A PROFILE OF ELITE SOCCER PLAYERS WITH SPECIAL REFERENCE TO THE LOAD IMPOSED ON PLAYERS DURING TRAINING AND MATCH-PLAY

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Abstract

In this thesis a four-way approach was adopted to investigate the demands of contemporary elite soccer. Firstly, the fitness characteristics of elite soccer players were assessed. Secondly, the physiological strain imposed on players was investigated during match-play and training. Thirdly, injury data were analysed to establish the consequences of physiological strain. Finally, a laboratory simulation was used to supplement the data provided during match-play.

Anthropometric and fitness profiles were obtained on elite male soccer players of a Premier League squad. Reference profiles were also obtained on elite young players and inter-county Gaelic football players for comparisons. Analysis of positional differences revealed that soccer players constitute a relatively heterogeneous group. Goalkeepers and central defenders were significantly taller than full-backs, midfield players and forwards (goalkeepers 1.91 ± 0.5 m; central defenders 1.89 ± 0.4; full-backs 1.77 ± 0.4; midfield players 1.78 ± 0.3; forwards 1.80 ± 0.6) [$P<0.001$]. Goalkeepers were significantly heavier than full-backs and midfielders (goalkeepers 87.3 ± 6.3 kg; full-backs 76.2 ± 4.1; midfield players 76.6 ± 5.6) [$P<0.01$]. Central defenders had a significantly higher rating of ectomorphy than forwards (central defenders 3.1 ± 0.9; forwards 2.0 ± 0.6) [$P<0.038$]. Estimated $\dot{V}O_{2max}$ values of midfield players and full-backs were significantly higher than for goalkeepers and central defenders (goalkeepers 57.8 ± 1.3 $ml \cdot kg^{-1} \cdot min^{-1}$; central defenders 59.2 ± 1.7 $ml \cdot kg^{-1} \cdot min^{-1}$; full-backs 61.1 ± 1.4 $ml \cdot kg^{-1} \cdot min^{-1}$; midfield players 61.9 ± 2.3 $ml \cdot kg^{-1} \cdot min^{-1}$) [$P<0.002$]. Forwards were faster than midfield players and central defenders over 5 m (forwards 0.98 ± 0.03 s; midfield players 1.05 ± 0.06 s; central defenders 1.05 ± 0.05 s) [$P<0.02$]. Squat jump height of forwards was significantly greater than that of midfield players and central defenders (forwards 46.0 ± 5.2 m; midfield players 40.0 ± 1.1 m; central defenders 41.5 ± 2.3 m) [$P<0.07$]. Discriminant function analysis identified three variables for distinguishing between successful and less-successful soccer players. The main variables contributing to group separation were body mass, endomorphy and estimated $\dot{V}O_{2max}$. The standardised canonical discriminant function coefficients were 0.792 for body mass, 0.587 for endomorphy and 0.568 for estimated $\dot{V}O_{2max}$. Wilks' Lambda value was 0.735, [$P<0.002$], and Rao's V was 11.94, [$P<0.02$). The canonical correlation was $r=0.515$. Superior values in anaerobic power output suggest that the power demands are greater in soccer than Gaelic Football.

The mean heart rate during competitive match-play was 171 ± 9 $beats \cdot min^{-1}$, corresponding to 87.2% of HR_{max}. Midfield players had higher relative heart rates compared to central defenders in the second half of competitive games (midfield players 88.2 ± 2.5% HR_{max}; central defenders 83.6 ± 1.4% HR_{max}) [$P<0.046$]. A reduction in heart rate was noted in the second half compared to the first half (first half 87.7 ± 3.3% HR_{max}; second half 86.0 ± 3.4% HR_{max}) [$P<0.023$]. The distance covered during match-play was 11065 ± 920 m, a greater distance being covered in the first half (5708 ± 530 m) compared to the second half (5357 ± 456 m) [$P<0.02$]. Activity during match-play consisted

of 40% jogging, 36% walking, 9% cruising, 2% sprinting and 13% utility movements. High intensity running accounted for 1171 $\pm$ 424 m, consisting of 914 $\pm$ 321 m cruising, and 257 $\pm$ 111 m sprinting. Midfield players and full-backs covered a greater distance during competition than central defenders and forwards (midfield players 11830 $\pm$ 683 m; full-backs 11540 $\pm$ 343 m; central defenders 10266 $\pm$ 714 m; forwards 10600 $\pm$ 900 m) ($P<0.018$).

In adult players, the incidence of injury or Injury Frequency Rate (IFR) was higher during matches than in training (matches 43.0/1000 hours; training 2.0/1000 hours) [$P<0.01$]. Competitive games, small-sided games and practice games accounted for 75% of all injuries sustained. Activities linked to a competitive game serve as the greatest risk to soccer players for sustaining injuries. The IFR during competitive games was lower in elite young players compared to that reported in elite adult professional soccer (young players 37.4/1000 hours; adult players 43.0/1000 hours). In adult players a greater number of injuries occurred in the second half compared to the first (58.6% v 35.3%; $P< 0.01$). The proportion of injuries was greater than expected in the final month of the season ($P<0.05$). These observations suggest that incidence of injury is associated with work-rate and accumulation of fatigue during competition.

The focus of the thesis was shifted to examine how the physical performance capabilities of players can be improved via nutritional support. This emphasis led to the use of a laboratory-based intermittent exercise protocol. The overall severity of the physiological strain for the soccer-specific intermittent protocol was similar to that of match-play. Dietary creatine supplementation at a rate of 20 g.day^{-1} for 5 days had no effect on sprint performance, leg power or endurance performance during a laboratory-based protocol that reflects the mean heart rate responses and work-rate profiles observed during real match-play.

In summary, contemporary elite match-play seems to be more demanding than suggested in much of the early literature. Contemporary players cover greater distances in a game than their earlier counterparts, indicating the increasing physiological demands in English soccer over the last three decades. Consequently, it would appear that elite contemporary players have distinct features. These include few low values of estimated $\dot{V}O_{2max}$, combined with greater speed and agility over short distances. Contemporary players are further characterised by a muscular make-up and low adiposity. Physical performance during match-play is reduced towards the end of a game, implying the occurrence of fatigue. In addition, the reduction in exercise intensity and sprint performance in the final phase of games indicates that most players utilize their physical potential during match-play. To raise the tempo of the game even higher, systematic training programmes may focus on maintaining high exercise intensities for the entire match. Moreover, selective recruitment of individuals with the appropriate physical characteristics will extend this process. Integrating sports science knowledge into a holistic process is generally advisable to move the tempo of the game onto a further level.

The experiments described herein have been reported elsewhere and the following is a list of relevant publications and conference presentations:-

Strudwick, T., and Reilly, T. (1999). The physiological load imposed on elite young professional soccer players during intense training and competitive match-play. *Journal of Sports Sciences*, **17**: 925.

Strudwick, T., and Reilly, T. (2001). Work-rate profiles of elite Premier League football players. *Insight: The FA Coaches Association Journal*, **4**(2), 28 – 29.

Strudwick, A., Reilly, T., and Doran, D. (2002). Anthropometric and fitness profiles of elite players in two football codes. *Journal of Sports Medicine and Physical Fitness*, **42**: 239 – 242.

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CHAPTER I

INTRODUCTION

1.1 INTRODUCTION TO RESEARCH STUDIES

Professional sports participants can now benefit from advances in knowledge without the necessity of visiting laboratory facilities. With the development of sports science support systems, particularly for games players, there has been a shift towards indirect methods of assessment in field conditions. Moreover, practitioners working with squads often adopt game-specific field tests as opposed to traditional laboratory based assessments, allowing greater numbers of players to be tested at one time (Reilly and Gilbourne, 2003). This change is reflected in the methods adopted in this thesis.

Insight into the demands of soccer can be attained by an integration of field-based and laboratory-based investigations. Field-based research in an elite context provides critical information about the demands of the sport and the relative importance of the different components of fitness to perform intermittent exercise. Where methodological problems may restrict the information that can be collected during competitive match-play, an emphasis can then be placed on laboratory representations for specific investigations.

Soccer by its very nature imposes unique physiological stresses on participants that need to be appreciated, quantified and confronted (Reilly, 1994a). The degree of stress and the physiological demands of soccer must be evaluated and the capability of the participants to meet these demands must be quantified. The physiological demands of soccer can be examined by making relevant observations during match-play, obtaining physiological responses during real and simulated games and determining the physiological capacities of elite players on performance tests.

The quantification of physiological demands during elite soccer match-play provides a challenge to the researcher due to the lack of experimental models to study games validly in the laboratory. Furthermore, practical research has been restricted at an elite level due to limited access to professional clubs. Nevertheless, there has been considerable research attention directed to the football codes, which has added to the body of knowledge about the scientific aspects of soccer.

Evidence for increased exercise intensity during contemporary soccer compared to previous decades has been shown by Williams et al. (1999). These authors presented match statistics, which highlighted the major changes in the game that occurred since the inception of the Premier League in 1992. Findings indicated that the game changed markedly during the intervening period (1991–1999). Contemporary matches include more passes, runs with the ball, dribbles and crosses than pre-1992 which suggest a significant increase in the 'tempo' of games. In order to cope with these increased demands, players must have the necessary physical resources for the high work-rates and critical actions during match-play.

Many activities in soccer require forceful and explosive bursts of energy including tackling, jumping, kicking, turning and changing pace. The power output during such activities is critical in determining the overall performance. In order to cope with the physical requirements for elite soccer match-play, it is important that the players have appropriate levels of speed, agility, muscular strength and anaerobic power. The use of fitness assessment in the identification of these physical characteristics may yield important information concerning the anaerobic demands for contemporary elite play.

These anaerobic activities are performed against a backdrop of aerobic energy supply. At an elite level of play, a professional soccer player should ideally be able to maintain a high exercise intensity throughout the whole game. Clearly, an enhanced oxygen delivery and utilisation system allows players to sustain higher work-rates throughout a match and also facilitate greater recovery between bouts of high-intensity activity. Insight into the aerobic characteristics of elite players will further the understanding of how they have adapted to the physiological loads imposed during contemporary match-play.

The intensive training and frequent competition in elite soccer are invariably accompanied by some manifestation of the stresses associated with the physiological demands of the game. Analysis of these stresses and the injuries that sometimes result is helpful in identifying risk factors associated with soccer-related activities. Moreover, monitoring injuries during training and competition may serve as an appropriate tool for the evaluation of the physiological loads associated with participation at an elite level. Such data can also offer valuable information to assess, monitor and adjust training and match practices in order to ensure optimal performance and avoid injuries.

Few researchers have adopted a field-based investigation of elite contemporary soccer players in an attempt to measure the physiological response to playing soccer. The present thesis is an attempt to provide insight into the physiological responses to soccer-specific exercise. In addition, few researchers have endeavoured to replicate the actual exercise patterns demonstrated during elite English Premier League match-play. The laboratory context gives the researcher the opportunity to collect accurate physiological information in a controlled setting. The present thesis represents an attempt to provide a greater insight into the physiological responses to an intermittent exercise protocol broadly compatible with soccer match-play. Furthermore, anthropometric and fitness assessments are used to help identify the key physical characteristics of elite players. Such information contributes to a holistic picture of the demands placed on individual contemporary participants.

CHAPTER 2

CHAPTER II

AIMS AND OBJECTIVES

2.1 AIMS AND OBJECTIVES OF THE RESEARCH STUDIES

In order to shed light upon the unique characteristics of any sport, there must be a consideration of the athlete and the sport per se. Information regarding the physiological characteristics of the participants provides insights into the nature of the sport and the adaptations associated with performance. While data on physiological characteristics are essentially descriptive, they nevertheless illustrate the uniqueness of soccer players as select groups within a population and the factors that determine success at an elite level of performance.

The advancement of sports science support systems has led to the adoption of field-based research to complement the traditional laboratory assessments. Field-based research has high ecological validity. However, such data are sometimes difficult to interpret physiologically, and so a laboratory-based protocol may be employed to investigate in more depth the demands of intermittent exercise and players' responses to it.

As the knowledge base of sports science has grown and developed, there has been an increasing application of general scientific principles and findings to the football codes. While the stresses associated with elite competition and training have been studied, much of the earlier literature may now be dated. Indeed, the contemporary game at a professional level may be more demanding than suggested in the earlier literature (e.g. Reilly and Thomas, 1976) and therefore calls for more systematic research in a field setting. This search for information concerning the physiological characteristics and responses to contemporary competition has stimulated the investigations conducted as part of this thesis.

In order to investigate the sport of soccer, both the soccer player and the sport are examined separately through the fulfilment of the following aims.

Information gained about the player and the game in a field setting is then integrated to provide a basis for laboratory-based research. The realisation of these aims will provide insight into the demands imposed on elite soccer players. Appreciation of the demands imposed on elite players is accomplished by means of the listed objectives.

THE ELITE SOCCER PLAYER

Aims:

1. To determine the anthropometric characteristics of elite soccer players.

2. To compile a comprehensive fitness profile of elite soccer players.

3. To determine the relationship between anthropometric and fitness characteristics of elite soccer players and success at both underage and adult level match-play.

4. To identify the effect of soccer training and competitive match-play on the injury status of elite soccer players.

ELITE SOCCER MATCH-PLAY AND TRAINING

Aims:

5. To establish work-rate profiles of elite soccer match-play.

6. To establish the heart rate responses of elite soccer players during competitive match-play and training.

LABORATORY BASED INVESTIGATION

Aims:

7. To modify a laboratory-based generic intermittent exercise protocol suitable for contemporary experimental investigations.

8. To determine the physiological responses to a laboratory-based intermittent exercise protocol.

9. To examine the effect of creatine supplementation on selected physiological and performance responses to an intermittent exercise protocol.

The aims will be achieved by means of the following objectives.

Objectives:

1. Conduct field-based measurement of anthropometric characteristics leading to the profiling of somatotype, body composition and body form.

2. Complete field-based fitness assessment of elite soccer players, incorporating aerobic and anaerobic fitness characteristics.

3. Identify potential discriminators of performance in elite level competition on the basis of successful v non-successful Football Academy players and a comparison between two different football codes.

4. Undertake a comprehensive prospective epidemiological study of the injuries sustained at elite adult level and Academy level over the duration of two competitive seasons.

5. Establish work-rate profiles of elite soccer players during competitive match-play from which a laboratory-based exercise protocol could be developed.

6. Monitor the heart via short-range telemetry, providing competition and training heart rate profiles.

7. Establish heart rate responses during competitive match-play and relate these to a generic intermittent exercise protocol.

8. Monitor metabolic and physiological responses to intermittent exercise on a non-motorised protocol.

9. Utilise the intermittent exercise protocol in an experimental investigation of creatine supplementation.

2.2 OVERVIEW

Throughout the past decade there has been a shift towards systematic methods of preparing elite players for match-play. Contemporary coaches have been exposed to scientific approaches to preparing teams for competition. In general, the clubs that have adopted a strategic approach have been rewarded with success by gaining an advantage over competitors. It has taken some time for the accumulation of scientific based knowledge to be translated into a form usable by practitioners. Efforts are being made to compile scientific information and make it accessible to the soccer world. This thesis is a step in that direction.

The search to compile scientific information concerning the physiological responses to elite English Premier League soccer has stimulated the investigations conducted as part of this thesis. These entail acquiring descriptive data on elite soccer players (both 1st Team squad and Football Academy Youths in a Premier League club) encompassing anthropometric and physiological characteristics. A comparison of fitness profiles between players in the soccer and an alternative football code would provide further insights into the exclusive demands of elite soccer participation. To complete the picture of the anthropometric and physiological characteristics of elite soccer players, deriving performance profiles of young players would help to determine the relationship between these profiles and eventual success in soccer.

Given that the physiological loads associated with training and competition lead to increased stresses on the musculoskeletal system, an analysis of the injuries sustained during training and matches is relevant. Anthropometric and fitness profiles may then be further analysed to consider the relationship between individual characteristics and injury rates.

