includes rapid turns, accelerations, and tackling, sidestepping and game-specific technical skills (Bangsbo, 1994; Ekblom, 1986; Reilly and Thomas, 1976; Tumilty, 1993). These activities place great stress on the lower limbs and so the development of strength in soccer players is very important (Reilly and Doran, 2003). During the match play, the players change activity on average every 5 sec and perform approximately 1300 actions, with 200 of these being completed at high intensity (Bangsbo et al., 2006). Additionally, many decisive phases during a soccer match require players to exercise at high intensity (Bangsbo et al., 2006).

The typical distance covered by an outfield player at top level during a match is 10-13 km with that of midfield players being greater than players in the other positions (Krustrup et al., 2005; Mohr et al., 2003; Reilly, 1997). However, the majority of the distance is covered by walking and low-intensity running, and in terms of energy production mainly the high-intensity exercise periods are important. Thus, it is clear that the amount of high-intensity exercise separates the top class players from players at a lower level. Previous studies showed that the mean distance covered during competitive matches was 10.80 km, and the average individual difference between matches was 0.92 km, with no difference in regard to high intensity activities (Bangsbo et al., 1991). Midfielders covered a 10% longer distance (11.4 km) than defenders and forwards, with no difference concerning high intensity running.

There are major individual differences in the physical demands of a player in part related to the position in the team. Mohr et al., (2003) studied top-class players and found that the central defenders covered less total distance and high-intensity running than players in the other positions, which probably is closely linked to the tactical roles of the central defenders and their lower physical capacity (Bangsbo, 1994; Krustrup et al., 2003; Mohr et al., 2003). The full-backs covered a considerable distance at a high-intensity and by sprinting, whereas they carried out fewer headers and tackles than players in the other playing positions. The attackers covered a distance at a high intensity equal to the full-backs and midfield players, but sprinted more than the midfield players and defenders. Furthermore, in the study by Mohr et al., (2003) the attackers had a more marked decline in sprinting distance than the defenders and midfield players.

Earlier studies have shown that midfield players cover a greater distance during a game than full-backs and attackers (Bangsbo, 1994; Bangsbo et al., 1991; Ekblom, 1986; Reilly and Thomas, 1976). Mohr et al., (2003) observed that players in all team positions had a significant decline in high-intensity running towards the end of a match. This finding indicates that almost all players in elite soccer utilize their physical capacity during a game. Individual differences are not only related to position in the team. Thus, in this study within each playing position there was a significant variation in the physical demands depending on the tactical role and the physical capacity of the players (Mohr et al., 2003).

1.3 Positional role in the team

Maximal oxygen uptake also varies with playing position, the quality of training and the level of competition (Tumilty, 1993) and is sensitive to soccer-specific endurance training programmes (Helgerud et al., 2001). Maximal oxygen uptake also seems to be related to the total amount of work spent during match-play (Hoff et al., 2002), with improvements in VO_{2max} corresponding to increases in the total distance covered during a match (Helgerud et al., 2001).

Maximal oxygen uptake appears to differentiate players of different abilities and playing positions and also detect improvements with training. It is not, however, viewed as the best indicator of the ability to perform soccer-specific intermittent exercise as required in a game. Therefore, VO_{2max} may be useful for describing players in relation to different populations and/or for evaluating changes in fitness when such alterations are expected to be large (e.g. pre-season). Mean VO_{2max} of elite soccer players is normally reported between 55 and 65 ml/kg/min with few individuals values over 70 ml/kg/min. There is some evidence that differences in physiological demands exists among offensive, midfield and defensive players, based on presumption of higher endurance demands on the more active midfield position (Wilsoff et al., 1998), but other studies did not observed significant difference in VO_{2max} between playing position in amateur soccer players (Metaxas et al., 2004). Several studies have concluded that midfield layers have higher VO_{2max} values when expressed per kilogram of body weight (Reilly, 1994).

1.4 Level of competition

When comparing match observations of Danish first and second division players no difference in the total distance covered during a match was found, but the first division players performed more moderate speed (6.1 vs 4.1 %) of total playing time, high speed (2.5 vs 1.6 %) and sprint (0.8 vs 0.5 %) running (Bangsbo, 1993). The difference was caused by move frequent running at high speed rather than a longer duration of each activity. There was no difference between the two groups in VO_{2max} and performance in a field test with duration of about 10 min. Thus, it appears that the higher frequency of high intensity exercise of the first division players was not due to a greater fitness level, but rather that these players had a move efficient utilization of their physical capacity by a better choice of tactics.

1.5 Variations in fitness level throughout the year

Fitness testing and evaluation of cardiorespiratory performance can provide all the vital information about the effectiveness of a training program, particularly after periods of altered training, which may occur during a year. Various measurements of fitness were made before and at the end of the pre-season and improvements were observed in most of the variables (Reilly and Thomas, 1976). Casajus, (2001) noted a higher VO_{2max} values at the end of the season, while Heller et al., (1991) and Metaxas et al., (2006) reported the opposite. They observed twelve top-class Czech players and Greek soccer players, respectively and it was found that performance during maximal running was significantly higher during the season compared with pre-season measurements, even though the players trained 5 times per week and played 1 or 2 games during the season. One reason for these improvements in study of Reilly and Thomas, (1976) was probably that the physical standard of the players prior to the pre-season training was low, as a result of a decrease in the amount of fitness training during the first part of the off-season.

1.6 Blood lactate concentration in soccer

The concentration of BLa is often used an indicator of the anaerobic lactate acid energy production in soccer. Agnevik, (1970) found that the mean BLa concentration after a match was about 10 $mmol \cdot l^{-1}$ with a single measurement above 15 $mmol \cdot l^{-1}$ when studying Swedish first division players. Similar values were reported by Ekblom, (1986). The BLa concentration for first division players were 9.5 and 7.2 $mmol \cdot l^{-1}$ after the first and second half, respectively, while the corresponding values for fourth division players were 4.0 and 3.9 $mmol \cdot l^{-1}$ (Bangsbo, 1993).

Average blood lactate concentrations of 2-10mM have been observed during soccer games, with individual values above 12mM. These findings indicate that the rate of muscle lactate production is high during match play, but muscle lactate has been measured in only a single study. In a friendly game between non-professional teams, it was observed that muscle lactate rose fourfold (to around 15mmol.kg^{-1}d.w.) compared with resting values after intense periods in both halves, with the highest value being 35mmol.kg^{-1}d.w. (Krustrup et al., 2006). Such values are less than one-third of the concentrations observed during short-term intermittent exhaustive exercise (Krustrup et al., 2003). An interesting finding in that study was a low correlation coefficient between muscle and blood lactate (Krustrup et al., 2006), which can be explained by the lactate clearance rate being higher in muscle than in blood (Bangsbo et al., 1993). This also means that the blood lactate level can be high even though the muscle lactate concentration often observed in soccer (Bangsbo, 1994; Ekblom, 1986; Krustrup et al.,

2006) may not represent a high lactate production in a single action during the game, but rather an accumulated or balanced response to a number of high-intensity activities. This is important to take into account when interpreting blood lactate concentrations as a measure of muscle lactate concentrations. Nevertheless, based on numerous studies using short-term maximal exercise performed in the laboratory and the finding of high blood lactate and moderate muscle lactate concentrations during a match play, it can be suggested that the rate of glycolysis is high for short periods of time during a game.

1.7 Energy production in soccer

Soccer entails intermittent exercise in which the aerobic energy system is highly taxed with average and peak heart rates around 85 and 98 per cent of maximal values, respectively (Ali and Farally, 1991; Bangsbo, 1994; Ekblom, 1986; Krustrup et al., 2005; Reilly and Thomas, 1979). These values can be 'converted' to oxygen uptake using the relation between heart rate and oxygen uptake obtained during treadmill running (Bangsbo, 1994; Esposito et al., 2004; Krustrup and Bangsbo, 2001; Krustrup et al., 2005). However, it is likely that the heart rate values during a match lead to an overestimation of the oxygen uptake, since a number of factors such as dehydration, hyperthermia and mental stress elevate the heart rate without affecting oxygen uptake. Taking these factors into account the heart rate measurements during a game seem to suggest that the average oxygen uptake is around 70% VO_{2max}. This suggestion is supported by measurements of core temperature during a soccer game. The findings of core temperatures in the range of 39-40^{o}C during a game also suggest that the average aerobic loading during a competitive game is around 70% VO_{2max} (Ekblom, 1986; Mohr et al., 2004a).