Field-based observations allow for limited data collection due to the necessity for employment of unobtrusive and socially accepted methods. However, the traditional laboratory-based models of intermittent exercise fall short of the patterns of exercise induced by competitive match-play. Nevertheless, generic models of intermittent exercise may be appropriate means of representing the global factors of match-related activities. Laboratory representations of match-related activities may then supplement physiological information gained in a field context. In the present thesis, a generic model of intermittent exercise was designed to reflect the demands of contemporary soccer match-play. The overall appropriateness of the model could then be determined by comparing the work-rate profiles and heart rate responses during the exercise protocol with real match-play.

CHAPTER 3

CHAPTER III

REVIEW OF THE LITERATURE

The aim of this review of literature is to provide the reader with information on the physiological demands of soccer with special reference to the physical characteristics of elite soccer players. The research available on players' work-rate profiles is reviewed as well as the physiological responses to playing the game. The final section of the review of literature relates to soccer-specific performance tests that may also provide an indication of the demands of the game.

3.1 PLAYERS' CHARACTERISTICS

3.1.1 Anthropometric characteristics

At a behavioural level, the specific demands of the sport determine the relative importance of the different aspects of physical performance. It is therefore prudent to concentrate on those individual characteristics of elite soccer players, and to interpret the unique demands of participation through these profiles.

According to Reilly and Thomas (1980), 23% of the total variance among English First Division players could be accounted for by a component related to body size. Tall players tend to have an advantage in certain playing positions and therefore are oriented toward these roles, more notably in goalkeepers and central defenders (Bangsbo, 1994a). More recently, Croatian goalkeepers were found to be the tallest (182.9 ± 4.3 cm) and heaviest (80.1 ± 5.1 kg) players within the team (Matkovic et al., 2003). It is likely that particular positional roles have their own physical demands and that an appropriate body size allows players to meet the demands imposed on them by their position. Evidence for this has been shown in the consistent observation that elite soccer players constitute a relatively heterogeneous group (Raven et al., 1976; Davis et al., 1992; Puga et al., 1993; Bangsbo, 1994b).

Differences in body size are found not only between positions, but also across different styles of play and origin of team. These differences in stature and body mass may then be representative of ethnic and cultural influences. In a study of European players, Bloomfield et al. (2003), reported variations in stature and body mass between players in different leagues. These authors reported that teams from different leagues prefer different types of players in certain positions. Players from the German Bundesliga were found to have the greatest height, body mass and body mass index (BMI), in comparison to top English, Italian and Spanish league players. Clearly, coaches modify team formation and style of play according to physical attributes and cultural influences.

There is a suggestion of an 'expanding universe' of athletic bodies (Norton and Olds, 2001). The line of argument implies that characteristic body sizes in different sports are moving away from the general population. The view is that each sport, event and even position within a sport demands its own set of physical attributes. While not every physical characteristic can be expected to play a key role in this selection process, two clearly important variables are height and body mass.

Norton and Olds (2001) reviewed extensively data on height and mass for athletes competing at the highest level. They presented data demonstrating that elite athletes have been evolving over the past century. Moreover, the ideal athletic type proposed over a century ago, is being replaced by radically different, highly specialised and increasingly divergent body types. According to these authors, soccer players were on average similar in height to the general population, with a similar degree of variability as expressed by standard deviation (SD) values. In contrast, Australian Football League players were approximately 0.07 m taller than the general population but had similar SD values. In light of the fact that size offers an advantage in certain playing positions (goalkeeper; central defence; central forward), one may expect to see an increase in the size of players, and the suggestion of an increase in players' height has been made (Matkovic et al., 2003). At an elite level there does appear to be a trend whereby players are becoming taller and heavier. For example, the average height and body mass of players in the top division in England was reported as 1.76 m and 73 kg compared with 1.81 m and 75 kg during the 1976-1977 and 2001-2002 playing seasons, respectively, (Reilly and Thomas, 1977; Bloomfield et al., 2003).

The most comprehensive anthropometric profile of elite soccer players was completed within the SOKIP project at Copa America in Uruguay (Rienzi et al., 1998). Mean estimated adiposity values of 11% and muscle mass values of 62% were reported (Rienzi et al., 1998). The average data highlighted the highly muscular make-up of players with their large muscle mass. The overall somatotype for elite South American international players has been reported as $2.2 \pm 0.7 - 5.4 \pm 1.0 - 2.2 \pm 0.6$ (Rienzi et al., 2000). This somatotype for elite players represents a trend towards mesomorphy or muscularity. Such a muscular profile would be of benefit to contemporary players in game contexts with respect to withstanding external forces, turning and accelerating away from opponents.

Anthropometric profiles are subject to inter-individual and intra-individual fluctuations depending on position, playing standard, and the time of season (Thomas and Reilly, 1979; Brewer and Davis 1991; Davis et al., 1992). Davis et al. (1992) reported the highest percentage adiposity in goalkeepers ($13.3 \pm 2.1\%$), with lower levels in outfield players ($10.5 \pm 1.8\%$) for English first and second division players. Thomas and Reilly (1979) reported lower percent adiposity in first team players when compared to second team players. Similarly, Brewer and Davis (1991) reported distinct differences in percent adiposity between different level of soccer players with values of 11% for professional and 15% for semi-professional players. These data would suggest that the relationship between body composition and performance is of considerable importance in soccer.

Evidence from the athletic population has demonstrated an inverse relationship between adiposity and performances of physical activities requiring translocation of the body mass either vertically, as in jumping, or horizontally as in running (Boileau and Lohman, 1977; Pate et al., 1989). Excess adiposity is detrimental in activities such as soccer because it adds mass to the body without additional capacity to produce force. McLeod et al. (1983) examined performance and body fat levels of high school athletes. These authors reported that performance in endurance tests was significantly poorer in athletes whose body fat level exceeded 10%. Similarly, an investigation into the relationship between anthropometric characteristics and work-rate profiles of South American international players found a positive relationship between total distance covered and muscle mass. Moreover, players with higher muscularity were able to maintain a higher overall work rate throughout the game, (Rienzi et al., 2000). It is suggested that high degrees of muscle mass along with low levels of adiposity reduce the energy requirement of movement, thereby decreasing the physiological load and facilitating recovery from high-intensity exercise.

3.1.2 Fitness characteristics

There is evidence that maximal oxygen uptake ($\dot{V}O_{2max}$) varies according to positional role. The $\dot{V}O_{2max}$ of 19 professional players in the Portuguese First Division was below 60 $ml \cdot kg^{-1} \cdot min^{-1}$ for goalkeepers and central defenders and above 60 $ml \cdot kg^{-1} \cdot min^{-1}$ for midfield players and forwards (Puga et al., 1993). Midfield players frequently have the highest $\dot{V}O_{2max}$ values in the team and these values may reflect the higher endurance demands on the more active midfield position during match-play. When English League players were subdivided into positions according to their 4-3-3 configuration, the midfield players had significantly higher $\dot{V}O_{2max}$ values than those in the other positions. The central defenders had significantly lower relative values than the other outfield players while the full-backs and strikers had intermediate values (Reilly, 1990).

From a tactical viewpoint, midfield players serve as a link between defence and attack. Their duties include not only supporting the forwards in pursuit of goal-scoring opportunities but also assisting defenders in preventing goal-scoring opportunities. Such requirements include a greater distance to be covered during match-play, as there is an emphasis on sustained running. Midfield players also have the most tactically flexible roles within the team, which allows them to come closest to taxing their full performance capacities. Common tactical characteristics of midfield play include movement, interchange and flexibility. Clearly, tactics should be devised to suit the strengths of individual players (Gray, 1969). If players are to utilise their physiological capacities as reflected in $\dot{V}O_{2max}$, tactical restrictions placed on individuals in playing positions need to be kept to a minimum and a playing strategy that emphasises mobility around the playing field adopted. Such a strategy was employed by South Korea in the last World Cup 2002 whose team attempted to pressure opponents all over the playing field (Wilkinson, 2002).

Previous reports of higher $\dot{V}O_{2max}$ values for midfield players were not supported by Wisloff et al. (1998). According to these authors, the observed similarities between positions for $\dot{V}O_{2max}$ may be a result of both higher movement demands of forward and defensive positions in contemporary soccer and the failure of previous studies to apply appropriate scaling for body mass differences. Given that defensive players may be consistently heavier than midfield and forward players (Davis et al., 1992), they will be underestimated using the traditional expression $ml{\cdot}kg^{-1}{\cdot}min^{-1}$. However, cultural practices and training regimens adopted by the Norwegian players in the study by Wisloff et al. (1998) are different to many of the other teams reported in the literature. Moreover, elite Norwegian players have the advantage of a longer preparation period (4 months) prior to the onset of their regular season. It is during this preparation period that an emphasis is placed on aerobic fitness work (Mercer et al., 1995).

A significant correlation between $\dot{V}O_{2max}$ and distance covered during a match has been reported (Reilly, 1994). Players with a higher $\dot{V}O_{2max}$ also carry out the highest number of sprints and take part more often in decisive situations during a match than those with lower values (Smaros, 1980). This is to be expected as players with a high $\dot{V}O_{2max}$ and who are endurance trained have a faster recovery from intense exercise and have greater stores of muscle glycogen (Astrand and Rodahl, 1986; Ekblom, 1986; Bangsbo and Mizuno, 1988). Individuals with a high $\dot{V}O_{2max}$ would be expected to spare glycogen during moderate intensity exercise due to an increased utilisation of fat, thereby making them less susceptible to the reduction in work-rate associated with fatigue (Reilly and Thomas, 1976). The players with the higher $\dot{V}O_{2max}$ are also capable of running more and at a higher intensity, before a reduction in glycogen stores and an accumulation of lactate forces them to reduce their intensity (primarily because of a greater capability to spare glycogen stores).

A high $\dot{V}O_{2max}$ will have consequences for players during competitive match-play, leading to an increased work-rate. Moreover, it may lead to a reduction in static rest pauses and a concomitant increase in the distance covered. This suggestion is supported by the consistent findings of midfield players and full backs covering the greatest distances during competitive matches and intermittent field tests and central defenders the lowest distances (Reilly and Thomas, 1976; Withers et al., 1982; Bangsbo and Lindquist, 1992).

In soccer, the ability to accelerate quickly from either a stationary or a moving start and achieve the fastest possible running speed, particularly over short distances, is an important fitness quality. Indeed, there is a consensus amongst the soccer fraternity that the modern game is becoming more dynamic (Buttifant et al., 2002). On average, a sprint occurs every 90 s of play (Reilly and Thomas, 1976) and is no longer than 2-4 s (Bangsbo et al., 1991). More recently it has been reported that 96% of all sprint bouts are shorter than 30 m and 49% are less than 10 m (Valquer et al., 1998). Several studies have determined sprint times for elite soccer players (Cometti et al., 2001; Wisloff et al., 2002). In a study of elite German 1st Division soccer players, sprint times for 0-5 m, 0-10 m and 0-30 m were 1.03 ± 0.08, 1.79 ± 0.09 and 4.19 ± 0.14 s respectively (Kollath and Quade 1993). Moreover, elite players were significantly faster than amateur players over 10 m, 20 m and 30 m, suggesting a greater requirement for speed over short distances at an elite level of soccer match-play. Few studies in the literature have compared sprint times across different positions. Kollath and Quade (1993) found no significant differences between offensive and defensive German 1st division soccer players. However, due to the narrow categorisation between offensive and defensive players, much of the qualitative data that can be used for comparative purposes was omitted. More recently, Wisloff et al. (2002) reported inter-positional variations in sprint times of elite Norwegian soccer players. In particular forward players were the fastest of all outfield players suggesting that speed is an important determinant of match winning actions for forward players.

In several studies with elite soccer players, muscle biopsies have been taken from m. vastus lateralis or m. gastrocnemius. The mean percentage of type I fibres ranged from 40 to 61% for m. vastus lateralis and from 49% to 60% for m. gastrocnemius (Bangsbo and Mizuno, 1988; Bangsbo, 1998). According to Bangsbo and Mizuno (1988), the profile of mitochondrial enzyme activities in the gastrocnemius of the players was closer to that of endurance athletes than to strength-trained individuals. As with many observations on elite soccer players, a large variability was noted between players. Parente et al. (1992) reported that players in different positions exhibited different muscle characteristics. Midfield players had a higher percentage of type I fibres (67%), than defenders (44%) and forwards (38%). In light of such findings, it is plausible that genetic variations in muscle morphology may be reflected in performance on field-based physiological tests.

3.1.3 Talent identification

There is evidence to suggest that an individual's anthropometric characteristics are important determinants of performance (Borms, 1996) Anthropometric assessment procedures may help in identifying young talent (Carter, 1985). Malina et al. (2000) suggested that successful young athletes have similar somatotypes to older successful athletes. In addition, Panfil et al. (1997) reported that elite youth soccer players have a higher morphological age (more physically mature) than their less elite counterparts and that coaches favour players advanced in morphological growth during the selection process. The advantage of advanced biological maturity for selection into certain sports is highlighted by the observation that in some sports, individuals born at the start of the selection year have a distinct advantage of being selected over those born later in the year (Baxter-Jones et al., 1995; Brewer et al., 1995).

Physiological measures have also been employed in an attempt to identify key predictors of talent (Jankovic et al., 1997; Reilly et al., 2000; Williams and Reilly, 2000). Jankovic et al. (1997) compared successful and less successful 15 to 17-year olds using measures of anaerobic power, grip and trunk strength, heart volume and $\dot{V}O_{2max}$. The successful players were taller and heavier, had higher $\dot{V}O_{2max}$ and anaerobic power values, and greater heart volume than their less successful counterparts. Jankovic et al. (1997) concluded that these measurements could be useful in predicting later success in soccer. More recently, Franks et al. (1999) analysed data for 64 players who attended the English Football Association's National School (14-16 years). Players were categorised according to playing 'position' and whether they had signed a full-time 'professional' contract on graduation. No differences in anthropometric characteristics and aerobic measurements were observed between those who were deemed to be more or less successful. However, the batteries of measures employed at the school were neither extensive nor exhaustive. Furthermore, the players at the School had already been pre-selected on the basis of certain performance characteristics. As a whole the group was relatively homogenous compared to the variability that is found in elite adult teams (Reilly et al., 2000). Such homogeneity may reflect the talent detection process of the National School, where players were selected on the basis of body size, growth indices and fitness profiles.

3.2 THE PHYSIOLOGICAL DEMANDS OF MATCH-PLAY

3.2.1 Motion-analysis

In order to gain a correct impression of the physiological loads imposed on soccer players during competitive soccer, observations have to be made during real match-play. Motion analysis entails determining work-rate profiles of players within a team and classifying activities in terms of intensity, duration and frequency (Reilly, 1994b). In this way an overall picture of the physiological demands of soccer can be gathered.

The application of motion analysis to soccer has enabled the objective recording and interpretation of match events, describing the characteristic patterns of activity in soccer. The total distance covered during match-play has been employed as an index of work-rate. This is a global measure of work-rate that can be broken down into a number of discrete actions (Reilly, 1994). The application of motion analysis to soccer will now be discussed.

3.2.2 Distance covered

According to Reilly and Thomas (1976) the total distance covered provides information about the physiological load associated with soccer match-play. Several authors have determined the individual distance covered during a game, which can then be used as an indicator of the total work performed. Several methods have been used to quantify distance covered during a soccer game, including the use of hand notation systems (Knowles and Brooke, 1974), coded commentary (Reilly and Thomas, 1976), video recordings (Bangsbo et al., 1991) and computerised techniques (Oshashi et al., 1988). The differing techniques have meant that varying distances covered by players have been reported in the literature. Nevertheless, there is a general consensus that elite players cover a distance of 9-12 km during match-play (Table 3.2.1).

The distance covered by players in different positions has been found to vary significantly (Reilly and Thomas, 1976; Ekblom, 1986; Bangsbo et al., 1991; Rienzi et al, 2000) with midfield players covering a greater distance during a match than other players (Table 3.2.2). The greater distance covered by midfield players is suggested to be a product of both higher levels of fitness associated with such players and the role which they play in the team, linking between defence and attack, a role which evidently requires more sustained running (Bangsbo, 1994a).

Table 3.2.1. Summary of reported distances covered by players during a game.