Analysis of this information would suggest that VO_{2max} is a useful tool in the assessment of soccer players. However, VO_{2max} does not always appear to be a sensitive measure of performance in important aspects of soccer match-play (Bangsbo and

Lindqvist, 1992) or in the detection of detraining (Bangsbo and Mizuno, 1988). This deficiency may be due to discrepancies in the activity patterns, and the underlying physiology, associated with soccer match-play and that incorporated in a VO_{2max} test. The intermittent exercise pattern, as observed in soccer match-play, often necessitates performance at exercise intensities in excess of those achieved during a VO_{2max} test (Bangsbo, 1994). As a result, energy must be derived at the onset of exercise from substrates and oxygen supplies within the active musculature (Bangsbo et al., 2002; Edwards et al., 1973). Such evidence would indicate that the oxidative potential of the muscle is important for the performance of intense bouts of intermittent exercise. Peripheral adaptations do not; however, appear to be crucial for VO_{2max}, as Henriksson and Reitman (1977) demonstrated similar values of aerobic power despite reductions in succinct dehydrogenase and cytochrome oxidase following a period of detraining. These data would suggest that VO_{2max} may not be a sensitive enough indicator of the ability to perform soccer-specific exercise despite observations of a positive relationship with the level of play and the covered distance in a match play.

More important for performance than the average oxygen uptake during a game, may be the rate of rise in oxygen uptake during the many short intense actions. A player's heart rate during a game is rarely below 65 per cent of HR_{max}, suggesting that blood flow to the exercising leg muscles is continuously higher than at rest, which means that oxygen delivery is high. However, the oxygen kinetics during the changes from low- to high-intensity exercise during the game appear to be limited by local factors and depend, among other factors, on the oxidative capacity of the contracting muscles (Krustrup et al., 2004). The rate of rise of oxygen uptake can be changed by intense interval training (Krustrup et al., 2004). The observation that elite soccer players perform 150-250 brief, intense actions during a game (Mohr et al., 2003) indicates that the rate of anaerobic energy turnover is high during periods of the game.

1.8 Purpose of physiological testing

Performance in soccer is the result of a blend of several factors, including genetic endowment, training and health status of the individual athlete (MacDougall and Wenger, 1991; Viru and Viru, 2001). The sports scientist can, through physiological testing of the participants, analyse these factors and use the information to provide individual profiles of their respective strengths and weaknesses. These data can form the basis for the development of optimal training strategies. Further tests can then be used to evaluate the impact of these interventions on the physical fitness profile of individual players, thereby evaluating the effectiveness of the programme.

1.9 Laboratory exercise tests

Maximal aerobic capacity (VO_{2max}) is the highest amount of oxygen that the body can utilize during exhaustive exercise while breathing air at sea level (Astrand and Rodahl, 1986). Maximal oxygen uptake is one of the most commonly used indicators of aerobic metabolism and power, as it provides an indication of the functional limit of the oxygen transport system in individuals (Howley et al., 1995; Sutton, 1992). During a soccer match-play, the majority of energy provision is derived from the aerobic energy system (Bangsbo, 1994). The determination of a soccer player's maximal aerobic power is therefore important, as the oxygen transport system underpins the ability to play for 90 min (Bangsbo, 1993) and to recover between short bouts of high-intensity exercise (Balsom, et al., 1994a; Balsom, et al., 1994b; Tomlin and Wenger, 2001). When maximal aerobic power is evaluated in athletes, it is important that the test resembles the activity pattern of the specific sport (Strömme, et al., 1977). Therefore, VO_{2max} tests for soccer players should be performed on a treadmill ergometer to enhance the specificity of the active musculature to that used in activity patterns in soccer. Such procedures will ensure valid assessments of VO_{2max} (Hermansen and Saltin, 1969). Standardized laboratory protocols to establish VO_{2max} include continuous and discontinuous exercise modes, both of which are used extensively in the assessment of VO_{2max} (Duncan et al., 1997).

Table 1 summarizes some of the data reported in the literature for the VO_{2max} of elite soccer players. These data suggest that VO_{2max} may be useful in differentiating between successful and unsuccessful teams, as teams who perform better in a specific league or at a higher standard possess higher VO_{2max}.

Table 1. Selected data on maximal oxygen uptake of soccer players in the literature.

Study	Players	Number of players	VO_2max
Agnevik (1970)	Swedish National Team		56.5
Williams et al. (1973)	Aberdeen	(9)	57.8
Reilly (1975)	First English Division		66.0
Smaros (1980)	Second Finland Division	(8)	63.6
Rhodes et al. (1986)	Olympic Team of Canada		58.7
Apor (1988)	Hungary Teams		66.6
	1st place		64.3
	2nd place		63.3
	3rd place		58.1
	5th place		
Bangsbo and Mizuno (1988)	Denmark professional players	(4)	66.2
Faina et al. (1988)	Italian soccers	(17)	64.1
	Amateurs	(27)	58.9
	Professionals	(1)	63.2
	Elite		
Bangsbo et al. (1991)	Denmark professional players Division I and II	(14)	60.6
Bangsbo and Lindquist (1992)	Denmark professional players Division I	(20)	60.8
Chin et al. (1992)	National players of Hong-Kong	(24)	59.1
Bangsbo et al. (1993)	Denmark professional players Division I and II	(14)	60.3
Puga et al. (1993)	Portugal professional players Division I and II	(16)	61.3

Wisløff et al. (1998)	Norway players	(14)	67.6
	Posenborg	(15)	59.9
	Tronhaim		
Metaxas et al.(2000)	Greek players		
	Professional	(50)	64.5
	Amateurs	(50)	59.1
Reilly et al. (2000)	Denmark players	(25)	58.7
	Defenders	(21)	62.6
	Midfielders	(14)	60.0
	Attackers		
Aziz et al. (2000)	National players of Singapure	(23)	58.2
Al-Hazaa et al. (2001)	National players of Saudi Arabia	(23)	56.8
Casajús (2001)	Professional Spanish players	(15)	65.5
			66.4
Helgerud et al. (2001)	Elite young players	(19)	64.3
Hoffetal.(2002)	Norway players	(6)	67.8
	1st Division		
Kemi et al. (2003)	Norway players	(10)	65.6
	1st Division		

1.10 Anaerobic threshold

The modern soccer is characterized by numerous explosive short exercise bursts interspersed by brief recovery periods over an extended period of time (90 minutes). In this situation, the activation of both energy systems, the aerobic and the anaerobic, is needed to fulfil the muscle energy demands during the game. The anaerobic threshold is defined as the highest exercise intensity in terms of HR or VO2 where the production and clearance of lactate is equal. There exist several methods to determine anaerobic threshold, including measurement of blood lactate and ventilatory measurements.

1.11 Test of determination of muscle strength

Muscle strength is defined as the amount of force or tension that a muscle or muscle group exerts against a resistance at a specified velocity during a maximal voluntary contraction (Bell and Wenger, 1992). In the laboratory, isokinetic apparatus can be used in the assessment of the muscle strength of performers across most sports. Isokinetic dynamometry provides a controlled environment in which the neuromuscular performance of the joint system can be stressed (Baltzopoulos and Gleeson, 2001; Sapega et al., 1982). The muscular force against the motor-driven lever arm, or the torque, is measured with the angular velocity controlled when performing movements in the vertical plane such as knee flexion and extension (Gransberg and Knutsson, 1983; Sale, 1991). One of the main advantages of isokinetic dynamometry is the accuracy in assessment provided by the constant pre-selected velocity of movement (Iossifidou and Baltzopoulos, 1998). Isokinetic systems also permit muscle function tests to be completed across a variety of different angular velocities and joint angles.

There are some methodological limitations associated with isokinetic assessment. During the assessment, the relevant muscle group is isolated (e.g. quadriceps), which restricts any assessment to the specific joint being examined (Herzog, 1988). The isolation of muscle groups will reduce the validity of the measurements to functional performance, as the multi-joint movements involved in most sports will not be re-created (Kannus, 1994). As a result, isokinetic dynamometry does not fully reflect performance in specific movement patterns of the limbs associated with sports such as soccer (Cometti et al., 2001). Assessment involving free weights may be more accurate in determining the functional strength in a soccer context (Wisloff et al., 1998), as the individual has a greater freedom of movement, though such procedures may not be easy to control. Despite the application of standardized assessment protocols, data from one trial may not be representative of an individual’s maximal isokinetic leg strength, making the validity of key variables an important consideration when investigating muscle performance.