Source	Players	Distance Covered (km)
Saltin (1973)	Swedish Amateur	11.5
Whitehead (1975)	English 1st Division	11.7
Reilly and Thomas (1976)	English 1st Division	8.7
Withers et al. (1982)	Australian 1st Division	11.5
Ekblom (1986)	Swedish 1st Division	9.8
Gerisch et al. (1988)	German Amateurs	9.0
Ohashi et al. (1988)	Japanese International	9.8
Van Gool et al. (1988)	Belgian University	10.3
Bangsbo et al. (1991)	Danish 1st Division	10.8
Rienzi et al. (2000)	S. American International	8.6
	English Premier League	10.1
Mohr et al. (2003)	Danish 1st Division	10.3
	Italian 1st Division	10.9

Table 3.2.2. Mean distances covered during a game according to playing position (From Mohr et al., 2003)

Source	Players	Position	Distance Covered (km)
Mohr et al. (2003)	Italian/Danish 1st Division	Central Defenders	9.74 ± 0.22
		Full-backs	10.98 ± 0.23
		Midfield	11.0 ± 0.21
		Forwards	10.48 ± 0.30

Ideally players should be able to maintain the same level of effort for both halves of a game. However, studies of university players (Van Gool et al., 1988), Danish League players (Bangsbo et al., 1991), and South American international players (Rienzi et al., 2000) confirm the earlier findings of Saltin (1973), with observations of a 3-9% greater distance being covered in the first as opposed to the second half of a game. Fatigue in the second half of a game has been noted during the last 15 minutes, when less high-intensity work is performed (Mohr et al., 2003). This observation is supported by the finding that substitutes who came on in the second half sprinted and ran at a higher intensity (63 and 25% more, respectively) than players who played the entire game. Accordingly, the ability to perform repeated sprints is reduced after compared with before a game (Rebelo et al., 1998; Krustrup et al., 2003; Mohr et el., 2004). The reduction in exercise intensity and sprint performance in the final phase of games is independent of playing position, level of competition and gender, indicating that most players utilize their physical potential during a game (Mohr et al., 2005).

A reduction in distance covered in the second halves of matches has been ascribed to a reduction in energy stores within the active muscles (Saltin, 1973). More recently, muscle tissue obtained before and after match-play was analysed for muscle fibre type specific glycogen depletion, using the PAS-staining technique (Krustrup et al., 2003). It was shown that following the game about half of the type I and type IIA fibres were almost completely depleted of muscle glycogen. Thus, fatigue at the end of soccer games may be caused by glycogen depletion of individual muscle fibres. Hypoglycaemia has also been suggested to cause fatigue during long-term exercise (Fitts, 1994), but the blood glucose concentration does not reach critical values during a soccer game (Krustrup et al., 2003). Other factors that may reduce the distance covered, particularly in the second half when fatigue is more evident, include dehydration and the concomitant hyperthermia (Mohr et al., 2005). In an attempt to prevent fatigue towards the latter stages of competition, coaches and sports scientists may maximise the physical capacity of players. Recently, Krustrup et al. (2005) observed that $\dot{V}O_{2max}$, treadmill test performance, running speed at 2mM lactate, and the Yo-Yo test result all were correlated with the amount of high intensity running performed during match-play. Thus it appears that the physical fitness characteristics of a player provides a good indication of the distance covered during a game, and may be one of the main factors differentiating between levels of performance and the amount of fatigue experienced (Krustrup et al., 2005)

3.2.3 Work-rate profile

The pattern of exercise in soccer is characterised by intermittent bursts of intense muscular activity interspersed with longer periods of rest or lower intensity activity (Williams, 1990). In soccer match-play, these patterns of activity are characterised not only by an intermittent high-intensity workload, but also by the contribution of a wide variety of motor skills. These motor skills are vital components of match-play and often their successful execution determines the result of the game.

Players perform approximately 1,000 discrete activities during a game, each lasting 5-6 s on average (Reilly and Thomas, 1976). In the study of English 1st Division players, Reilly and Thomas (1976) utilized video recordings in conjunction with pitch markings to assess work-rates. Observations were made from a seat in the stand overlooking the half-way line with a coded commentary of events being registered on a tape recorder. Distance was estimated in 1 m units by utilizing cues on the pitch and on its boundaries. The percentages of activity for the total distance covered during match-play consisted of 37% jogging, 25% walking, 20% cruising, 11% sprinting and 7% utility movements. High-intensity activities were the least frequently performed actions with sprinting and cruising accounting for 62 $\pm$ 15 and 114 $\pm$ 16 discrete bouts respectively. Although these data were derived in the 1970's, Reilly (1994b) reported that observations made on World Cup players performing in the English League in 1990 indicate that these profiles were still representative of elite club soccer at that time. Whether these profiles continue to be representative of players in the English Premier League requires further investigation.

Various authors have broken down the distances covered during games into specific modes of movement utilizing different methodologies and techniques. Mayhew and Wenger (1985) analysed video recordings of 3 midfield players from the North American Soccer League over a 4 game period. Two players were followed per game for alternate 7-min periods. The data collected were analysed for the time spent in each activity and the frequency of each activity. Walking and jogging accounted for a combined 1706 s. This figure represented 84.8% of the total time. In contrast, 11.3% of the time was spent in high-intensity activity (striding and sprinting). This represents a ratio of approximately 1:7 for high: low intensity activity during a game. Based on these observations, it was suggested that 88% of match-play stresses primarily the aerobic energy system with the remaining 12% being anaerobic in nature.

The application of time and motion analysis to soccer has facilitated the objective recording and interpretation of match events, describing the characteristic pattern of activity in soccer. Comparisons and inferences made from these studies must acknowledge the different methods employed to define the players' modes of movement. What is clear is the finding that the greatest proportion of a player's movement is at low speeds. In a study of

Danish professional players, Bangsbo et al. (1991) reported that standing, walking and moving at a low intensity (jogging, low speed running, backwards running) accounted for 17.1%, 40.4% and 35.1% of the total playing time. This resulted in an average speed over an entire game of approximately 7.2 $km.h^{-1}$. In contrast, high-intensity running accounted for 8.1% of the total time, consisting of 5.3% moderate speed running, 2.1% high speed running, and 0.7% sprinting. These authors found no intra-individual differences between games in the high-intensity distance, concluding that the observation of one match could provide an accurate assessment of the high-intensity activity of an individual player. It may well be that in contemporary match-play an increase in high-intensity distance covered contributes to a greater overall distance covered. Recently the ratio of work for elite South American International players in terms of high, low and rest was found to be 1:16:3 (Renzi et al., 2000).

Characteristic movement patterns have emerged in relation to playing position. Midfielders are observed to cover a greater percentage of their total distance jogging, whilst forwards cover a greater percentage of their distance sprinting (Reilly and Thomas, 1976; Rienzi et al., 2000) (Table 3.2.3). Overall, centre-backs cover less total distance and perform less high intensity running than players in other positions (Mohr et al., 2003). The forward player's work-rate profile is characterized by sudden bursts of high-intensity activity, usually into space to receive a pass form a supporting player. These intensive bouts of activity are usually interspersed with periods of recovery at low intensity, when they have no direct involvement with the play. This view is in keeping with the finding that forward players perform more sprints than defenders and midfield players during a game (Mohr et al., 2003).

Table 3.2.3. Total distance covered (m) in each category by defenders, midfield and forward players (from Rienzi et al, 2000).

Activity pattern	Defenders	Midfielders	Forwards
Walk	2694 ± 324	2454 ± 599	3007 ± 742
Walk backwards	562 ± 161	569 ± 206	526 ± 148
Jog	3869 ± 834	4892 ± 1029	2605 ± 1383
Jog backwards	276 ± 155	300 ± 439	68 ± 25
Jog sideways	362 ± 194	319 ± 133	73 ± 25
Cruise	701 ± 276	1110 ± 299	900 ± 383
Sprint	231 ± 141	316 ± 150	557 ± 288

Differences in patterns of movement modes have been observed between teams of different quality. Bangsbo (1992) reported no difference in the total distance covered by Danish 1st and 2nd division players. However, 1st division players performed a greater percentage of the total playing time in moderate speed, high speed and sprint running (6.1% vs 4.1%; 2.5% vs 1.6%; and 0.8% vs 0.5% respectively). Similarly, Ekblom (1986) reported a relationship between standard of play and work intensity in the Swedish National League. More recently, English Premier League players were found to cover a significantly greater distance during games than South American International players (Rienzi et al., 2000). However, no significant differences were observed for the total distance covered in any of the modes of movement between the English and international players, except for walking backwards.

Rienzi et al. (2000) suggested that the overall increase in demands of the English Premier League was not attributable to any one specific mode of movement but rather is a consequence of a more general increase in the distance covered across a number of movement modes. This view is in contrast to the findings of Mohr et al. (2003) who examined work rate profiles of top-class Italian players and less elite Danish players. The top-class players performed more high-intensity running (0.53 km or 28%) and sprinting

(0.24 km or 58%) than their Danish counterparts. These authors concluded that the greater total distance covered by the top-class players (~0.5 km) was due to the greater amount of high-intensity running performed. Moreover, these differences may be attributed to the developing physiological demands of top-class Italian soccer.

3.2.4 Aerobic energy production

Attempts have been made to assess directly the aerobic contribution to match-play by measuring oxygen uptake ($\dot{V}O_2$) during game situations (Durnin and Passmore, 1967; Miyagi et al., 1998). The apparatus used to collect expired air during early studies was often criticised for hampering the normal activity of a player. The development of lightweight, portable telemetry systems such as the K2 (Cosmed, Italy) has made it possible to obtain more precise measurements of $\dot{V}O_2$ during match play. Ogushi et al. (1993) reported that the $\dot{V}O_2$ for two players during match-play was approximately 35 to 38 $ml.kg^{-1}.min^{-1}$. Kawakami et al. (1992) utilised the K2 telemetric system to determine the $\dot{V}O_2$ during the performance of various soccer activities. Dribbling produced the highest $\dot{V}O_2$ values of 4 $l.min^{-1}$ with drills such as 1 v 1 and 3 v 1 eliciting values between 2 and 4 $l.min^{-1}$.

An alternative approach to determine the aerobic contribution to the energy expenditure during match-play is to monitor heart rate (HR) during competition and subsequently estimate energy expenditure form the individual's HR-$\dot{V}O_2$ relationship determined in a laboratory. The collection of heart rate data is less restrictive for players in comparison to expired air samples, and may represent a more exact picture of the aerobic energy contribution during soccer. However, it is likely that this leads to an overestimation of the oxygen uptake during a soccer match since a number of factors such as dehydration, hyperthermia and mental stress elevate the heart rate without affecting oxygen uptake (Bangsbo, 1994a; Esposito et al., 2004). Indeed, studies where heart rate and oxygen uptake have been measured during soccer drills have observed higher heart rates for a given oxygen uptake compared to values found during treadmill running (Castagna et al., 2003; Esposito et al., 2004).

A number of authors have determined heart rate values during elite male and female match-play (Table 3.2.4). Heart rates average around 165 beats min^{-1}, which corresponds to a relative metabolic loading of about 75% $\dot{V}O_{2max}$. The resultant energy expended for a player with 75 kg body mass is approximately 70 kJ min^{-1} (Reilly, 1997). This is in excess of the energy requirements of locomotion over 11 km because of the extra energy demands associated with soccer activities. They include jumping, changing direction, accelerating, decelerating, tackling and other games skills.

Table 3.2.4. Mean heart rate during soccer matches.

Source	Match situation	Heart rate (beats min^{-1})
Ali & Farrally (1991)	Friendly 90 min match	169
Ogushi et al. (1993)	Friendly 90 min match	161
Bangsbo (1994b)	Competitive 90 min game	171
Florida-James & Reilly (1995)	Competitive 90 min game	161
Helgerud et al. (2001)	Competitive 90 min game	171
Krustrup et al. (2005)	Competitive 90 min game (female)	167

Attempts have been made to quantify the additional demands of match-related skills such as dribbling and unorthodox directions of movement in a laboratory setting. Reilly and Bowen (1984) documented the additional costs of changes in directional modes of running, reporting that running backwards and sideways produced energy expenditure levels which were significantly greater than running forwards at the same speed. In a further study, Reilly and Ball (1984) sought to assess the physiological cost of dribbling a soccer ball. Dribbling a ball significantly increased the energy cost of motion by approximately 7.2 to 10.8% when compared to running at a given speed. These findings offer some explanation of the relatively high work rate associated with soccer. Further explanation may be gained from studying the intermittent nature of exercise during soccer. Blood lactate concentrations are higher during intermittent as opposed to continuous running at the same mean running speed (Bangsbo, 1994b). Accelerating, decelerating, turning and jumping all contribute to the exercise intensity observed during a game (Ekblom, 1986; Shephard, 1992; Reilly, 1997).

Additional evidence confirming the relatively high exercise intensity associated with soccer comes from measurements of rectal temperature. Observations of this type have reported post-match temperatures in excess of 39°C (Smodlaka, 1978; Ekblom, 1986). These values are consistent with a relative work rate of 70-80% $\dot{V}O_{2max}$, based on the original findings of Astrand (1960), and Saltin and Hermansen (1966), who observed that rectal temperature is related to relative energy consumption during high-intensity intermittent exercise in temperate climates.

3.2.5 Anaerobic energy production

The observation that elite soccer players perform 150-250 short, intense actions during a game indicates that the rate of anaerobic energy turnover is high during periods of match-play (Mohr et al., 2003). The muscle phosphogen stores, adenosine triphosphate (ATP) and creatine phosphate (CP) provides the immediate energy source for these actions (Shephard, 1982). The intense exercise during match-play leads to a high rate of CP breakdown, which is resynthesised in the following low intensity exercise periods (Bangsbo, 1994b). While measurements of CP in muscle biopsies obtained after intense periods during a game have shown levels above 70% of resting levels, it may be expected that during parts of the game the CP may become as low as 30% of the level at rest. Such figures are also likely to be due to the delay in obtaining the biopsy (Krustrup et al., 2003a).

Blood lactate concentrations of 2-10 $mmol.l^{-1}$ have been observed during match-play, with individual values above 12 $mmol.l^{-1}$ (Ekblom, 1986; Gerisch et al., 1988; Rhode and Espersen, 1988; Smith et al., 1993; Aroso et al., 2003). Blood lactate concentration is dependent on the release of lactate from the muscle and the removal of lactate from the blood. Consequently, it has been suggested that blood lactate concentration may underestimate lactate production, as not all of the lactate produced will appear in the blood. Furthermore, the rate of lactate production may be high, but the duration of activity too short to result in large blood lactate concentrations (Bangsbo, 1994b). More recently, it has been demonstrated that a low correlation coefficient is observed between muscle and blood lactate when subjects performed repeated intense exercise carrying out the Yo-Yo intermittent recovery test (Krustrup et al., 2003b). This means that the rather high blood lactate concentrations often observed in soccer may not represent a high lactate production in a single action during the game. Nevertheless, the finding of high blood lactate and moderate muscle lactate concentrations during match-play, can suggest that the rate of glycolysis is high for short periods of time during the game.

3.2.6 Energy provision

The unique demands placed upon individuals during soccer match-play necessitate an adequate supply of energy provision for fuelling muscular activity as well as restoring metabolism during periods of formal and informal rest. The ability to recover sufficiently between multiple bursts of high intensity exercise is essential for the maintenance of performance. To fully comprehend the physiology of this form of exercise, it is important to understand the energy demand and which substrates are utilised during a game.

Muscle glycogen is an important substrate for the soccer player. Saltin (1973) reported that muscle glycogen stores were almost depleted at half time when pre-match levels were low (~200 mmol/kg d.w.). Moreover, those players who started the game with normal muscle glycogen levels (~400 mmol/kg d.w.) did not suffer the detrimental effects on performance in terms of distance covered and intensity during the second half of the match, as those who started the game with low muscle glycogen levels. Others have found muscle glycogen values to be ~200 mmol/kg d.w. following a match, indicating that muscle glycogen stores are not always depleted in a soccer game (Smaros 1980; Jacobs et al. 1982). Nevertheless, analysis of single muscle fibres following a game has demonstrated that a significant number of fibres are completely depleted at the end of a game (Krustrup et al., 2003a).

Muscle and liver glycogen stores in the body are limited. Therefore the use of free fatty acids (FFA) and intramuscular lipids for energy production in soccer is essential. Increased concentrations of blood borne free fatty acids have been observed during soccer match-play (Bangsbo, 1994). A decrease in the uptake of glucose and increase in uptake and oxidation of FFA by the exercising muscle as the match progresses is supported by the findings of Essen (1978) and Hargreaves et al. (1991). These subtle changes in the process of energy provision are in line with a reduction in the amount of high intensity exercise observed toward the end of a game (Mohr et al., 2003). Hormonal changes may play a major role in the progressive increase in the FFA level. The insulin concentrations are lowered and catecholamines levels are progressively elevated during a match (Bangsbo, 1994) stimulating a high rate of lipolysis, and thus release of FFA to the blood (Galbo, 1983). This effect is reinforced by lowered lactate levels towards the end of a game, leading to less suppression of mobilisation of FA from the adipose tissue (Bangsbo, 1994).

When interpreting the respective contribution of carbohydrate and fat to energy production during soccer, a number of factors may influence substrate utilisation (e.g. environmental conditions, standard of play, age and training status). The key determinants of substrate utilisation, however, are the intensity and duration of exercise. Based on the characteristic demands of soccer (high-intensity, intermittent exercise, with an average work rate of 70-80% $\dot{V}O_{2max}$, corresponding to a mean respiratory exchange ratio of 0.88), it is estimated that carbohydrate and fat contribute 60% and 40%, respectively to total oxidation (Bangsbo, 1994). This highlights the underlying importance of carbohydrate utilisation as an energy source for soccer.

3.3 SOCCER-SPECIFIC TESTING

Soccer belongs to a group of sport disciplines characterised by intermittent bursts of intense muscular activity interspersed with longer periods of rest or low-intensity activity (Williams, 1990). In these sports, patterns of activity are characterised not only by an intermittent high-intensity workload, but also by the contribution of specific motor skills. These game-related tasks are vital components for successful performance and may add substantially to the physiological stresses placed on players. These match-specific activities further increase the complexity of evaluating the energetic demands imposed on players during match-play.

An indication of the importance of the aerobic and anaerobic energy systems to energy provision during soccer can be provided by examining an individual's performance on exercise tests designed to quantify the fitness characteristics of players. Such test results may reflect a level of adaptation to the stresses of the exercise and thus provide an indication of the physiological demands of the sport. This section of the review of literature will attempt to highlight the different forms of performance tests that have been used with soccer players to assess both aerobic and anaerobic capacities.

3.3.1 Laboratory-based testing

Laboratory tests provide a means for coaches and sports scientists to establish the general fitness of players, as these tests are not necessarily specific to soccer. Indeed, through the use of specialised equipment in the laboratory, accurate test results can be obtained in isolated fitness components (Svensson and Drust, 2005).

Aerobic fitness is considered important for soccer performance. Research has demonstrated a positive relationship between aerobic fitness and competitive ranking, team level and distance covered in a match (Smaros, 1980; Apor, 1988; Wisloff et al., 1998). For these reasons, aerobic fitness is commonly measured in soccer players. Historically, maximal oxygen uptake ($\dot{V}O_{2max}$) has been viewed as the 'Gold Standard' measurement of aerobic fitness.

Maximal oxygen uptake ($\dot{V}O_{2max}$) is the maximal energy output that can be produced by aerobic processes within the limitation of the functional capacity of the circulatory system (Astrand and Rodahl, 1986). Assessment takes place on a motor driven treadmill or cycle ergometer. Exercise intensity is raised progressively until the subject reaches voluntary exhaustion. Expired air is collected during the test and the oxygen consumed recorded, the highest value of which constitutes $\dot{V}O_{2max}$.

Several authors have determined the maximum oxygen uptake for elite soccer players and mean values between 56-69 $ml \cdot kg^{-1} \cdot min^{-1}$ have been reported (Reilly, 1996). These values support the belief that there is a large contribution from aerobic power during elite competitive match-play. More recently, individual values as high as 70 $ml \cdot kg^{-1} \cdot min^{-1}$ have been recorded (Wisloff et al., 1998). These high, but unremarkable values are greater than those reported for amateur soccer players (45-50 $ml \cdot kg^{-1} \cdot min^{-1}$), but are considerably lower than those obtained for elite endurance athletes, where $\dot{V}O_{2max}$ levels of higher than 80 $ml \cdot kg^{-1} \cdot min^{-1}$ have been observed.

Although $\dot{V}O_{2max}$ represents the maximal ability of the exercising musculature to consume oxygen, it is not possible to sustain exercise for a prolonged period of time at $\dot{V}O_{2max}$. The upper level at which exercise can be sustained for a prolonged period is thought to be represented by the 'anaerobic threshold' (Reilly, 1994b). Many studies have reported that the 'anaerobic threshold' is a better predictor of aerobic endurance performance than $\dot{V}O_{2max}$ (Weltman, 1995). The 'anaerobic threshold' is usually expressed as the work-rate corresponding to a blood lactate concentration of 4 $mmol.l^{-1}$ determined from invasive incremental tests, or determined non-invasively by associated changes in respiratory gas exchange (Wasserman et al., 1973). Moreover, the 'anaerobic threshold' appears to be sensitive to changes in training, with the threshold occurring at higher running speeds during a graded exercise test following a period of training in soccer players (Edwards et al., 2003).

The mean anaerobic threshold has been measured non-invasively at 77% of $\dot{V}O_{2max}$ in English League 1st Division players (White et al., 1988), a value close to a work intensity associated with marathon running. In tests on elite Finnish soccer players, the 'anaerobic threshold' (determined as the inflection point in the blood lactate response from incremental exercise) was 83.9% of $\dot{V}O_{2max}$. Using a fixed blood lactate concentration (FBLC) of 3 $mmol.l^{-1}$, Bangsbo and Lindquist (1992), reported that this FBLC corresponded to about 80% of $\dot{V}O_{2max}$ for both continuous and interval testing on a treadmill.

When considering anaerobic performance, a distinction has to be made between anaerobic power and anaerobic capacity. Anaerobic power represents the highest rate of anaerobic energy release, whereas anaerobic capacity reflects the maximal anaerobic energy production an individual can obtain in any exercise bout to exhaustion (Reilly et al., 2000). The development of the Wingate anaerobic power test in the mid to late 1970 s led the way for the analysis of maximal intensity exercise (Bar-Or, 1987). The prototype of the test involved cycling against a resistance that represented supramaximal intensity (~ 2 to 4 times $\dot{V}O_{2max}$). This test underwent numerous modifications during the late 1970's and early 1980's and subsequently developed into an exercise protocol which consisted of 30 s of sprinting at maximal effort on a cycle ergometer, from which power output related to time could be determined (Lakomy, 1986). However, questions concerning the activity pattern of the Wingate test to the relevance of games players have led to the development of both running (Cheetham et al., 1986) and jumping (Bosco et al., 1983) tests. While all these protocols are valid and reliable, their use has been limited in soccer due to practical problems such as expensive equipment and required expertise. Furthermore, athletes are sometimes reluctant to be assessed in the laboratory.

3.3.2 Field-based testing

While laboratory-based tests have an advantage of controlled environments and superior forms of assessment, field-based tests enhance the specificity of the evaluation (Svensson and Drust, 2005). Indirect field-based tests have been employed to provide an estimation of $\dot{V}O_{2max}$. One such test that has become popular with the soccer playing population is the 20 m multistage shuttle test (20 MST) (Ramsbottom et al., 1988). During the 20 MST, subjects are required to complete 20 m shuttles at a progressively increasing intensity. The test begins at a shuttle speed of 2.22 $m.s^{-1}$ and increases by approximately 0.14 $m.s^{-1}$ every minute. The subjects follow the 20 MST protocol by touching the appropriate 20-m line with a foot in tandem to an auditory signal. Ramsbottom et al. (1988) reported that $\dot{V}O_{2max}$ values could be predicted from the 20 MST ($r=0.92$; $p<0.01$) with an estimated standard deviation about the regression line of 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$. More recently, Erith and Williams (2005) examined the validity of the 20 MST for predicting $\dot{V}O_{2max}$ values in female soccer players. Following a training intervention, predicted $\dot{V}O_{2max}$ values and actual $\dot{V}O_{2max}$ values were 50.3 ± 0.6 and 51.5 ± 0.9 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively.

The 'Yo-Yo' intermittent endurance test (Bangsbo, 1993b) is a modified version of the 20 MST with a 5-s recovery period following every pair of 20-m shuttles. The inclusion of such a recovery period is considered to be more representative of the intermittent pattern of exercise observed in soccer (Balsom, 1994). The validity and reliability of the Yo-Yo test in soccer referees and players have been recently reported (Krustrup and Bangsbo, 2001; Krustrup et al., 2003b). Correlations between distance covered during the Yo-Yo test and the distance covered running at high intensity during a match (> 15 $km.h^{-1}$) were found to be $r=0.75$ and $r=0.71$, in referees and players respectively. Furthermore, Yo-Yo test results are correlated to $\dot{V}O_{2max}$ ($r=0.71$), suggesting that this test could give information on both general aerobic performance and soccer-specific endurance performance.

The use of sports science support networks in soccer has prompted the design of a number of field-based soccer-specific endurance tests. Ekblom (1989) developed a continuous running test for soccer players that included forward, backward and 'slalom' running, turning and jumping. The test result is the time taken to complete 4 laps of the 540-m course. This test has been found to be sensitive to changes in fitness following pre-season training (Ekblom, 1989). More recently, Bangsbo (1994c) developed a soccer-specific intermittent endurance test. The test incorporates exercise patterns found in soccer and consists of 40 bouts of 15 s high-intensity running interspersed with 10 s recovery periods. Performance in the test is correlated with performance on an intermittent endurance test (r=0.83), thus indicating its usefulness as a predictor of an individual's soccer-specific intermittent endurance capacity (Bangsbo and Lindquist, 1992).

Several methods have been used to evaluate maximal performance of soccer players during short-term exercise and thus, indirectly, their anaerobic power. Among these is the stair-run test developed by Margaria et al. (1966). Measurement is made of the time taken for the player to run between two stairs, the vertical distance between which is known. Using this test, Withers et al. (1977) reported that forward players had the highest and midfield players the lowest levels of anaerobic power. Studies in the literature have quoted the results of anaerobic power tests by player position. While differences in protocols make comparison of actual test results fruitless, there is value in comparing the rankings between the position categories (Tumilty, 1993). It would appear that anaerobic power is related to the position in the team (Cochrane and Pyke 1976; Raven et al., 1976; Wisloff et al. 1998). Moreover, there are consistent observations on midfield players scoring lower on many of the measures for anaerobic power when compared with all other positions.

The important link between anaerobic power and soccer match-play may, in part, explain the high prevalence of fitness testing which occurs in contemporary professional soccer. Erith and Williams (2005) revealed that 96% of professional soccer clubs surveyed conducted some form of fitness testing. Field-based tests were far more frequently used than laboratory-based procedures with the most popular tests being the acceleration sprint and vertical jump tests. Mean values for the vertical jump test have ranged from 41-60 cm (Reilly, 1990) while a score of 219 ± 3 cm has been observed for English League soccer players performing the standing broad jump. More recently, contact platforms have been employed that calculate the flight time of jumps (Wisloff et al. 1998; Casajus 2001; Cometti et al., 2001). This principle implies that flight time up equals flight time down during the jump. This method of calculation has been used in repeated jump tests that have been used to evaluate soccer players (Bosco, 1990; Kirkendall, 1985).

Acceleration sprint tests have been conducted on a number of elite soccer playing populations (Dunbar and Power, 1995; Wisloff et al. 1998; Cometti et al., 2001; Dowson et al., 2002). Both English and German professional players have been shown to be faster than amateurs (Kollath and Qaude, 1993; Brewer and Davis, 1991) over 30 m and 40 m distances. Given that soccer is characterized as a 'multiple sprint sport', a number of field-based tests have been devised in an attempt to measure intermittent sprint capacity. Two popular tests that have been employed in professional soccer include the Intermittent Sprint Test (IST) (Reilly, 2001) and the 'Bangsbo Sprint Test' (BST) (Bangsbo, 1994c). The aim of the IST and the BST is to examine a subject's capability to reproduce high-intensity sprints following a short recovery period. The IST test consists of 7 x 30 m repetitions of sprint running interspersed by regular short rest intervals (15 s). The BST test consists of 7 x 34.2 m intervals of sprint running interspersed by regular short rest periods (25 s). The duration of each of the sprints during the tests are recorded from which the best time, mean time and fatigue time can be calculated.

3.4 SOCCER-SPECIFIC LABORATORY PROTOCOLS

A number of techniques have been developed to measure the effects of intermittent exercise. Some have permitted movements that actually take place in sports events whilst others have concentrated on a specific movement about a single joint. Examples of equipment developed to measure movements in sports include a non-motorised treadmill for sprint running (Lakomy, 1984) and cycle ergometers for cycling (Gaitanos et al., 1993; Balsom et al., 1995). For movements about a specific joint, isokinetic dynamometers have become a favoured method for the assessment of dynamic muscle function in both sports environments and clinical research (Gleeson and Mercer, 1996; Gleeson et al., 1998).

Several research groups have attempted to replicate the demands of the so-called multiple-sprint sports (Bangsbo et al., 1992; Nevill et al., 1993; Fallowfield et al., 1997). Nicholas et al. (2000) devised a free running test, performed indoors that simulates the activity patterns common to soccer, without any contact. The Loughborough Intermittent Shuttle Test (LIST) comprises two parts, Part A and Part B. Part A is of a fixed duration and consists of five 15 min exercise periods separated by 3 min of recovery. The exercise periods consist of a set pattern of intermittent high-intensity running (Table 3.4.1). Part B is an open-ended period of intermittent shuttle running, designed to exhaust the participants within approximately 10 min. Participants are required to run at speeds corresponding to 55% and 95% of predicted $\dot{V}O_{2max}$, the speed alternating every 20 m.

Table 3.4.1 The pattern of exercise for Part A of the LIST

3 x 20 m @ walking pace
1 x 20 m @ maximal running speed
4 s recovery
3 x 20 m @ a running speed corresponding to 55% of individual $\dot{V}O_{2max}$
3 x 20 m @ a running speed corresponding to 95% of individual $\dot{V}O_{2max}$

The LIST has been employed in the investigation of the effects of drinking a carbohydrate-electrolyte solution on endurance running capacity (Nicholas et al., 1995) and muscle glycogen utilization (Nicholas et al., 1994). It has also been used to show the effect of fluid ingestion on soccer skill (McGregor et al., 1997) and the effects of high environmental temperatures on intermittent performance (Morris et al., 1998).

Few laboratory studies to date have employed exercise protocols that have attempted to replicate the demands of soccer match-play. More recently Drust et al. (2000 a,b) developed an intermittent protocol representative of the work-rates involved in soccer match-play. The soccer-specific intermittent protocol designed by Drust et al. (2000 a,b) is performed on a non-motorised treadmill (Woodway, Vor Dem, Auf Schrauben, Germany). Such apparatus has the benefits of almost instantaneous acceleration and deceleration. The combination of speeds and activity changes are designed to mimic the activity pattern typically recorded for soccer match-play (Reilly and Thomas, 1976; Withers et al., 1982) and consist of four movement categories: walking, jogging, cruising and sprinting. Static periods are also included in the protocol in which the subjects are stationary on the treadmill. Due to the technical limitations of the equipment, utility movements (backwards and sideways) are not included.

The protocol is arranged around a 15-min activity cycle. This cycle is performed six times in total to make up a 90-min protocol. The 15-min cycle is further sub-divided into 3-separate 5 min cycles. Each section of 5 min cycles consisted of 3 discrete bouts of walking, 3 bouts of jogging, 3 bouts of cruising, 3 static pauses and one maximal sprint. The time spent in each category is designed to replicate the physiological stresses of match-play. Treadmill speeds for each activity are: walking 4 $km.h^{-1}$, jogging 8 $km.h^{-1}$, and cruising 12 $km.h^{-1}$. No speed restrictions are placed on the sprinting category as subjects are instructed to produce a maximal effort. The physiological and metabolic responses to the intermittent protocol are similar to those reported in the literature for soccer match-play (Drust et al., 2000 a,b). Therefore, the protocol is deemed suitable for the examination of soccer-related performance.