Several trials may be needed to familiarize the participants and to overcome any reliability problems during isokinetic measurement (Gleeson and Mercer, 1992). Both internal (e.g. positioning of participant, gravitational forces, calibration of dynanometer) and external (e.g. time of day, participant's limb dominance, participant's motivation) factors may affect test results, so attention must be made to create standardized conditions (Kannus, 1994).

Strength training has been reported to improve kicking performance as a result of a resistance training programme (De Proft, et al., 1988; Dutta and Subramanium, 2002), highlighting the importance of muscle strength for match-specific actions. Muscle strength can also differentiate between age categories, levels of play and playing positions. Oberg et al., (1986) reported that players of the Swedish national team and in the Swedish First Division had a higher torque value at fast- and slow-speeds for knee flexors and extensors than players from Fourth Division clubs. Similar findings were reported by Togari et al., (1988) between Japanese elite players and university players. Gissis et al., (2003) found that maximal strength about the knee joint was significantly greater for young Greek elite players than young age-matched Greek amateur players of a similar age. Rochcongar et al., (1988) and Gur et al., (1999) have reported differences in the strength of the quadriceps and hamstrings muscles in young and adult soccer players, with muscle strength increasing with age. Goalkeepers and defenders were reported to have a higher knee extension torque than midfielders and forwards but differences for most players were attributed to body size (Oberg et al., 1984). These findings suggest that high absolute muscle strength in the lower limbs is an important component of fitness for successful soccer play and muscle strength increases with progressive standards of play.

Isokinetic dynamometry can be used to assess the balance of strength between the hamstrings (H) and quadriceps (Q) muscle groups about the knee joint, calculated as either the conventional or functional H/ Q ratio (Aagaard et al., 1995; Aagaard et al., 1998). The conventional H/Q ratio is calculated by dividing maximal knee flexion strength by maximal knee extension strength. However, this ratio is calculated at the same angular velocity and contraction mode (eccentric, concentric or isometric), which does not provide adequate information on agonist – antagonist muscle contraction. Therefore, the functional H/Q ratio or dynamic control ratio (DCR) was introduced as a descriptor of the agonist – antagonist balance of strength during knee flexion or extension (Aagaard et al., 1995). Moreover, the functional H/Q ratio can provide an assessment of potential injury risk. It is calculated as maximal eccentric hamstring strength divided by maximal concentric quadriceps strength during extension, or vice versa during flexion (Aagaard et al., 1998). The ideal functional H/Q ratio should be 1.0, which indicates that the hamstrings can resist as much force as the quadriceps can produce (Graham-Smith and Lees, 2002). The ratio can vary with joint angle and, moreover, the value 1.0 may be derived from peaks at different angles for concentric and eccentric actions. The ratio may, however, have limited practical application in rehabilitation settings, as H/Q ratios can be identical for both injured and healthy individuals (Kannus, 1994). This may make it difficult to determine optimal H/Q ratios that can be used with injured individuals undergoing rehabilitation programmes. Nevertheless, both the conventional and functional H/Q ratios, but in particular the latter, may be helpful in identifying the functional muscle balance and stability at the knee joint in soccer players (Reilly, 1994; Zakas et al., 1995). A high muscle strength relative to the functional H/Q ratio in order to stabilize the knee joint is important in the prevention of injury (Orchard et al., 1997), with the H/Q ratio ranging between 41 and 81% in soccer players depending on the angular velocity of movement (Rahnama et al., 2003b). An ideal H/Q ratio of 60% has been suggested (Ekstrand and Gillqvist, 1982).

There is evidence to suggest that players have a lower H/Q ratio towards the end of matches as a result of the fatigue associated with prolonged exercise: Rahnama et al., (2003a) reported a reduced H/Q ratio in amateur soccer players at the end of a simulated match compared with pre-match values, which may indicate that the H/Q ratio is sensitive to fatigue. The H/Q ratio is also sensitive to detect changes in muscle strength following preseason training (Kayatekin, 1995). It seems that the H/Q ratio can also differentiate between different levels of play, as Cometti et al., (2001) reported that French elite players had a higher H/Q ratio than sub elite players at several angular velocities between 2.09 and 5.23 $rad \cdot s^{-1}$, except at 5.23 $rad \cdot s^{-1}$.

1.12 Purpose of the study

The aim of this study was to examine and evaluate the cardiorespiratory endurance and isokinetic muscle strength of soccer players and to compare the performance among three different professional divisions.

2. METHODS

2.1 Participants

Seventy three male soccer players from divisions I – III of the Greek national leagues participated in the study. Twenty four (n=24) professional soccer players consisted group A (mean aged 22.6±5.1 years, training experience 13.0±4.4 years), B players (n=24) (mean aged 23.6±5.2 years, training experience 12.7±4.7 years) (division I and II) and twenty five (n=25) players group C (mean aged 25.4±5.8 years, training experience 14.3±4.7 years) (division III), respectively. The groups and the anthropometric characteristics of the subjects are demonstrated in table 2.

Each subject volunteered to participate in the study after being fully informed of the nature, risks and benefits of participation in the investigations and signed an informed consent form. All participants were non – smokers and did not use any nutritional supplements or medications known to affect their performance. They reported no musculoskeletal injuries of the lower limbs that would prevent them from performing maximal running and maximal isokinetic contractions. Before the study, each subject was informed and signed a consent form in accordance with the Declaration of Helsinki. All the players within a team were assessed on the same day and the tests were performed in the same order.

2.2 Anthropometric measurements

All participants underwent anthropometric examinations, including body fat assessment with skinfold measurements (four-fold method): biceps (S_1), triceps (S_2), suprailiac (S_3) and subscapular (S_4) by specific calliper (Lafayette, Ins. Co., Indiana, USA). Estimation of the body density was calculated according to the Durnin and Rahaman, (1967) equation for male adults over 16 years old:

$$D = 1.161 - 0.0632 \times \log(S_1+S_2+S_3+S_4)$$

The percentage body fat was estimated by the equation of Siri, (1956):

$$BF(\%) = [(4.95 / D) - 4.5] \times 100$$

The height and body weight were measured using an electronic digital scale (Seca, Hamburg, Germany).

2.3 Laboratory exercise tests

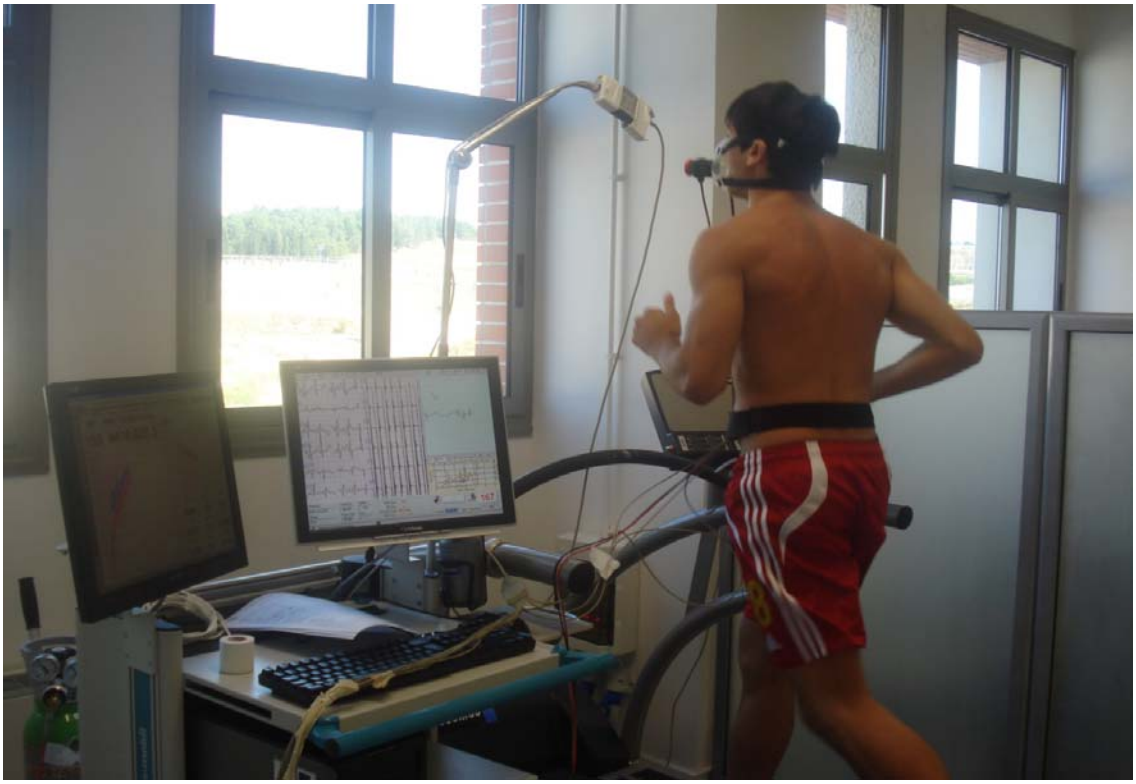
All players performed a maximal exercise test on a treadmill (H/P COSMOS, Germany) after a ten-minute warm-up and stretching. Participants exercised to exhaustion according to a maximal incremental continuous protocol consisted of seven 2-minute stages. The initial grade and speed were set at 1% and 10km/h, respectively, followed by an increase in speed of 2km/h per stage (figure 1).