3.5 SUMMARY

The findings of this review of literature have been directed towards the physiological demands of soccer with a special reference to the physical characteristics of elite soccer players. Investigations are required to establish contemporary work-rate profiles as well as the physiological responses to playing the game. While this review has placed the literature in a historical context, there is now a requirement for more systematic research at an elite level. Therefore a laboratory based soccer-specific protocol will be used to quantify metabolic and physiological responses to exercise patterns representative of elite Premier league match-play. The application of these findings may further our understanding of the stresses associated with competition and ultimately enhance performance within the football codes.

CHAPTER 4

CHAPTER IV

4. THE ELITE SOCCER PLAYER

Soccer players have to adapt to the requirements of the game to compete at an elite level of play. Moreover, the physical characteristics of elite players may give an indication of the physiological demands of soccer. This chapter contains four studies, which combine to provide information relating to the physical characteristics of elite male soccer players. The purpose of the first two studies was to establish the anthropometric and performance characteristics of elite players and identify any effects of positional roles. In the third study the anthropometric and performance profiles of elite young players were investigated to determine the relationship between these profiles and success in match performance. The final study explored the characteristics unique to soccer performance with a comparison of elite adult players in two football codes.

4.1 ANTHROPOMETRIC PROFILE OF ELITE MALE SOCCER PLAYERS

4.1.1 Introduction

For the purpose of this thesis, body size, structure and composition are considered separate yet interrelated aspects of anthropometry that contribute to physique. Body size refers to the volume, mass, length and surface area of the body. Body structure refers to the distribution or arrangement of body parts. Body composition refers to the amounts and constituents in the body. Anthropometric factors and physique of the elite athlete have been extensively studied. Several authors have highlighted that the anthropometric profile is an important selective factor for success in sport (Carter, 1970; Reilly, 1990). Data from the Olympic games have shown differences in the anthropometric profile of athletes between and within competitive events (Carter, 1984). Such findings have led to the belief that the quantification of these aspects of physique through anthropometry can provide a better basis for understanding limits related to the physiology of performance (Carter, 1985).

The physiological demands of soccer match-play vary with the work-rates in different positional roles (Reilly and Thomas, 1976). These differences may be reflected in the anthropometric measures among players. When the level of competition, duration and intensity of training are similar, differences between body structures may be a reflection of the demands of match-play. Indeed, it appears that the biomechanical, physiological and technique demands of a particular sport limit the range of body structures that can satisfy the demands (Carter and Heath, 1990). Furthermore, anthropometric predispositions for positional roles may exist, where the physical demands of soccer lead to selection of body types best suited to that position. Such a proposition has led to the formulation of hypothesis A, expressed as a null hypothesis:

A. H_O: At an elite level of play, anthropometric characteristics do not vary according to different playing positions.

There have been few contemporary investigations of anthropometric characteristics of elite Premier League soccer players. The purpose of this study was to establish anthropometric characteristics of elite soccer players and identify any positional variations between players.

4.1.2 Methods

4.1.2.1 Subjects

Subjects were 32 (5 goalkeepers, 7 central defenders, 6 full-backs, 7 midfield players and 7 forwards) full-time professional male soccer players of a Premier league squad (age 26 ± 4 years). For the purpose of the study, only subjects that had represented the 1st team in the Premier League were included.

4.1.2.2 Procedures

Anthropometric profiles were obtained on all players following a period of intensive pre-season training (September). The anthropometric variables included segmental lengths, breadths of the humerus and femur, limb girths, adiposity (Reilly et al., 1996, Durnin and Womersley, 1974), muscle mass (Martin et al., 1990), body mass and somatotoype calculated by the Heath-Carter (1967), anthropometric method.

Body mass was determined to the nearest 0.1 kg using a set of calibrated precision scales (Salter Academy, Model 100). Stature was determined to the nearest 0.1 cm using a portable stadiometer (Leicester Ltd). Gentle traction was applied on the mastoid process of the subject to compensate for any shrinkage of the intervertebral discs. Care was taken to ensure that the marked Frankfurt Plane remained horizontal throughout the measurement. 'Sitting stature' was determined using a similar method as described above. The subject was positioned on the base of the stadiometer on a raised table with the hip and knee joints in 90° flexion. The subject's back was positioned fully upright with the buttocks and scapulae touching the vertical part of the stadiometer.

Various techniques are available for the assessment/estimation of relative adiposity. The 'gold standard' reference method is underwater weighing or dual energy x-ray absorptiometry in well-funded laboratories, but the assumptions made with regard to body density are not transferable to highly trained athletes (Reilly et al., 1996). Moreover, such facilities are rarely available in field conditions. The consensus statement of the British Olympic Association has recommended the use of skinfold measurement by means of callipers up to the standard of the International Biological Programme (Reilly et al., 1996). Relative adiposity was measured by means of skinfold callipers (Harpenden) using the sum of five anatomical sites – biceps, triceps, subscapular, suprailiac and anterior thigh according to the position statement of the British Olympic Association (Reilly et al., 1996). The percent adiposity was estimated from the sum of four sites – biceps, triceps, subscapular, suprailiac using the equation developed by Durnin and Womersley (1974). Body density was calculated using equation **(1)** and was followed by the calculation of percentage adiposity using equation **(2)**.

Durnin and Womersley (1974)

Body density = 1.1610 – 0.0632 log $\sum 4$ **(1)**

Where $\sum 4 = \sum 4$ skinfolds as specified (mm)

Siri (1956)

% adiposity = [(4.95/body density) – 4.5] x 100 **(2)**

The biceps skinfold was measured at the vertical fold on the anterior surface of the biceps midway between the anterior axillary fold and the antecubital fossa. The triceps skinfold was measured at the vertical fold on the posterior midline of the upper arm, over the triceps muscle, midway between the acromion and olecranon processes. The subscapular skinfold was measured at the diagonal fold coming from the lower part of the medial border of the scapula to 1-2 cm from the inferior angle of the scapula. The suprailiac skinfold was measured at the diagonal fold above the crest of the ilium at the spot where an imaginary line would come down from the anterior axillary line (1 cm above and 2-3 cm medial to the anterior superior iliac spine). The anterior thigh skinfold was measured at the vertical fold on the anterior aspect of the thigh, midway between the hip and knee joints. The subject was seated for this measurement.

The anthropometric measures required for estimation of muscle mass included stature, thigh circumference (corrected for medial front thigh skinfold thickness), forearm circumference and calf circumference (corrected for medial skinfold thickness). Muscle mass was calculated using the equation developed by Martin et al. (1990).

M (kg)= [ht x (0.0553CTG^2 + 0.0987FG^2 + 0.0331CCG^2) – 2445] x 0.001
% M = (kg M/body mass) x 100

Where:

Ht = stature in cm

CTG = corrected thigh girth = thigh girth – π (front thigh SF/10)

FG = forearm girth

CCG = corrected calf girth = calf girth – π (medial calf SF/10)

The skinfold at the front thigh was measured as explained above. The skinfold of the medial calf was measured on the vertical fold on the medial side of the calf, at the level of the maximum circumference of the calf. The forearm circumference was taken at the proximal part of the forearm within 5 cm of the elbow. The subject stood erect with arm extended in the horizontal plane. The operator stood behind the subject's arm and moved the tape up and down the forearm perpendicular to the long axis until the maximum circumference of the forearm was located. The thigh circumference was taken at the midpoint between the trochanterion and the tibiale laterale. The circumference was taken at this point perpendicular to the long axis of the thigh. The calf circumference was taken perpendicular to the long axis of the calf at the point where the greatest circumference was located.

Somatotype was calculated using the skinfolds measured at the triceps, subscapular, supraspinale and medial calf sites, the maximal upper arm girth (corrected for triceps skinfold thickness), the standing calf girth (corrected for medial skinfold thickness) and the breadths of the humerus and femur. The following formulae were used for the calculation of the anthropometric Heath-Carter somatotype (Heath and Carter, 1967).

Endomorphy = -0.7182 + 0.1451X – 0.00068X^2 + 0.0000014X^3

Mesomorphy = 0.858HB + 0.601FB + 0.188AG + 0.161CG – 0.131SH + 4.5

Ectomorphy = 0.732 HWR –28.58 (if HWR > 40.74)

Where:

X = sum of 3-skinfolds (triceps, subscapular, supraspinale), corrected for height. For height corrected endomorphy, multiply X by 170.18/stature in cm

HB = humerus breadth

FB = femur breadth

AG = corrected arm girth

CG = corrected calf girth

SH = standing height

HWR = height/cube root of weight.

Triceps, subscapular and medial calf skinfolds and maximal calf circumference were measured as described above. Supraspinale skinfold was measured 5 to 7 cm above the anterior superior iliac spine on a line to the anterior axillary border and on a diagonal fold going downwards and inwards at 45°. Breadth of the humerus was the greatest distance between the medial and lateral epicondyles of the humerus, with the shoulder and elbow flexed at 90°. Breadth of the femur was the greatest distance between the lateral and medial epicondyles of the femur, with the knee bent at 90°. Upper arm circumference is the maximum circumference of the upper arm when the subject holds the upper arm horizontally, flexes the elbow at 45°, clenches the hand and maximally contracts the elbow flexors and extensors.

4.1.2.3 Technical error of measurement

Anthropometry, like any other scientific discipline, depends upon adherence to the particular requirements involved in the standards of measurement as determined by international bodies (Norton et al., 2000). The professional body for anthropometric standards is the International Society for the Advancement of Kinanthropometry (ISAK), and it is this organisation's standards that have been adopted for the purpose of this thesis. The standards of measurement relate to the following:

• The observance of landmarks in the determination of measurement sites
• Adherence to standard procedures when using equipment
• The continuous calibration of equipment.

(Norton et al., 2000).

The author conducted all anthropometric measures within this thesis. Site selection and its location were standardised according to the procedures of the ISAK laboratory manual (Eston and Reilly, 1996).

In order to give an indication of the precision associated with each anthropometric measure (the error of the method due to both biological and technical factors), the technical error measurement (TEM) and the percentage technical error of measurement (%TEM) were calculated for all major anthropometric variables (see Table 4.1.1). The TEM and %TEM were calculated using the following formulae:

$$\mathbf{TEM = \sqrt{\sum d^2 / 2n}}$$

$$\mathbf{\%TEM = (TEM / [M1 + M2] / 2) \times 100}$$

Where:
d = differences between 1st series of measurement and 2nd series of measurements
n = number of subjects
M1 = mean of the 1st series of measurement
M2 = mean of the second series of measurements

The data used in the calculation of TEM and %TEM consisted of the first duplicate observations on twenty subjects. The accepted anthropometric TEM values and experimental values are presented in Table 4.1.1 (Norton et al., 2000). Given the small magnitude of technical errors, the intra-observer measurement variability on anthropometric variables was therefore negligible.

Table 4.1.1. Accepted anthropometric TEM values (Norton et al., 2000).

Anthropometric variable	Accepted value	Experimental value
Body mass (kg)	0.1	0.0
Stature (cm)	0.3	0.1
Skinfolds (mm)	5 %	1 %
Breadths (cm)	0.1	0.0
Girths (cm)	0.2	0.1

4.1.2.4 Statistical analyses

The statistical analyses of data were carried out using one-way analyses of variance (ANOVA). Post-hoc Tukey tests were used to identify where any differences that were found lay. The level of significance was accepted at $P<0.05$.

4.1.3 Results

The anthropometric characteristics of the subjects are presented in Table 4.1.3. The results of analyses of variance demonstrated significant differences in stature between the positions ($F_{4,27} = 12.830$; $P<0.001$). Goalkeepers and central defenders were significantly taller in stature than full-backs, midfield players and forwards (goalkeepers 1.91 ± 0.05 m; central defenders 1.89 ± 0.04; full-backs 1.77 ± 0.04; midfield players 1.78 ± 0.03; forwards 1.80 ± 0.06). The difference in stature between goalkeepers and central defenders was not found to be significant. Variability in stature was greatest in goalkeepers and forwards than for the other positions. The mean ± S.D stature for all the positions combined was 182 ± 0.07 m.

Sitting height demonstrated a similar trend to stature with goalkeepers being significantly taller than full-backs, midfield players and forwards (goalkeepers 0.97 ± 0.03 m; full-backs 0.93 ± 0.01; midfield players 0.93 ± 0.02; forwards 0.92 ± 0.02) ($F_{4,27} = 5.660$; $P<0.02$). Sitting height of central defenders (0.96 ± 0.02) was also significantly greater than forwards ($P<0.02$). There were no significant differences between the positions for age.

Differences between positions were further highlighted when examining the body mass of the players. Goalkeepers were significantly heavier than full-backs and midfielders (goalkeepers 87.3 ± 6.3 kg; full-backs 76.2 ± 4.1; midfield players 76.6 ± 5.6) ($F_{4,27} = 3.767$; $P<0.01$). Variability in body mass was greater in forwards compared to the other positions. The mean ± S.D body mass for all the positions combined was 80.5 ± 6.8 kg (Table. 4.1.2).

Table 4.1.2. Anthropometric characteristics of elite male soccer players grouped according to their position in the team (mean ± S.D).

	Age (Years)	Stature (m)	Sitting height (m)	Body mass (kg)
	Mean ± S.D (Range)	Mean ± S.D (Range)	Mean ± S.D (Range)	Mean ± S.D (Range)
Goalkeepers	26.0 ± 6.0	1.91 ± 0.05	0.97 ± 0.03	87.3 ± 6.3
(n=5)	(20.0 – 34.0)	(1.82 – 1.97)	(0.94 – 1.03)	(76.0 – 91.0)
Central	26.0 ± 4.0	1.89 ± 0.04	0.97 ± 0.02	83.4 ± 3.9
Defenders	(20.0 – 32.0)	(1.83 – 1.94)	(0.94 – 1.00)	(78.2 – 90.9)
(n=7)				
Full-backs	25.0 ± 4.0	1.77 ± 0.03 †*	0.93 ± 0.01†	76.2 ± 4.1†
(n=6)	(21.0 – 30.0)	(1.73 – 1.82)	(0.93 – 0.95)	(71.0 – 81.1)
Midfield	26.0 ± 4.0	1.78 ± 0.02 †*	0.93 ± 0.02 †	76.6 ± 5.6 †
players	(20.0 – 33.0)	(1.73 – 1.82)	(0.90 – 0.96)	(70.1 – 86.0)
(n=7)				
Forwards	24.0 ± 4.0	1.80 ± 0.05 †*	0.91 ± 0.02 †*	80.3 ± 8.1
(n=7)	(17.0 – 30.0)	(1.73 – 1.90)	(0.89 – 0.94)	(67.5 – 88.0)
Mean ± S.D.	26.0 ± 4.0	1.82 ± 0.07	0.94 ± 0.03	80.5 ± 7.0

† $P < 0.05$ v Goalkeepers

* $P < 0.05$ v Central Defenders

Variables related to the body composition of subjects are presented in Table 4.1.3. No significant differences were observed between the positions for adiposity, percent adiposity, muscle mass or percent muscle mass. Central defenders (10.1 ± 1.7) had the lowest percent adiposity calculated from the equation of Durnin and Womersley (1974) but these were not significantly different from the other positions.

Figure 4.1.1 illustrates the somatotypes for all the players according to their position in the team. The mean ± S.D. somatotype of goalkeepers, central defenders, full-backs, midfield players and forwards was 2.4 ± 0.6 – 4.3 ± 0.5 – 2.9 ± 0.5; 2.2 ± 0.6 – 4.5 ± 1.4 – 3.1 ± 0.9; 2.5 ± 0.5 – 5.0 ± 0.5 – 2.1 ± 0.3; 2.5 ± 0.4 – 5.1 ± 1.0 – 2.1 ± 0.7; 2.5 ± 0.4 – 5.7 ± 0.8 – 2.0 ± 0.6 respectively. The somatotype for these players represents a trend towards mesomorphy or muscularity. Significant differences were observed between positions for ratings of ectomorphy ($F_{4,27}$ = 4.077; $P<0.01$). Moreover, central defenders had a significantly higher rating of ectomorphy than forwards ($P<0.038$). Therefore it appears that central defenders posses moderate relative linearity and less bulk per unit height than other players. No significant differences were observed between positions for mesomorphy ratings ($F_{4,27}$ = 2.096; $P<0.1$). Forwards demonstrated a higher mesomorphy rating than other positions but these values were not statistically significant.

Muscle girth characteristics of the subjects are presented in Table 4.1.4. No significant differences were found between the subjects for thigh, calf, forearm or bicep circumference.

Table 4.1.3. Body composition of elite male soccer players grouped according to their position in the team (mean ± S.D).

	Adiposity (mm) Mean ± S.D (Range)	Adiposity (%) Mean ± S.D (Range)	Muscle mass (kg) Mean ± S.D (Range)	Muscle mass (%) Mean ± S.D (Range)
Goalkeepers	34.0 ± 5.9	11.2 ± 3.2	51.8 ± 3.7	59.3 ± 1.2
(n=5)	(29.1 – 44.2)	(7.9 – 14.6)	(45.2 – 54.0)	(57.2 – 60.1)
Central	30.9 ± 5.8	10.1 ± 1.7	51.3 ± 4.4	61.5 ± 3.5
Defenders	(25.9 – 43.1)	(8.0 – 13.5)	(46.0 – 60.1)	(57.0 – 66.2)
(n=7)				
Full-backs	34.7 ± 4.6	11.4 ± 1.5	47.5 ± 3.3	62.3 ± 1.8
(n=6)	(26.3 – 38.8)	(8.5 – 12.7)	(43.2 – 51.4)	(60.4 – 65.7)
Midfield	33.8 ± 4.3	11.2 ± 1.4	47.6 ± 4.7	62.3 ± 2.5
players	(28.6 – 38.7)	(9.3 – 12.4)	(43.2 – 56.9)	(59.0 – 66.2)
(n=7)				
Forwards	34.2 ± 3.9	11.3 ± 1.3	48.9 ± 4.4	61.0 ± 1.5
(n=7)	(28.4 – 38.2)	(9.0 – 13.0)	(42.0 – 53.2)	(59.4 – 63.2)
Mean ± S.D.	33.5 ± 4.8	11.0 ± 1.8	49.4 ± 4.3	61.4 ± 2.4

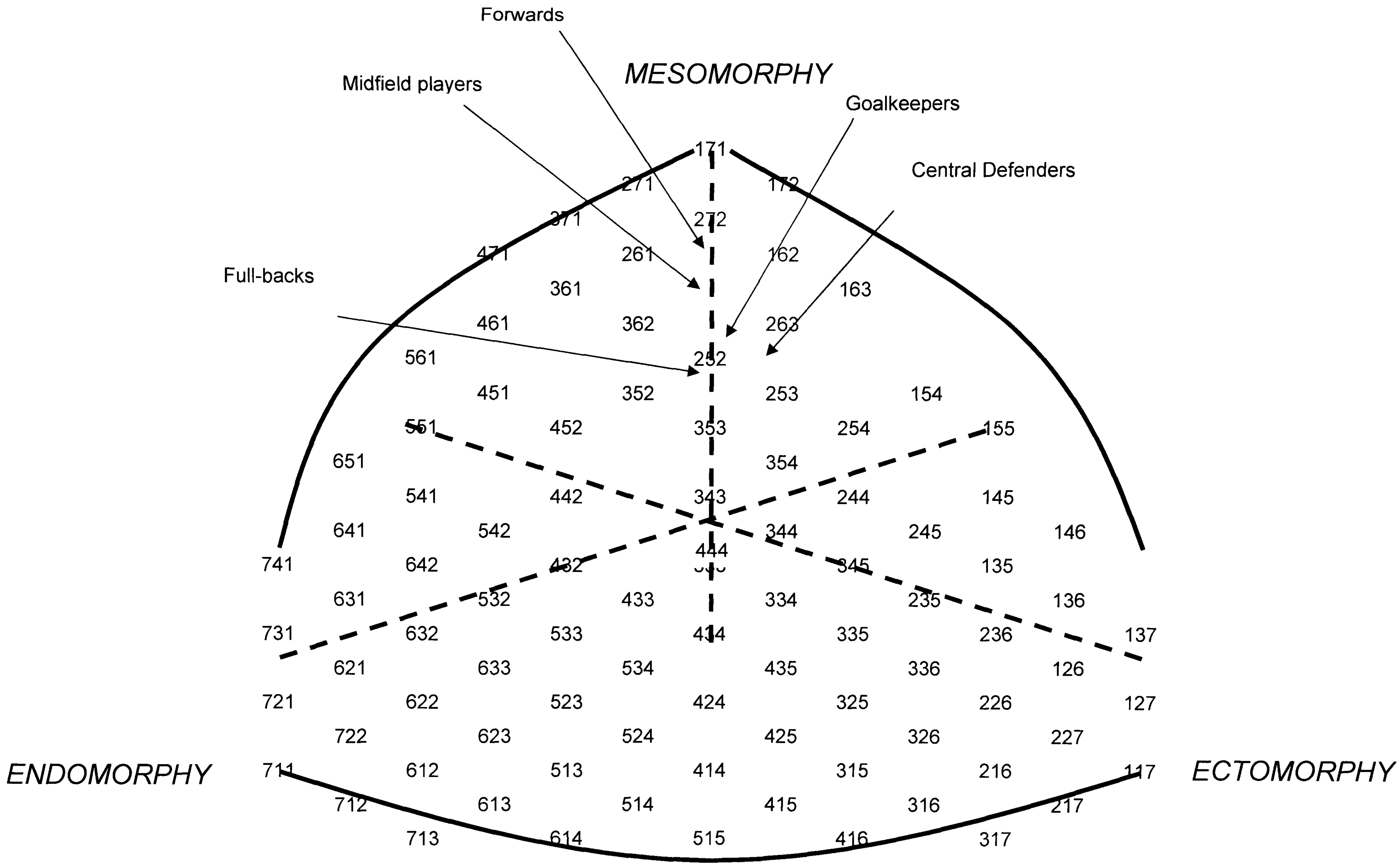

Figure 4.1.1 Somatochart for elite male soccer players grouped according to their position in the team. (Goalkeepers = 5, Central defenders = 7, Full-backs = 6, Midfield players = 7, Forwards = 7 players).

Table 4.1.4. Muscle girth circumference of elite male soccer players grouped according to their position in the team (mean ± S.D).

	Thigh (cm)	Calf (cm)	Forearm (cm)	Bicep (cm)
	Mean ± S.D (Range)	Mean ± S.D (Range)	Mean ± S.D (Range)	Mean ± S.D (Range)
Goalkeepers (n=5)	55.3 ± 1.5 (53.2 – 56.5)	38.4 ± 0.5 (37.9 – 39.0)	27.8 ± 0.6 (27.0 – 28.5)	32.2 ± 1.3 (30.0 – 33.5)
Central Defenders (n=7)	56.4 ± 2.5 (54.7 – 60.2)	38.1 ± 1.8 (36.2 – 41.5)	27.0 ± 1.2 (25.5 – 28.6)	32.2 ± 2.5 (28.7 – 34.7)
Full-backs (n=6)	55.4 ± 1.7 (53.5 – 58)	37.9 ± 0.9 (36.9 – 39.0)	27.6 ± 0.4 (27.2 – 28.6)	32.6 ± 1.4 (31.2 – 35.0)
Midfield players (n=7)	55.3 ± 3.6 (52.5 – 62.5)	37.4 ± 2.1 (34.8 – 40.0)	27.5 ± 0.5 (26.1 – 28.1)	33.5 ± 2.4 (30.2 – 36.6)
Forwards (n=7)	56.4 ± 2.4 (53.0 – 59.5)	38.1 ± 1.9 (36.8 – 40.1)	27.1 ± 0.9 (26.0 – 28.5)	33.7 ± 1.4 (30.8 – 35.2)
Mean ± S.D.	55.8 ± 2.4	38.0 ± 1.5	27.3 ± 0.9	32.9 ± 1.9

4.1.4 Discussion

The Premier League soccer players in the current study constitute a relatively heterogeneous group. Similar observations have been obtained in other studies (Raven et al., 1976; Davis et al., 1992; Puga et al., 1993; Bangsbo, 1994b). The goalkeepers (1.89 ± 0.05 m) and the central defenders (1.87 ± 0.04 m) were the tallest while the mean height for full-backs, midfield players and forwards was equivalent (1.77 ± 0.04 – 1.78 ± 0.06). It is therefore likely that particular positional roles impose unique physical demands and that an appropriate body size allows players to meet the demands placed on them by their playing position.

Results from the present study support the earlier findings of Reilly and Thomas (1980) who reported that 23% of the total variance among English first Division players could be accounted for by a component related to body size. In contemporary soccer, tall players have an advantage in certain playing positions and therefore are oriented toward these roles, more notably in goalkeepers and central defenders (Bangsbo, 1994b). While smallness in stature is not itself a bar to success in soccer, it may influence the tactical role allocated to individual players. A coach may also modify team formation and style of play to accommodate individuals according to physical attributes (Reilly, 1990).

A large percentage (40.3%) of goals scored in the 2002 World Cup soccer finals came from sequences involving set plays (Taylor et al., 2002). Effective performance at set plays is becoming increasingly important in International, European and domestic football (Taylor et al., 2002). Furthermore, there is an increasing trend toward the scoring of goals from corners or free kicks that are wide of the penalty area. In-swinging crosses and corners played to the front half of the goal seem to be the most profitable (Franks, 1988). The key principle for consideration, however, is the availability of individual players for these particular roles. Clearly, tactics should be devised to suit the strengths of individual players (Gray, 1999). Tall players who will attack the ball at the near goal-post are ideal for these particular roles, and teams that maximise their strengths ultimately increase their chances of scoring from set plays.

Moreover, tallness is an advantage to those players whose role is to prevent opponents from goal scoring opportunities. This is particularly the case for players who occupy the central defensive and goalkeeper positions.

In the present study, a large variation was observed within the forwards with respect to stature. This observation has been made in other studies (Bangsbo, 1994b). Stature will clearly influence the tactical role of the player. Taller forwards, who have longer levers (limbs) and a higher centre of gravity, have an advantage in jumping, whereas shorter forwards have the advantage when the body must be rotated around an axis, such as turning away from opponents. In a soccer context, the tall forward may be used as a target player for high balls, while the short forward may 'spin' away from defenders and run for balls played deep into the opponents' defence (Bangsbo, 1994b). Furthermore, smallness in stature may facilitate success in soccer performance via agility and suppleness.

The results of the present study also indicate that elite Premier League soccer players have unique body mass characteristics, which depend on positional role. Goalkeepers and central defenders were the heaviest with full backs and midfield players the lightest (goalkeepers 85.3 ± 6.3; central defenders 82.4 ± 3.9; full-backs 76.2 ± 4.1; midfield players 76.6 ± 5.6). These findings are in agreement with those of Davis et al. (1992) who reported data on the physiological characteristics of soccer players. These authors presented data to suggest that central defenders were the heaviest of all outfield players. They concluded that these physiological characteristics reflect the demands during competitive match-play. Table 4.1.5 and Table 4.1.6 demonstrate the differences observed in stature and body mass in soccer groups with respect to player position.

The influence of body mass on soccer performance must be considered when analysing the demands of specific positions. This is most apparent when considering the concept of momentum. When two players moving in opposite directions at velocities of equal magnitude collide, the change in their respective velocities will be inversely proportional to their masses (Enoka, 1988). Therefore, the greater the player with higher body mass, the greater the advantage especially in body contact situations. Moreover, a large body mass is beneficial to central defenders and goalkeepers (whose role is to prevent opponents scoring during the game) with respect to stability, inertia and momentum, provided that there is no adverse effect on speed. Similar observations have been reported in Rugby Union when comparing the diversity in positional roles according to physical attributes and game specific demands (Nicholas, 1997).

There is a suggestion of an 'expanding universe' of athletic bodies (Norton and Olds, 2001). Norton and Olds (2001) reviewed data on height and mass for athletes competing at the highest level. According to these authors, soccer players were on average similar in height to the general population, with a similar degree of variability as expressed by standard deviation (SD) values. The reported mean value for stature for soccer players was 1.78 ± 0.06 m, whereas in the present study, the mean value was 1.82 ± 0.07 m. When the present values are compared to the general population, it appears that contemporary soccer players are moving away from the midpoints of the general population. Furthermore, given the heterogeneity of the group, discriminating players by positions will yield a more divergent picture of physical characteristics compared to the general population and therefore support the notion of an expanding athletic population.

While mean values may mask the heterogeneity of elite soccer players, they nonetheless demonstrate that reported values of body mass and stature have risen in the past few decades. Average reported stature values for British soccer players (Williams et al., 1973) three decades ago were 1.74 ± 0.09 m compared to 1.81 ± 0.07 m in the present study. Body Mass Index (BMI) and body mass values have followed a similar trend. Indeed, average body mass values of British soccer players have risen 10.3 kg over the past three decades, a change that equates to approximately 3.0 kg per decade. Figure 4.1.2 demonstrates the increases in body mass over the past three decades. Where these increases in stature and mass will end is indefinite, but what is clear is that contemporary elite players are taller and heavier than their elite counterparts three decades ago. These characteristics may have implications for fitness profiles, work-rate profiles, risk of injury and dietary interventions. Such areas will be further addressed throughout this thesis.

The percent adiposity (11.0 ± 1.8%) for the players in the present study is in the range reported by Reilly (1990) for soccer players (See Table 4.1.7). While the average values for percent adiposity of elite level soccer players tend to be relatively low, they are nevertheless higher than those found in elite endurance athletes where mean levels of 4-7% are reported (Reilly, 1990). In previous research, higher values of percent adiposity have been reported for goalkeepers than outfield players (Raven et al., 1976). According to Reilly (1990), these higher values probably reflect the lighter metabolic loading imposed by match-play and training of goalkeepers. However, in the present study the adiposity of goalkeepers was equivalent to outfield players. This probably reflects the systematic preparation of contemporary goalkeepers and the increased work-rate of goalkeepers during games following the introduction of the back pass rule in 1991. That is, contemporary goalkeepers at an elite level have specialist training regimens and adopt more prominent roles during match-play.

The values of percent adiposity reported in the present study are considerably lower than values observed by White et al. (1988) for English 1st Division players, and higher than values observed by Mathur et al. (1985) for Nigerian players (Table 4.1.7). Within the athletic population, there is a variation among races and groups with regards to physique and body composition (Himes, 1988). Moreover, there are demonstrated genetic effects for many of these characteristics. Slightly greater relative lean body mass, and proportionately less relative adiposity have been reported for African and Caribbean soccer players relative to English counterparts (Mathur et al., 1985; Rico-Sanz et al, 1996).

Clearly, increased recruitment of 'overseas' players will have an effect on reported anthropometric mean data for elite English soccer teams. Perhaps the reduced adiposity reported in the present study compared to the study by

White et al. (1988), reflects the increased recruitment of international players into the Premier League. While a more systematic approach to training will clearly influence these reported mean values, the effect of international recruitment, with a mixture of ethnic backgrounds, must also be considered. A salient characteristic of the current top Premier League teams is the number of imported players within the squads. This trend may indicate the selective recruitment of players that are most difficult to obtain (tall, lean and muscular) which has led to a search beyond the boundaries of the UK population to include almost all countries of the world. Moreover, this factor may have led to increased recruitment from specific regions of the world based on appropriate anthropometric characteristics.