The oxygen uptake (VO_2) was determined by means of absolute ($ml \cdot min^{-1}$) and relative values adjusted to body weight ($ml \cdot kg \cdot min^{-1}$), via an ergospirometric device based on breath-by-breath gas analyzing system (Jaeger Oxygen-PRO, Würzburg, Germany). The highest value of VO_2 was accepted as the maximal oxygen uptake, after achieving the stabilization of VO_2 for at least five measurements (steady state). The used exercise test criteria for achieving VO_{2max} were:

1. levelling off (plateau) of oxygen uptake with an increase of work rate (Åstrand and Rodahl, 1986)
2. level of concentration of blood lactate >8 $mmol \cdot l^{-1}$ (Shephard and Åstrand, 1992)
3. respiratory exchange ratio (VCO_2/VO_2) superior to 1.0 or 1.1 (Åstrand and Rodahl, 1986) and finally,
4. achieving >90% of the age-adjusted estimated maximal heart rate.

In addition, the following cardiorespiratory indices were determined: exercise duration; the maximal pulmonary ventilation (VE_{max}); the heart rate (HR) was recorded during the test by sport tester (Polar, RS 800, Kempele, Finland) connected to the ergospirometric system; the heart rate at anaerobic threshold (HR_{AT}); the maximal heart rate (HR_{max}) and the respiratory exchange ratio (RER).

Figure1.



2.4 Blood lactate concentration

Duplicated blood lactate concentrations were drawn from samples of the hand fingertips at the 4th and 6th min of recovery using an enzymatic lactate analyzer (Boehringer, Mannheim, Germany) and the average value of the two analyses for each min was used.

2.5 Isokinetic muscle strength

Warm-up

Participants performed a standardized warm-up on a Monark cycle ergometer for 10min with a low resistance at 60 rev/min prior to all strength assessments. This exercise was followed by 6 minutes of stretching of the hamstrings and quadriceps muscles. All participants performed 5min preliminary test in order to familiarize themselves with the equipment and testing procedure.

Testing protocol

Isokinetic peak torques were measured using Humac/Norm™ dynamometer (Model 770, CSMI, Stoughton, MA) with a specially designed program which included torque comprehension for the combined weight of the lower leg and level arm of the dynamometer at angular velocities of 60, 180, and 300°$\cdot$sec^{-1} (figure 2). For each angular velocity, peak isokinetic torque was recorded simultaneously. Maximum isokinetic strength was recorded as the torque of the quadriceps and hamstring muscles at every 1^{o} throughout the whole range of motion. The torque generated by the limb weight and the dynamometer arm was extracted from the obtained data. The subjects were seated on the chair of the dynamometer, with stabilization straps at the trunk, thigh and tibia to prevent extraneous joint movement. The knee to be tested was positioned at 90° of flexion, (0° = fully extended knee), to align the axis of the dynamometer lever arm with the distal point of the lateral femoral condyle. Subjects were instructed to kick the leg as hard and as fast they could through a complete range of motion. Verbal encouragement was given during every trial. Three repetitions were carried out at each angular velocity and the best torque value was used for the reanalysis. A 30 sec rest period was taken between each trial and a 60 sec rest period between each velocity measurement.

Figure 2.

2.6 Statistical analysis

All values are expressed as mean ± standard deviation (SD). The assumption for normality was examined with Shapiro-Wilk test (n<50).One-way analysis of variance (ANOVA) and post-hoc analysis using a Scheffé test was used to determine differences of variables between divisions. The statistical analysis was performed via the Statistical Package for Social Sciences SPSS (version 16.0, Chicago, Illinois, USA). The level of significance was set at $p<0.05$.

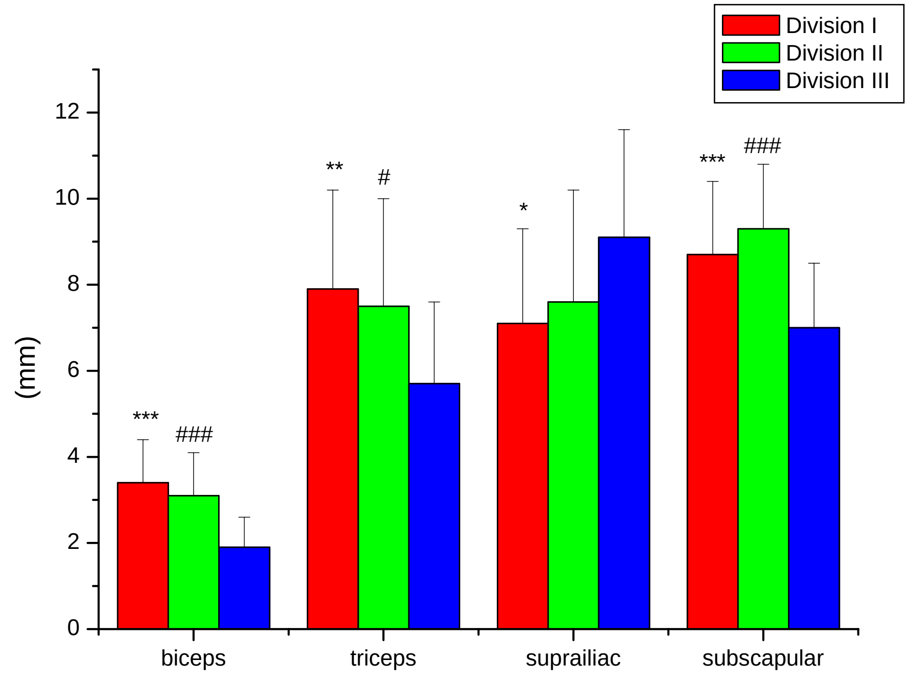
3. RESULTS

Height, weight and body fat did not differ between the players of the different divisions (Table 2). Skin-fold measurements of soccer players are shown in figure 3.

Table 2. Anthropometric characteristics of soccer players (mean±SD).

	Height (m)	**Weight (kg)**	**Body fat (%)**
Soccer players			
Division I (n=24)	1.77 ± 0.06^{NS}	73.6 ± 6.3^{NS}	10.8 ± 1.8^{NS}
Division II (n=24)	1.79 ± 0.06^{NS}	75.2 ± 7.4^{NS}	10.8 ± 2.3^{NS}
Division III (n=25)	1.79 ± 0.05^{NS}	75.8 ± 4.9^{NS}	9.7 ± 2.0^{NS}
(n=73)	*1.79 ± 0.05*	*74.9 ± 6.3*	*10.4 ± 2.1*

NS: no significant differences between soccer and of the different divisions.



*: p<0.05 I vs III

**: p<0.01 I vs III

***: p<0.001 I vs III

#: p<0.05 II vs III

###p<0.001 II vs III

Figure 3. Skinfold measurements of soccer players (mean±SD).