In order to cope with the physical requirements for elite soccer match-play, it is important that players have a high level of muscularity. Soccer players tend to be well developed in muscularity (Reilly, 1990). The overall somatotype for players in the present study was close to the 2.2 ± 0.7 – 5.4 ± 1.0 – 2.2 ± 0.6 observed for elite South American International players and the 2.4 ± 0.5 - 5.0 ± 0.8 - 2.4 ± 0.7 observed for elite 1st Division Spanish players (Rienzi et al., 2000; Casajus 2001). Furthermore, the contemporary players in the present study have a higher mesomorph rating than compared with their earlier counterparts (White et al., 1988). Such ratings demonstrate an increasing trend toward muscularity in the modern game.

The relatively higher ectomorphy rating of the central defenders in the present study is a reflection of their relative linearity and less bulk per unit height than other players. Taller individuals with longer limbs have an advantage in contesting high balls, particularly in critical areas of the field of play. These players may also be selected for these positions on the basis that they conform to the ideal physique as proposed by coaches. Nevertheless, they represent conformity to the demands of the position.

An estimation of muscle mass can be obtained by using the equation of Martin et al. (1990). Muscle mass percentage in the present study is similar to the 63% observed for elite South American players (Rienzi et al., 2000). Such figures again reflect the muscular make up amongst soccer players and are larger than the 51.2 ± 9.6% reported by Hasan (1998), for elite male handball players and the 58.4 ± 5.2% observed for undergraduate students who regularly participated in sport (Coldwells et al., 1993). A significant positive relationship between muscle mass and total distance covered during soccer match-play has been observed (Rienzi et al., 2000). This relation implies that individuals with a higher muscle mass can maintain a higher overall work-rate throughout competitive match-play, and their endurance is not necessarily compromised by the possession of a muscular trend in physique. According to Rienzi et al. (2000), a large muscle mass, with low adiposity helps to avoid having to lift excess weight (adiposity) repeatedly against gravity during movement. Lower adiposity also results in a reduction in the energy required to move individual body mass around the playing area thereby decreasing the physiological strain associated with exercise.

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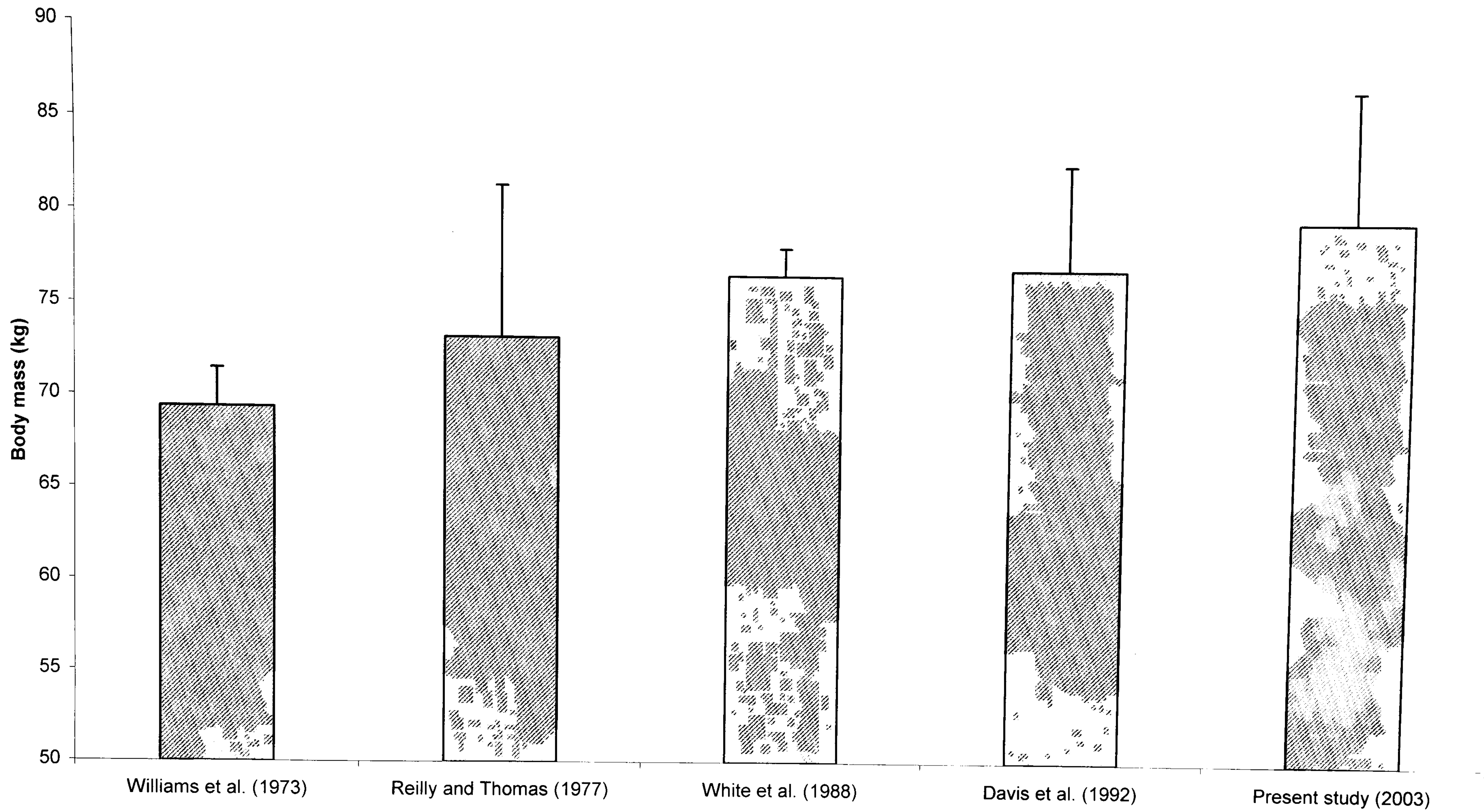


Figure 4.1.2 Mean (± S.D.) body mass of soccer teams in a sample of reports in the literature.

Table 4.1.5. Stature (m) of elite players according to positional roles (mean ± S.D).

Source	Players	Combined Mean (mean ± S.D)	Goalkeepers (mean ± S.D)	Central defenders (mean ± S.D)	Full-backs (mean ± S.D)	Midfield players (mean ± S.D)	Forwards (mean ± S.D)
Present study	English Premier	1.82 ± 0.07 (n=33)	1.91 ± 0.05 (n=5)	1.89 ± 0.04 (n=7)	1.77 ± 0.03 (n=6)	1.78 ± 0.02 (n=7)	1.80 ± 0.05 (n=7)
Al-Hazzaa et al. (2001)	Saudi National	1.77± 0.05 (n=23)		1.82± 0.06	1.74 ± 0.06	1.77± 0.05	1.77 ± 0.05
Bangsbo (1994b)	Danish 1st Division	1.81 ± 0.06 (n=65)	1.90 ± 0.06 (n=5)	1.89 ± 0.04 (n=13)	1.79 ± 0.06 (n=12)	1.77 ± 0.06 (n=21)	1.78 ± 0.07 (n=14)
Puga et al. (1993)	Portuguese 1st Division	(n=21)	1.86 (n=2)	1.85 (n=3)	1.75 (n=2)	1.76 (n=8)	1.74 (n=6)
Raven et al. (1976)	USA 1st Division	1.76 ± 0.1 (n=18)	1.78 ± 0.02 (n=2)		1.76 ± 0.01 (n=9)	1.75 ± 0.02 (n=2)	1.76 ± 0.02 (n=5)

Table 4.1.6. Body mass (kg) of elite players according to positional roles (mean ± S.D).

Source	Players	Combined Mean (mean ± S.D)	Goalkeepers (mean ± S.D)	Central defenders (mean ± S.D)	Full-backs (mean ± S.D)	Midfield players (mean ± S.D)	Forwards (mean ± S.D)
Present study	English Premier	79.7 ± 7.0 (n=32)	85.3 ± 6.3 (n=5)	82.4 ± 3.9 (n=7)	76.2 ± 4.1 (n=6)	76.6 ± 5.6 (n=7)	78.3 ± 8.1 (n=7)
Al-Hazzaa et al. (2001)	Saudi National	73.1 ± 6.8 (n=23)		82.1 ± 6.9	72.4 ± 4.1	68.2 ± 4.4	72.7 ± 5.9
Bangsbo (1994b)	Danish 1st Division	77.1 (n=65)	87.8 ± 8.0 (n=5)	87.5 ± 2.5 (n=13)	72.1 ± 10.0 (n=12)	74.0 ± 8.0 (n=21)	73.9 ± 3.1 (n=14)
Puga et al. (1993)	Portuguese 1st Division	(n=21)	84.4 (n=2)	75.9 (n=3)	67.5 (n=2)	74.0 (n=8)	71.1 (n=6)
Davis et al. (1992)	English 1st /2nd Division	77.1 ± 5.6 (n=122)	86.1 ± 5.5 (n=13)	83.3 ± 6.3 (n=24)	75.4 ± 4.6 (n=22)	73.2 ± 4.8 (n=35)	76.4 ± 7.2 (n=41)
Raven et al. (1976)	USA 1st Division	75.7 ± 1.9 (n=18)	86.4 ± 4.5 (n=2)		73.6 ± 1.8 (n=9)	77.3 ± 3.6 (n=2)	74.5 ± 5.5 (n=5)

Table 4.1.7. Somatotype and body composition of elite soccer teams (mean ± S.D).

Source	Players	Somatotype	Percentage Muscle Mass (%)	Percentage Adiposity (%)
Present study	English Premier (n=32)	2.4-5.0-2.4 ±0.5±1.0±0.8	61.0 ± 1.5	11.0 ± 1.8
Rienzi et al. (2000)	S. American International (n=11)	2.2-5.4-2.2 ± 0.7±1.0±0.6	63.0 ± 4.0	11.6 ± 3.3
Casajus (2001)	Spanish 1st Division (n=15)	2.4-4.9-2.3 ±0.5±0.8±0.7	71.9 ± 6.0	8.6 ± 0.9
White et al. (1988)	English 1st Division (n=17)	2.6-4.2-2.7 ±0.2±0.2±0.2		19.3 ± 0.6
Mathur et al. (1985)	Nigerian International (n=25)	2.2-5.4-2.9 ±0.8±1.5±0.9		9.3 ± 1.5
Al-Hazzaa et al. (2001)	Saudi National (n=23)		64.6 ± 4.7	12.3 ± 2.7
Apor (1988)	Hungarian 1st Division (n=10)	2.1-5.1-2.3		

In conclusion, the Premier League soccer players in the current study constitute a relatively heterogeneous group in terms of anthropometric characteristics. The unique demands on players occupying the various positional roles was reflected in the anthropometric measurements. Moreover, anthropometric characteristics allow players to meet the demands imposed upon them by their position. The fact that individuals with a range of physiques and physical characteristics are able to play in the same team makes soccer unique when compared to other sports where homogeneity of physique is common. Each position demands specific tasks during specific phases of the game and players have to meet these requirements with a demonstration of appropriate anthropometric characteristics. A Darwinian selection process directs soccer at an elite level of performance, where each position demands its own set of physical attributes. Only the 'fittest' in terms of anthropometry reach the highest level.

Therefore the following hypothesis was rejected:

A. H_O: At an elite level of play, anthropometric characteristics do not vary according to different playing positions.

4.2 FITNESS PROFILE OF ELITE MALE SOCCER PLAYERS

4.2.1 Introduction

Within the past few decades there has been an increasing emphasis on work-rate during competitive play with a requirement for mobility around the field. Contemporary matches include more passes, runs with the ball, dribbles and crosses which suggest a significant increase in the 'tempo' of games (Williams et al., 1999). In order to cope with these demands, players must react quickly to changes in movement patterns. Speed of movement and the ability to reproduce intermittent bouts of high-intensity are essential characteristics for successful performance in contemporary professional soccer.

Enhanced aerobic endurance in soccer players improves soccer performance by increasing the distance covered, enhancing work intensity, and increasing the number of sprints and involvements with the ball during a match (Helgerud et al., 2001). The average values of $\dot{V}O_{2max}$ for elite level soccer players tend to be high, supporting the notion that there is a large contribution from aerobic power to playing the game (Reilly, 1990). Reilly et al. (2000) suggested that the consistent observations of $\dot{V}O_{2max}$ values above 60 $ml.kg^{-1}\ min^{-1}$ in elite teams implied a threshold below which an individual player is unlikely to possess the physiological requirements for success in elite contemporary soccer. It may be that this reference value needs to be adjusted upwards as training programmes at elite level are optimised.

In the previous section, the unique demands on players occupying the various positional roles were reflected in the anthropometric measurements. The aim of this section is to determine whether the stresses associated with playing soccer at the highest level are reflected in the fitness profiles of players according to their position within a team. The use of anaerobic and aerobic fitness assessments permits the identification of physical characteristics of soccer players that in turn yield important information concerning the physiological demands for elite match-play. Such data may also facilitate better understanding of the specific requirements of positional roles.

4.2.1.1 Statement of hypothesis

B. H_O: At an elite level of play, fitness characteristics do not vary according to different playing positions.

4.2.2 Methods

4.2.2.1 Subjects

Subjects were 40 (4 goalkeepers, 7 central defenders, 8 full-backs, 11 midfield players and 10 forwards) full-time professional male soccer players of a Premier league squad (age 25 ± 4 years). For the purpose of the study, only subjects who had represented the 1st team in the Premier League, or the reserves in the Premier Reserves League were included.

4.2.2.2 Procedures

Fitness profiles were obtained on subjects at the end of a period of intensive pre-season training (August). All subjects conducted testing at the same time of the day and in the same order of tests. The testing took place over a period of three days. Due to logistic factors, not all subjects conducted each specific element of the test battery. All procedures were approved by the Human Ethics Committee of Liverpool John Moores University. Subjects were fully informed about the aims, procedures and the demands that the tests would place upon them, together with any possible risks and discomforts before written consent was obtained. All of the tests undertaken were familiar to the subjects as part of their ongoing fitness assessment. The test battery included a number a field tests designed to measure anaerobic and aerobic performance (see Table 4.2.1).

The methods used to determine anthropometric variables are described in section 4.1.2.2. Maximal oxygen uptake was estimated by means of the progressive 20 m multistage shuttle test (20 MST) (Ramsbottom et al., 1988), modified from the original protocol (Leger and Lambert, 1982). All subjects had previous experience performing the 20 MST. A 10-min warm up period consisting of running and stretching, ad libitum, was allowed prior to the start of the test. During this time the subjects were reminded that the test was maximal and progressive and that they should continue to run at the required pace for as long as possible. All testing took place in a gymnasium environment.

Table 4.2.1. Battery of field tests employed to determine fitness variables

Test	Function	Source
Progressive 20 m multistage shuttle test	To determine estimated maximal oxygen uptake	Ramsbottom et al. (1998)
Anaerobic interval running test	To determine anaerobic capacity	Semenick (1994)
High-intensity aerobic interval running test	To determine aerobic capacity	
30 m sprint test	To determine sprint speed and acceleration	Kollath and Quade (1993)
Jump test	To determine leg power	Casajus (2001)
Rotational agility test	To determine agility	Buttifant et al. (2002)
Bench press test	To determine upper body strength	Wisloff et al. (2002)
Yo-Yo intermittent recovery test	To determine intermittent recovery performance	Krustrup et al. (2003b)
Intermittent sprint test	To determine intermittent sprint capacity	Reilly (2001)
Bangsbo sprint test	To determine intermittent sprint capacity	Bangsbo (1994c)

During the 20 MST, subjects were required to complete the 20-m shuttles at a progressively increasing intensity. Only ten subjects were recorded at any one time. The test began at a shuttle speed of 2.22 $m.s^{-1}$ and then shuttle speeds increased by approximately 0.14 $m.s^{-1}$ every minute. The subjects followed the 20 MST protocol by touching the appropriate 20 m line with a foot in tandem to an auditory signal. Subjects ran until they were unable to maintain the required pace and withdrew themselves, or were withdrawn by the investigator. The level attained and the number of shuttles reached when the subjects retired was recorded and maximal oxygen uptake was estimated using a table of predicted values (Ramsbottom et al., 1988). Each subject's heart rate was monitored during the test via short-range radio telemetry (SportTester™, PE3000, Polar Electro Fitness Technology) sampled at 5-s intervals.