Resting heart rate was significantly lower in division I compared to divisions II and III ($p<0.001$). However, no significant differences were found in resting systolic (sBPrest) and diastolic blood pressure (dBRrest) as well as in the time to exhaustion among the players of different divisions (Table 3). Heart rate at the anaerobic threshold (HR_{AT}) was significantly higher ($p<0.01$) in players of division I compared to division III and in players of division II compared to division III ($p<0.05$) (Table 3). HR_{max} differed among the 3 divisions of soccer players while players in division III had the lowest compared to division I ($p<0.01$) and division II ($p<0.05$). Maximal oxygen uptake

(VO_{2max}), in absolute and relative values was significantly higher fin players of division I compared to players of division III ($p<0.05$, $p<0.001$) and to division II ($p<0.05$). The RER and the maximal values of blood lactate were significantly higher in players of division III compared to players of division I ($p<0.001$) and II ($p<0.05$, $p<0.001$), respectively (Table 3).

Table 3. Physical and physiological characteristics of soccer players (mean±SD).

	Division I *(n=24)*	**Division II** *(n=24)*	**Division III** *(n=25)*
HR_{rest} ($b \cdot min^{-1}$)	57.5±6.1***	61.2±10.9	67.4±8.9
sBp_{rest} (mmHg)	122.9±7.0	122.4±6.4	126.2±9.7
dBp_{rest} (mmHg)	61.6±5.9	62.5±7.6	65.4±6.8
Time (min)	9.50±0.41	9.12±0.68	8.27±0.79
HR_{AT} ($b \cdot min^{-1}$)	170.4±7.3**	168.1±4.7#	163.5±6.8
VO_{2AT} ($ml \cdot min^{-1}$)	3800±428	3643±461	3488±447
HR_{max} ($b \cdot min^{-1}$)	199.9±4.7**	198.5±6.2#	192.2±10.7
VO_{2max} ($ml \cdot min^{-1}$)	4460±386*	4301±423	4172±363f
VO_{2max} ($ml \cdot kg \cdot min^{-1}$)	61.13±5.91***,$	57.27±5.71	55.11±3.93
RER	1.14±0.07***	1.16±0.06#	1.21±0.07
BL_{max} ($mmol \cdot l^{-1}$)	8.9±1.7***	9.1±1.9###	11.6±2.1

$ p<0.05 I vs II

*: p<0.05 I vs III

**: $p<0.01$ I vs III

***: $p<0.001$ I vs III

$^{\#}$: $p<0.05$ II vs III

$^{\#\#\#}p<0.001$ II vs III

Peak torque values of quadriceps and hamstring between divisions of soccer players are shown in table 4. At angular velocity of $60^{o}sec^{-1}$, the players of division I had significantly higher values of quadriceps compared to the players of division III. However, no significant differences were found between the players in divisions II and III. Peak torque values of hamstrings at regular velocity of $60^{o}sec^{-1}$ were significantly higher for players in division I compared to players of division II ($p<0.05$) and division III ($p<0.001$). Furthermore, significantly increased peak torque values were found between players of divisions II and III ($p<0.05$). In the other higher angular velocities of 180^{o} and $300^{o}sec^{-1}$ no significant differences were observed among the players of divisions I, II, III, respectively (Table 4).

Table 4. Comparisons of quadriceps and hamstring peak torques (Nm) at angular velocities of 60, 180 and 300^{o}·sec^{-1} between divisions of soccer players (mean±SD).

Soccer players	**Division I**	**Division II**	**Division III**	***Total (n=73)***
Quadriceps 60^{o}·sec^{-1}	278.7 ± 31.5*	270.4 ± 31.4	253.2 ± 27.7	267.3 ± 31.7
Quadriceps 180^{o}·sec^{-1}	187.5 ± 27.6	180.0 ± 18.5	178.8 ± 21.1	182.0 ± 22.6
Quadriceps 300^{o}·sec^{-1}	128.6 ± 14.5	123.4 ± 18.2	125.2 ± 14.4	125.8 ± 15.7
Hamstring 60^{o}·sec^{-1}	155.5 ± 13.9***	149.1 ± 19.6$^{\#}$	136.7 ± 15.0	147.2 ± 17.9
Hamstring 180^{o}·sec^{-1}	114.3 ± 18.0	105.6 ± 14.5	104.2 ± 13.2	107.9 ± 15.7
Hamstring 300^{o}·sec^{-1}	77.2 ± 14.7	73.5 ± 17.0	72.3 ± 14.3	74.4 ± 15.3

*: p<0.05, I vs III

***: p<0.001, I vs III

#: p<0.05, I vsII

In figure 4 the hamstring to quadriceps peak torque ratio (H/Q) differences are presented between the players from the three divisions. It is shown that no significant difference exists between all players.

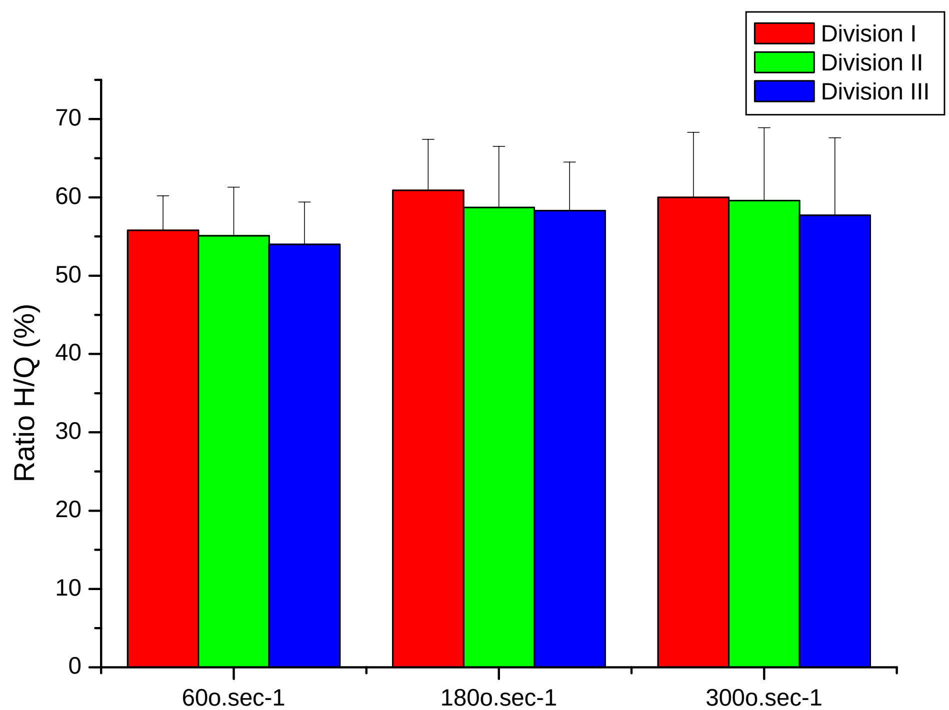


Figure 4. H/Q peak torque ratios for soccer players at three angular velocities (mean±SD)

4. DISCUSSION

The aim of this study was to examine and compare the cardiorespiratory capacity and isokinetic muscle strength in soccer players of different divisions. The results showed that the players of division I had higher VO_2 max (absolute and relative values) and higher isokinetic muscle strength compared to the other two divisions (II and III).

Several studies have determined the maximum oxygen uptake for male elite adult players and mean values 50-75 $ml.kg^{-1}.min^{-1}$ have been found (see Table 1). Verstappen and Bovens, (1989) were found mean values of 68 and 63 in a Dutch first division and 59.6 $ml.kg^{-1}.min^{-1}$ for goalkeepers and central defenders, midfield players and forwords were above 60 $ml.kg^{-}.min^{-1}$. Puga et al., (1993) and Bangsbo and Mizuno, (1988) reported values of 66 $ml.kg^{-1}.min^{-1}$. Most studies of soccer players have reported a large variation in VO_{2max}, which is partly associated with the different positions of the players within the team. Based on results obtained for Danish elite players, full-backs and midfield players appear to have the highest values, and goalkeepers and central defenders the lowest (Bangsbo, 1993). Similar findings were obtained by Reilly, (1975) but not by Raven et al., (1976).

The highest values reported using treadmill test were for a German club team 69.2 (±7.8) $ml.kg^{-1}.min^{-1}$ (Nowacki et al., 1988). Values for professional players tend to be higher than for amateurs, though this can depend on the quality of the training and the level of competition. For Swedish recreational players, Ekblom (1986) cited values of 45-50 $ml.kg^{-1}.min^{-1}$.

The values of VO_{2max} in soccer players are similar to those obtained in other team sports, but are considerably lower than values fore elite athletes within endurance sports, where VO_{2max} levels are higher than 80 $ml.kg^{-1}.min^{-1}$ (Reilly et al., 1990). The higher VO_{2max} that was found in the players of division I in our study may be due to the high speed and sprint running they have in training and match. Bangsbo, (1992) did not found any difference in the total distance covered during a match in Danish first and second division players. The players of division I performed more moderate speed (6.1% vs 4.1% of the total playing time), high speed and sprint running. The difference was caused by more frequent running at high speed rather than a longer duration of each activity. In a field test with duration of about 10 min, there was no difference between the players of division I and II in VO_{2max} and performance (Bangsbo, 1992).

Metaxas et al., (2009) who examined VO_{2max} in absolute and relative values in different divisions of soccer and basketball players reported that VO_{2max} was significantly lower in division IV for soccer players when compared to the other 3 divisions. However, soccer players for division II had significantly lower VO_{2max} in absolute values as compared to basketball players.

Study by Reilly and Thomas, (1976) showed that the players covered a longer distance in the first half compared to the second half of a match. Bangsbo, (1993) reported that the difference was about 5% or 300m. This difference was caused by more low intensity exercise in the first and last 15min in the first half when compared to the second half. Match observations of Danish First and Second Division Players showed no difference in the total distance covered during a match (Bangsbo, 1993). However, the First Division players performed moderate speed (6.1% vs 4.1% of total playing time), high speed (2.5% vs 1.6%) and sprint (0.8% vs 0.5%) running.

Observations by Ekblom, (1986) showed that Swedish players of division I had higher blood lactate concentrations and body temperature both at half-time and after a match compared to players of lower divisions. Our results from laboratory exercise test for the determination of VO_{2max} during short – term maximal exercise showed that our players of division I had significantly lower concentration of blood lactate that the players of the other divisions.

In soccer, players perform many different types of activities and the intensity can alternate at any time and range from standing still to maximal running. The physiological demands of soccer require players to be competitive in several aspects of fitness, whith include aerobic and anaerobic power. In soccer the players perform intermittent exercise. For elite male players, the total duration of high intensity exercise during a match play is about 7 min (Bangsbo et al., 1991). Degradation of CP and to a lesser extent stored ATP, provides a considerable amount of energy during the sprint exercise. The remaining anaerobic energy is delivered from glycolysis leading to formation of lactate. The CP reaction that rebuilds ATB by CP breakdown is activated at the onset of exercise. The CP stores are limited and can last only a few seconds during maximal running if CP was the only energy source. It is known that after intense exercise, CP is resynthesized rapidly, more than half of the used CP can be replenished within 1 min by utilization of ATP produced, from aerobic sources (Sahlin et al., 1992).

Although the net utilization of CP is quantitatively small during a football match, CP has a very important function as an energy buffer, making energy available for the muscles during rapid elevations in the exercise intensity. The concentration of lactate in the blood is often used as an indicator of the anaerobic lactacid energy production in soccer. Agnevik, (1970) found that the mean blood lactate concentration after a match was about 10 $mmol/l^{-1}$ with a single measurement above 15 $mmol/l^{-1}$, when studying Swedish First Division Players. Similar values were obtained by Ekblom, (1986). Bangsbo (1993) shows values of both blood and plasma lactate at various time points during a competitive match (Bangsbo 1993).

It seems that some differences exist between first and second half in blood lactate concentration. Blood lactate concentrations were lower in the second compared to the first half. This was related to the findings that the players covered a shorted distance (4.7 vs 5.4 Km) and performed less high intensity running (0.83 vs 1.24 Km) in the second half, which was also reflected in a lower mean HR of about 10 $beats.min^{-1}$ (Bangsbo 1993).

5. CONCLUSIONS

The results of the present study support previous investigations indicating a relationship between aerobic endurance, muscle strength and performance in professional soccer players.

Laboratory tests are performed in a controlled environment to reduce the impact of extraneous variables. In general, data from a laboratory test provide accurate information that is very detailed, although care should be taken with respect to the reliability of the equipment. It is recommended that several trials of the same test should be performed to increase the reliability of the data. Physical trainers and sports scientists can therefore obtain an accurate general physical profile of the individual soccer player if extensive testing is conducted. Accurate information on a player's aerobic power, lactate threshold and muscle strength of the lower limbs can help in the setting of individual training programmes or form part of a player selection strategy. Access to laboratory facilities may be difficult for some soccer clubs and tests are also expensive to administer. Testing can also be time-consuming, as numerous visits to the laboratory may be required to obtain reliable results. Such tests are also sensitive enough to allow the detection of significant changes in the fitness of players. As a result, ergometric test procedures may be most effective during specific periods of the season. Pre-season may be the time when administration of laboratory tests is most important, as the fitness of players needs to be established during this period following de-conditioning in the off-season. In the competitive season, the administration of such tests may be more difficult due to their time-consuming nature and the limitations associated with the data provided. Laboratory tests should, therefore, be used in the assessment of general fitness rather than soccer-specific fitness.

It is clear that the data from the assessment of muscle strength in soccer players using isokinetic dynamometers can be employed to assess general muscle strength, compare positional differences in strength and evaluate the effect of resistance training. It is recommended that data for both conventional and functional H/Q ratios should be combined to provide a thorough evaluation of knee joint stability and subsequent risk of injury in individuals. Test criteria may be improved by taking the angle of occurrence of peak torque into account. Due to the expensive and time-consuming nature of accommodating a whole squad for isokinetic assessment, tests should be performed at strategic intervals pre-, in- and offseason, especially when monitoring rehabilitation of muscle strength in injured players.

In conclusion, the professional soccer players of division I had higher VO_2max relative values, respiratory exchange ratio and maximal strength in hamstrings and quadriceps muscle groups at 60°/sec (heavy load) compared to Divisions II and III. These findings may be attributed to the different intensity of training which is applied at higher competitive levels as well as the qualitaty of training (aerobic endurance, strength training). Finally, the results of the tests could be used by the trainers in order to ameliorate and stabilize the performance through training practice during the competitive season.

REFERENCES

1. Aagaard, P., Simonsen, E. B., Trolle, M., Bangsbo, J., & Klausen, K. (1995). Isokinetic hamstring/quadriceps strength ratio: Influence from joint angular velocity, gravity correction and contraction mode. Acta Physiologica Scandinavica, 154, 421 – 427.
2. Aagaard, P., Simonsen, E. B., Magnusson, S. P., Larsson, B., & Dyhre-Poulsen, P. (1998). A new concept for isokinetic hamstring:quadriceps muscle strength ratio. American Journal of Sports Medicine, 26, 231 – 237.
3. Agnevik, G. (1970). Footboll Idrottsfysiologia Rapport No. 7., Trygg-Hansa, Stockholm.
4. Ali, A. & Farally, M. (1991). Recording soccer players' heart rate during matches. Journal of Sports Sciences, 9, 183 – 189.
5. Åstrand, P.O., Rodahl, K. (1986). Textbook of work physiology: Physiological bases of exercise. McGraw-Hill.
6. Balsom, P. D., Ekblom, B., & Sjodin, B. (1994a). Enhanced oxygen availability during high-intensity intermittent exercise decreases anaerobic metabolite concentration in blood. Acta Physiologica Scandinavica, 150, 455 – 456.
7. Balsom, P. D., Gaitanos, G. C., Ekblom, B., & Sjodin, B. (1994b). Reduced oxygen availability during high-intensity intermittent exercise impairs performance. Acta Physiologica Scandinavica, 152, 279 – 285.
8. Baltzopoulos, V., & Gleeson, N. P. (2001). Skeletal muscle function. In R. Eston & T. Reilly (Eds.), Kinanthropometry and exercise physiology laboratory manual. Vol. 2: Exercise physiology (pp. 1 – 35). London: Routledge.
9. Bangsbo, J., Mohr, M., & Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football players. Journal of Sports Sciences, 24(7), 665 - 774.
10. Bangsbo, J., Gibala, M. J., Krustrup, P., Gonzalez-Alonso, J., & Saltin, B. (2002). Enhanced pyruvate dehydrogenase activity does not affect muscle O2 uptake at

the onset of intense exercise in humans. American Journal of Physiology, 282, R273 – R280.

11. Bangsbo, J. (1994). Fitness training in soccer. A scientific approach. Ho+Storm, Bagsvaed.

12. Bansgbo, J. (1993). The physiology of soccer: with special reference to intense intermittent exercise. Unpublished Doctoral Dissertation, Copenhagen.

13. Bansgbo, J. (1992). Is the O_2 deficit an accurate quantitative measure of the anaerobic energy production during intense exercise? Journal Applied Physiology, 73(3), 1207 - 1209.

14. Bangsbo, J. and Lindquist F. (1992). Comparison of various exercise tests with endurance performance during soccer in professional players. International Journal Sports Medicine, 13(2), 125 - 132.

15. Bansgbo, J., Norregaard, L., & Thorso, F. (1991). Activity profile of competition soccer. Canadian Journal of Sports Science, 16, 110 – 116.

16. Bangsbo, J., & Mizuno, M. (1988). Morphological and metabolic alterations in soccer players with detraining and retraining and their relation to performance. In T. Reilly, A. Lees, K. Davids, & W. J. Murphy (Eds.), Science and football (pp. 114 – 124). London: E & FN Spon.

17. Bell, G. J., & Wenger, H. A. (1992). Physiological adaptations to velocity-controlled resistance training. Sports Medicine, 13, 234 – 244.

18. Casajus, J. A. (2001). Seasonal variation in fitness variables in professional soccer players. Journal of Sports Medicine and Physical Fitness, 41, 463 – 467.

19. Cometti, G., Maffiuletti, N. A., Pousson, M., Chatard, J.-C., & Maffulli, N. (2001). Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. International Journal of Sports Medicine, 22, 45 – 51.

20. Davis, J. A., Brewer, J., & Atkin, D. (1992). Pre-season physiological characteristics of English first and second division soccer players. Journal of Sports Sciences, 10, 541 – 547.

21. De Proft, F., Cabri, J., Dufour, W., & Clarys, J. P. (1988). Strength training and kick performance in soccer players. In T. Reilly, A. Lees, K. Davids, W. J. Murphy (Eds.), Science and football (pp. 230 – 233). London: Routledge.

22. Duncan, G. E., Howley, E. T., & Johnson, B. N. (1997). Applicability of VO_{2max} criteria: Discontinuous versus continuous protocols. Medicine and Science in Sports and Exercise, 29, 273 – 278.

23. Durnin, J.V., Rahaman, M.M. (1967). The assessment of the amount of fat in the human body from measurements of skinfold thickness.Br J Nutr. 1967 Aug;21(3):681-9.

24. Dutta, P., & Subramanium, S. (2002). Effects of six weeks of isokinetic strength training combined with skill training on football kicking performance. In W. Spinks, T. Reilly, & A. Murphy (Eds.), Science and football IV (pp. 333 – 340). London: Routledge.

25. Edwards, R. H. T., Ekelund, L.-G., Harris, R. C., Hesser, C. M., Hultman, E., Melcher, A., & Wigertz, O. (1973). Cardiorespiratory and metabolic costs of continuous and intermittent exercise in man. Journal of Physiology, 234, 481 – 497.

26. Ekblom, B. (1986). Applied physiology of soccer. Sports Medicine, 3, 50 – 60.

27. Ekstrand, J., & Gillqvist, J. (1982). The avoid ability of soccer injuries. International Journal of Sports Medicine, 4, 124 – 128.

28. Esposito, F., Impellizzeri, F. M., Margonato, V., Vanni, R., Pizzini, G. & Veicsteinas, A. (2004). Validity of heart rate as an indicator of aerobic demand during soccer activities in amateur soccer players. European Journal Applied Physiology, 93(1-2), 167 – 172.

29. Gissis, I., Nikolaidis, D., Papadopoulos, C., & Papanikolaou, Z. (2003). Maximal isometric force and cycling speed in young male soccer players. Communication to the Fifth World Congress of Science and Football, p. 142. Madrid: Editorial Gymnos.

30. Gleeson, N. P., & Mercer, T. H. (1992). Reproducibility of isokinetic leg strength and endurance characteristics of adult men and women. European Journal of Applied Physiology, 65, 221 – 228.

31. Graham-Smith, P., & Lees, A. (2002). Risk assessment of hamstring injury in rugby union place kicking. In W. Spinks, T. Reilly, & A. Murphy (Eds.), Science and football IV (pp. 182 – 189). London: Routledge.

32. Gransberg, L., & Knutsson, E. (1983). Determination of dynamic muscle strength in man with acceleration controlled isokinetic movements. Acta Physiologica Scandinavica, 119, 317 – 320.

33. Gur, H., Akova, B., Punduk, Z., & Kucukoglu, S. (1999). Effects of age on the reciprocal peak torque ratios during knee muscle contractions in elite soccer players. Scandinavian Journal of Medicine and Science in Sports, 9, 81 – 87.

34. Heller, J., Prohazka, L., Bunc, V., Dlouha, R., & Novotny, J. (1991). Functional capacity in top league football players during competitive period. Abstract from 2nd World Congress on Science and Football, Veldhoven, The Netherlands.

35. Henriksson, J., & Reitman, J. S. (1977). Time course of changes in human skeletal muscle succinate dehydronenase and cytochrome oxidase activities and maximal oxygen uptake with physical activity and inactivity. Acta Physiologica Scandinavica, 99, 91 – 97.

36. Hermansen, L., & Saltin, B. (1969). Oxygen uptake during maximal treadmill and bicycle exercise. Journal of Applied Physiology, 26, 31 – 37.

37. Herzog, W. (1988). The relation between the resultant moments at a joint and the moments measured by an isokinetic dynamometer. Journal of Biomechanics, 21, 5 – 12.

38. Helgerud, J., Engen, L. C., Wisloff, U., & Hoff, J. (2001). Aerobic endurance training improves soccer performance. Medicine and Science in Sports and Exercise, 33, 1925 – 1931.

39. Hoff, J., Wisloff, U., Engen, L. C., Kemi, O. J., & Helgerud, J. (2002). Soccer specific aerobic endurance training. British Journal of Sports Medicine, 36, 218 – 221.

40. Howley, E. T., Bassett, J. R., & Welch, H. G. (1995). Criteria for maximal oxygen uptake: Review and commentary. Medicine and Science in Sports and Exercise, 27, 1292 – 1301.

41. Iossifidou, A. N., & Baltzopoulos, V. (1998). Inertial effects on the assessment of performance in isokinetic dynamometry. International Journal of Sports Medicine, 19, 567 – 573.

42. Kannus, P. (1994). Isokinetic evaluation of muscular performance: Implications for muscle testing and rehabilitation. International Journal of Sports Medicine, 15, S11 – S18.

43. Kayatekin, M. (1995). The effects of regular training on knee flexor – extensor muscle torques of soccer players. Turkish Journal of Sports Medicine, 30, 85 – 94.

44. Krustrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjaer, M., & Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: implications for sprint performance. Medicine and Science in Sports and Exercise, 38, 1165 – 1174.

45. Krustrup, P., Mohr, M., Ellingsgaard, H., & Bangsbo, J. (2005). Physical demands during an elite female soccer game: importance of training status. Medicine and Science in Sports and Exercise, 37, 1242 – 1248.

46. Krustrup, P., Hellstein, Y., & Bangsbo, J. (2004). Intense intermittent training elevates transient O_2 uptake in human skeletal muscle at high but not at low exercise intensities. Journal of Physiology, 559, 335 – 345.

47. Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., Pedersen, P. K., & Bangsbo, J. (2003). The Yo-Yo intermittent recovery test: Physiological response, reliability and validity. Medicine and Science in Sports and Exercise, 35, 697 – 705.

48. Krustrup, P., & Bangsbo, J. (2001). Physiological demands of top-class refereeing in relation to physical capacity: Effect of intense intermittent exercise training. Journal of Sports Sciences, 19, 881 – 891.

49. MacDougall, J. D., & Wenger, H. A. (1991). The purpose of physiological testing. In J. D. MacDougall, H. A. Wenger, & H. J. Green (Eds.), Physiological testing of the high-performance athlete (2nd edn., pp. 1 – 5). Champaign, IL: Human Kinetics.

50. Metaxas, T., Koutlianos, N., Sendelides, T., & Mandroukas A. (2009). Preseason physiological profile soccer and basketball players in different divisions. Journal of Strength and Conditioning Research, 23(6), 1704 - 1713.

51. Metaxas, T., Sendelides, T., Koutlianos, N., & Mandroukas K. (2006). Seasonal variation of aerobic performance in soccer players according to positional role. Journal of Sports Medicine and Physical Fitness. 46(4), 520 - 525.

52. Metaxas, T., Koutlianos, N., Sendelides, T., Kouidi, E., & Deligiannis A. (2004). Physiological profile of amateur top level soccer players according to positional role. Journal of Human Movement Studies, 46, 347 - 358.

53. Mohr, M., Krustrup, P., Nybo, L., Nielsen, J. J., & Bangsbo, J. (2004). Muscle temperature and sprint performance during soccer matches – beneficial effects or re-warm-up at half time. Scandinavian Journal of Medicine and Science in Sports, 14(3), 156 – 162.

54. Mohr, M., Krustrup, P., & Bangsbo, J. (2003a). Match performance of high standard soccer players with special reference to development of fatigue. Journal of Sports Sciences, 21, 519 – 528.

55. Mohr, M., Krustrup, P., & Bangsbo, J. (2003b). Physical preparation for the world cup using a sub-maximal Yo-Yo intermittent endurance test to evaluate training status. Communication to the Fifth World Congress of Science and Football, p. 40. Madrid: Editorial Gymnos

56. Nowacki, P. E., Cai, D. Y., Buhl, C., & Krummelbein, U. (1988). Biological performance of German soccer players (professionals and juniors) tested by

special ergometry and treadmill methods. In T. Reilly, A. Lees, K. Davids, & W. J. Murphy (Eds.), Science and football (pp. 145 – 147). London: E & FN Spon.

57. Oberg, B., Ekstrand, J., Mo¨ ller, M., & Gillqvist, J. (1984). Muscle strength and flexibility in different positions of soccer players. International Journal of Sports Medicine, 5, 213 – 216.

58. Oberg, B., Moller, M., Gillqvist, J., & Ekstrand, J. (1986). Isokinetic torque levels for knee extensors and knee flexors in soccer players. International Journal of Sports Medicine, 7, 50–53.

59. Orchard, J., Marsden, J., Lord, S., & Garlick, D. (1997). Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. American Journal of Sports Medicine, 25, 81 – 85.

60. Puga, N., Ramos, L., Agostinho, J., Lomba, I., Costa, O., & de Freitas, F. (1993). Physical profile of a first division Portuguese professional soccer team. In T. Reilly, J. Clarys, & A. Stibbe (Eds.), Science and football II (pp. 40 – 42). London: E & FN Spon.

61. Rahnama, N., Reilly, T., & Lees, A. (2003a). Effects of fatigue (simulated soccer) on muscle performance. Communication to the Fifth World Congress of Science and Football, p. 228. Madrid: Editorial Gymnos.

62. Rahnama, N., Reilly, T., Lees, A., & Graham-Smith, P. (2003b). A comparison of musculoskeletal function in elite and sub-elite English soccer players. In T. Reilly & M. Marfell-Jones (Eds.), Kinanthropometry VIII: Proceedings of the Eighth International Conference of the International Society for the Advancement of Kinanthropometry (pp. 151 – 164). London: Taylor & Francis.

63. Raven, P., Gettman, L., Pollock, M., & Cooper, K. (1976). A physiological evaluation of professional soccer players. British Journal of Sports Medicine, 109, 209 – 216.

64. Reilly, T. (2003). Motion analysis and physiological demands. In T. Reilly & A. M. Williams (Eds.), Science and soccer (2nd ed., pp. 59 – 72). London: Routledge.

65. Reilly, T., & Doran, D. (2003). Fitness assessment. In T. Reilly & A. M. Williams (Eds.), Science and soccer (2nd edn., pp. 21 – 46). London: Routledge.

66. Reilly, T., & Gilbourne, D. (2003). Science and football: a review of applied research in the football codes. Journal of Sports Sciences, 21(9), 693 – 705.

67. Reilly, T. (1997). Energetics of high intensity exercise (soccer) with particular reference to fatigue. Journal of Sports Sciences, 15, 257 – 263.

68. Reilly, T. (1994). Physiological profile of the player. In B. Ekblom (Ed.), Football (soccer) (pp. 78 – 94). London: Blackwell.Reilly, T., Thomas, V. (1977). Effects of a programme of pre-season training on the fitness of soccer players. J Sports Med Phys Fitness. 17(4):401-12.

69. Reilly, T., Secher, N., Snell, P., & Williams C. (1990). Physiology of Sports. London: E & FN Spon.

70. Reilly, T., & Thomas, V. (1979). Estimated energy expenditures of professional association footballers. Ergonomics, 22, 541 – 548.

71. Reilly, T., & Thomas, V. (1976). A motion analysis of work rate in different positional roles in professional soccer match-play. Journal of Human Movement Studies, 2, 87 – 97.

72. Rochcongar, P., Morvan, R., Dassonville, J. J., & Belliot, J. (1988). Isokinetic investigation of knee extensors and knee flexors in young French soccer players. International Journal of Sports Medicine, 9, 448 – 450.

73. Sale, D.G. (1991). Testing strength and power. In J. D. MacDougall, H. A. Wenger, & H. J. Green (Eds.), Physiological testing of the high-performance athlete (2nd edn., pp. 21 – 106). Champaign, IL: Human Kinetics.

74. Sahlin, K. (1992). Metabolic factors in fatigue. Sports Medicine, 13, 99 – 107.

75. Sapega, A. A., Nicholas, J. A., Solokow, D., & Saraniti, A. (1982). The nature of torque ‘‘overshoot’’ in Cybex isokinetic dynamometry. Medicine and Science in Sports and Exercise, 14, 368 – 375.

76. Shephard, R.J. & Åstrand P.O. (1992). Endurance in Sport. Blackwell Scientific Publications.

77. Siri, WE. (1956). The gross composition of the body. Adv Biol Med Phys. 4:239-80.

78. Stolen, T., Chamari, K., Castanga, C., & Wisloff, U. (2005). Physiologyof soccer: an update. Sports Medicine, 35(6), 501 – 536.

79. Stromme, S. B., Ingjer, F., & Meen, H. D. (1977). Assessment of maximal aerobic power in specifically trained athletes. Journal of Applied Physiology, 42, 833 – 837.

80. Sutton, J. R. (1992). Limitations to maximal oxygen uptake. Sports Medicine, 13, 127 – 133.

81. Togari, H., Ohashi, J., & Ohgushi, T. (1988). Isokinetic muscle strength of soccer players. In T. Reilly, A. Lees, K. Davids, & W. J. Murphy (Eds.), Science and football (pp. 181 – 185). London: E & FN Spon.

82. Tomlin, D. L., & Wenger, H. A. (2001). The relationship between aerobic fitness and recovery from high intensity intermittent exercise. Sports Medicine, 31, 1 – 11.

83. Tumilty, D. (1993). Physiological characteristics of elite soccer players. Sports Medicine, 16, 80 – 96.

84. Viru, A., & Viru, M. (2001). Biochemical monitoring of sports training. Champaign, IL: Human Kinetics.

85. Wisloff, U., Helgerud, J., & Hoff, J. (1998). Strength and endurance of elite soccer players. Medicine and Science in Sports and Exercise, 30, 462 – 467.

86. Zakas, A., Mandroukas, K., Vamvakoudis, E., Christoulas, K., & Aggelopoulou, N. (1995). Peak torque of quadriceps and hamstrings muscles in basketball and soccer players of different divisions. Journal of Sports Medicine and Physical Fitness, 35, 199 – 205.

ΑΡΙΣΤΟΤΕΛΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΟΝΙΚΗΣ
ΕΠΙΤΡΟΠΗ ΕΡΕΥΝΩΝ

Thessaloniki 26th of August 2010

To

Faculty of Physical Education and Sport

José Martího 31, 162 52 Praha 6-Veleslavín

The research entitled: "Physiological assessments of soccer players in different divisions" conducted by Athanasios Mandroukas, undergraduate student of the Faculty of Physical Education and Sport, Charles University in Prague, and was carried out during July and August of 2010 in the framework of a diplomatic project in the Laboratory of Ergophysiology-Ergometry of Department of Physical Education and Sports Science, Aristotle University of Thessaloniki. The study has been completed according to the guidelines of the Ethics Issues Code of the Research Committee of Aristotle University of Thessaloniki.

The member of Research Committee

Asterios Deligiannis

Professor of Sports Medicine

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