Anaerobic capacity was measured by means of an Anaerobic Interval Running Test (A_nIRT). The A_nIRT is a modified version of the line drill, which is a field test common in 'multiple sprint' sports (Semenick, 1994). The line drill is a highly intense bout of exercise that has been suggested to be an acceptable field measure for anaerobic capacity in multiple-sprint athletes (Hoffman et al., 2000). It consists of a continuous 143.4-m sprint with several changes of direction. Originally designed as a basketball conditioning practice, the line drill is performed on a regulation size basketball court. Subjects begin from a standing position at the baseline and run at maximal speed to four separate cones placed at the near free-throw line (5.8 m), half-court line (14.3 m), far free-throw line (22.9 m) and far baseline (28.7 m). As the subject arrives at each cone, he sprints back to the original baseline and proceed as quickly as possible to the next line. The line drill is performed three times with a 2-min passive recovery between each sprint.

The A_nIRT consisted of a continuous 400-m sprint with several changes of direction. A-10 min warm-up period consisting of running and stretching, ad libitum, was allowed prior to the start of the test. During this time the subjects were reminded that the test was maximal and that a pacing strategy was not appropriate. Subjects began from a standing position at the start line and ran at maximal speed to four separate cones placed at 20 m, 40 m, 60 m and 80 m (see Figure 4.2.1). As the subject arrived at each cone, they sprinted back to the original start line and proceeded as quickly as possible to the next line. The line drill was performed three times with a 2-min passive recovery between each sprint. Digital stopwatches (Accusplit, San Jose, CA) were used to record split times for each subject. Each subject's heart rate was monitored during the test via short-range radio telemetry (SportTester^{TM}, PE3000, Polar Electro Fitness Technology) sampled at 5-s intervals.

Fatigue index was calculated by expressing the slowest over the fastest time, converting to a percentage and subtracting 100 (Reilly, 2001). Therefore, if the fastest time was 96 s and the slowest time was 102 s, fatigue index was calculated as follows:

Fatigue Index **= (102/96) x 100 = 106.25** **(1)**

= 106.25 – 100 = 6.25%

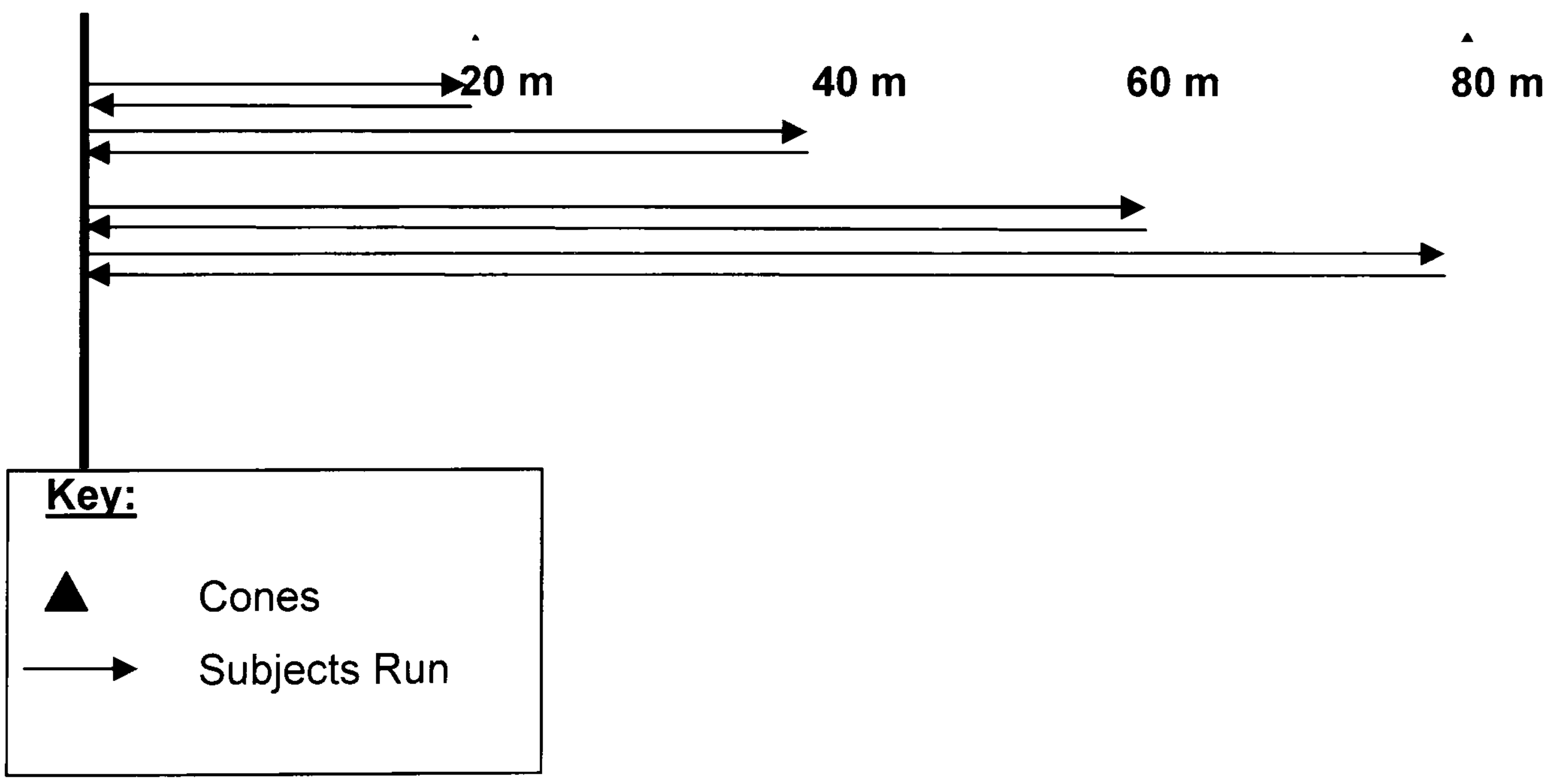


Figure 4.2.1. Diagrammatic representation of the Anaerobic Interval Running Test (A_nIRT).

Aerobic capacity was measured by means of a High-intensity Aerobic Interval Running Test (H_IAIRT). The H_IAIRT consisted of a repeated series of runs over a distance of 1200 m and 800 m with a 2-min passive recovery between each bout of exercise. A 10-min warm-up period consisting of running and stretching, ad libitum, was allowed prior to the start of the test. During this time the subjects were reminded that the test was maximal and that a pacing strategy was not appropriate. The H_IAIRT was conducted on an outdoor 400-m running track. Subjects ran 1200 m as quickly as possible. Following a 2-min period of passive recovery, the subjects then proceeded to run 800 m as quickly as possible. This protocol was performed three times with a 2-min passive recovery between each bout of 1200-m and 800-m exercise. Digital stopwatches (Accusplit, San Jose, CA) were used to record split times for each subject. Each subject's heart rate was monitored during the test via short-range radio telemetry (SportTester™, PE3000, Polar Electro Fitness Technology) sampled at 5-s intervals. A fatigue index was calculated using equation (1) described above.

Sprint speed was measured by means of a 30-m sprint test. A 10-min warm-up period consisting of running and stretching, ad libitum, was allowed prior to the start of the test. During this time the subjects were reminded that the test was a maximal effort. Electronic photocells (Newtest, Norway) mounted on tripods were set approximately 0.75 m above the floor and were positioned 3 m apart facing each other at the start line, 5 m, 10 m and 30 m (see Figure 4.2.2). The subjects decided themselves when to start the sprint test from a static position 1 m behind the start line. The time was recorded when the subjects intercepted the electronic photocell at the start line and terminated when the subjects crossed the photocell at 30 m. Each subject had three trials separated by a 5-min rest. Trials were recorded to the nearest one-hundredth of a second. The fastest trial for each subject was used for statistical analysis.

Three jump tests consisting of a counter-movement jump without utilising arms (CMJ), counter-movement jump utilising arms (CMJ_A) and a squat jump (SJ) were used to measure leg power. All jumps were performed on rubber coated contact platform (Newtest, Norway). The subjects stood on a contact platform (124 cm x 90 cm) connected by a cable to a digital timer (± 0.0001 s) that recorded the flight time of all jumps. The timer was triggered by the feet of the subject at the moment of release from the platform and was terminated at the moment of touch down. This principle suggests that flight time up equals flight time down during the jump. This method of calculation also assumes that the positions of the jumper on the platform were the same in takeoff and landing. To prevent possible differences in positions, on the landing, the subjects were instructed to perform five skips on the platform to make them land in the same position as for takeoff (Berthoin et al., 2001). Furthermore, subjects were instructed to take off and land within a marked area on the mat (see Figure 4.2.3). For the SJ test, subjects were required to bend the knee to about 90° and to maintain the posture at least 1 s prior to jumping. For the CMJ and the CMJ$_A$ tests, the subjects performed a fast counter-movement. They were also required to bend the knee to about 90° prior to jumping. Throughout the SJ and CMJ tests, the subjects' hands had to be kept on the hips. For the CMJ$_A$ test, the subjects were allowed to swing their arms freely.

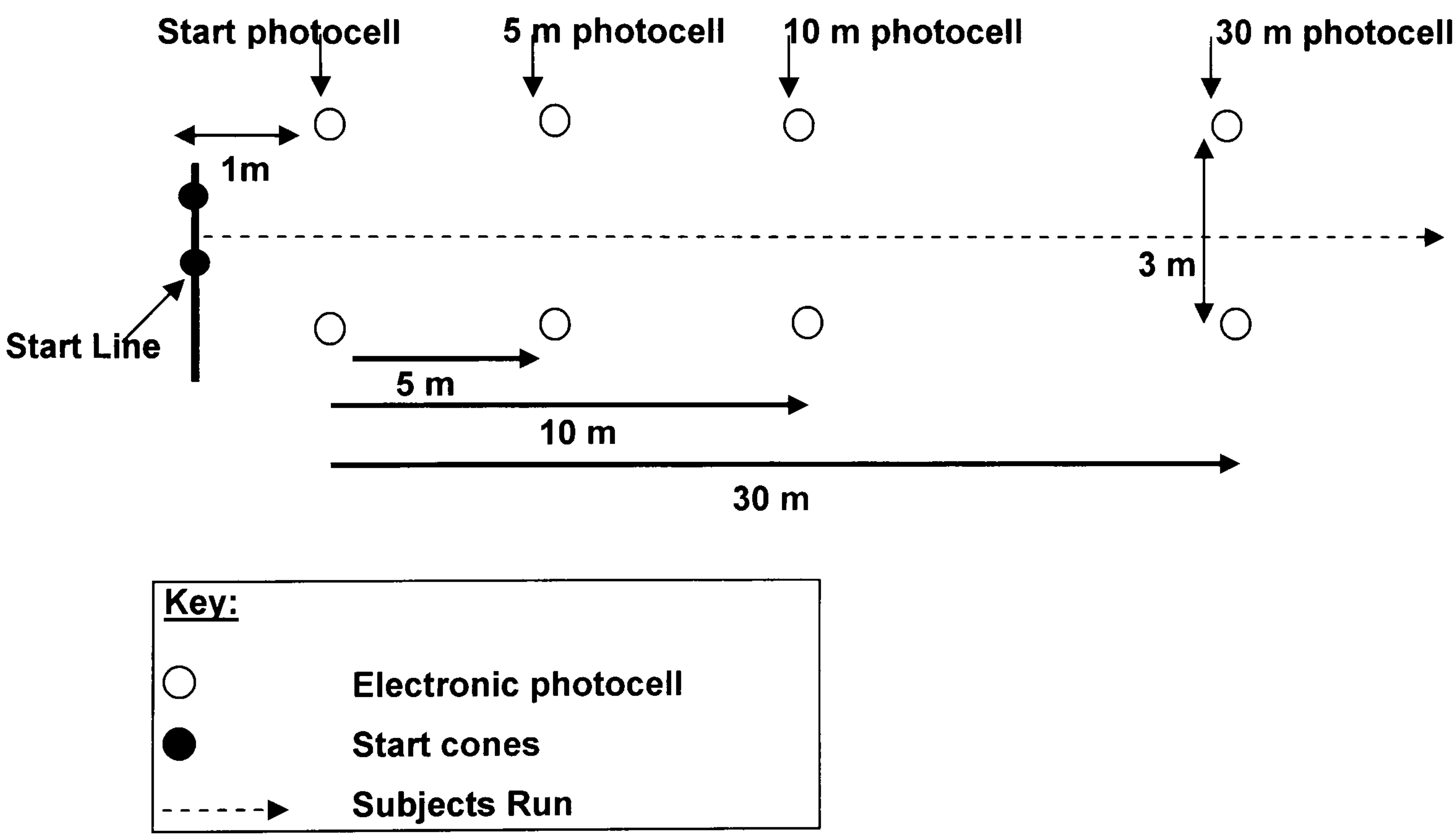


Figure 4.2.2. Diagrammatic representation of the 30-m sprint test.

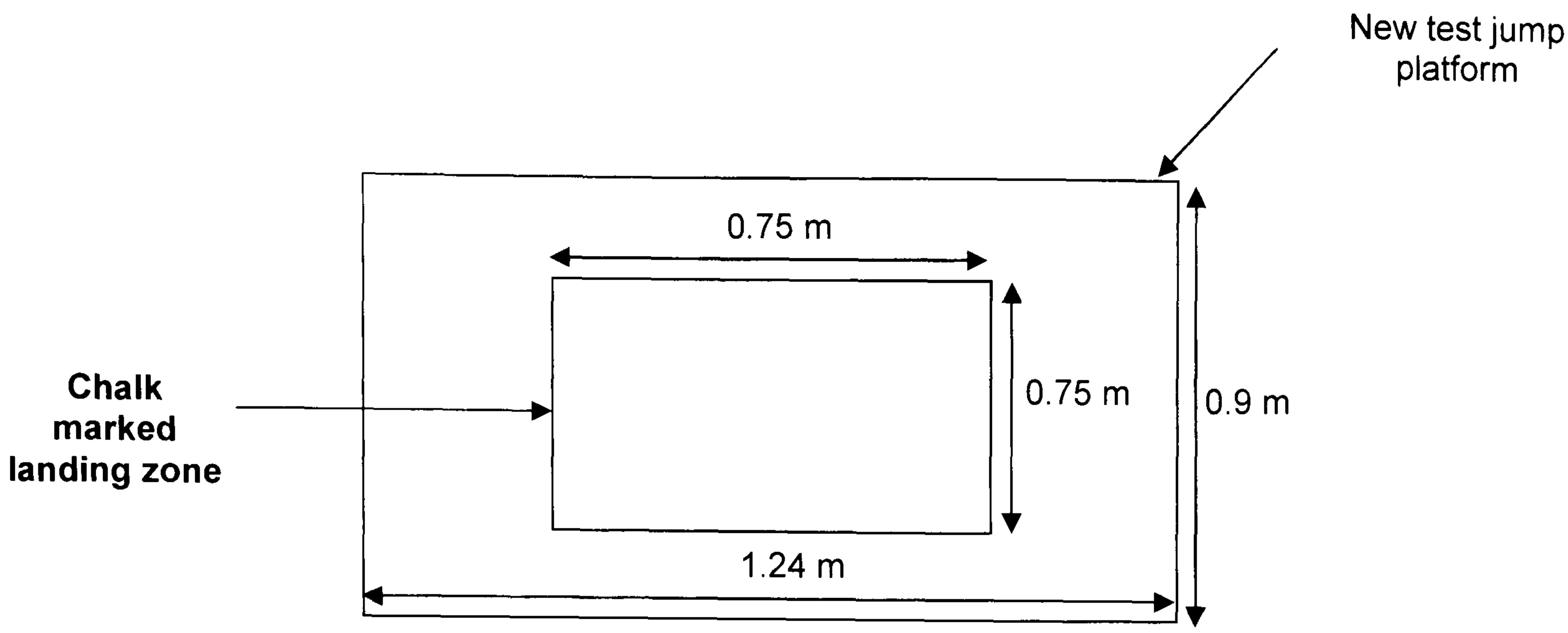
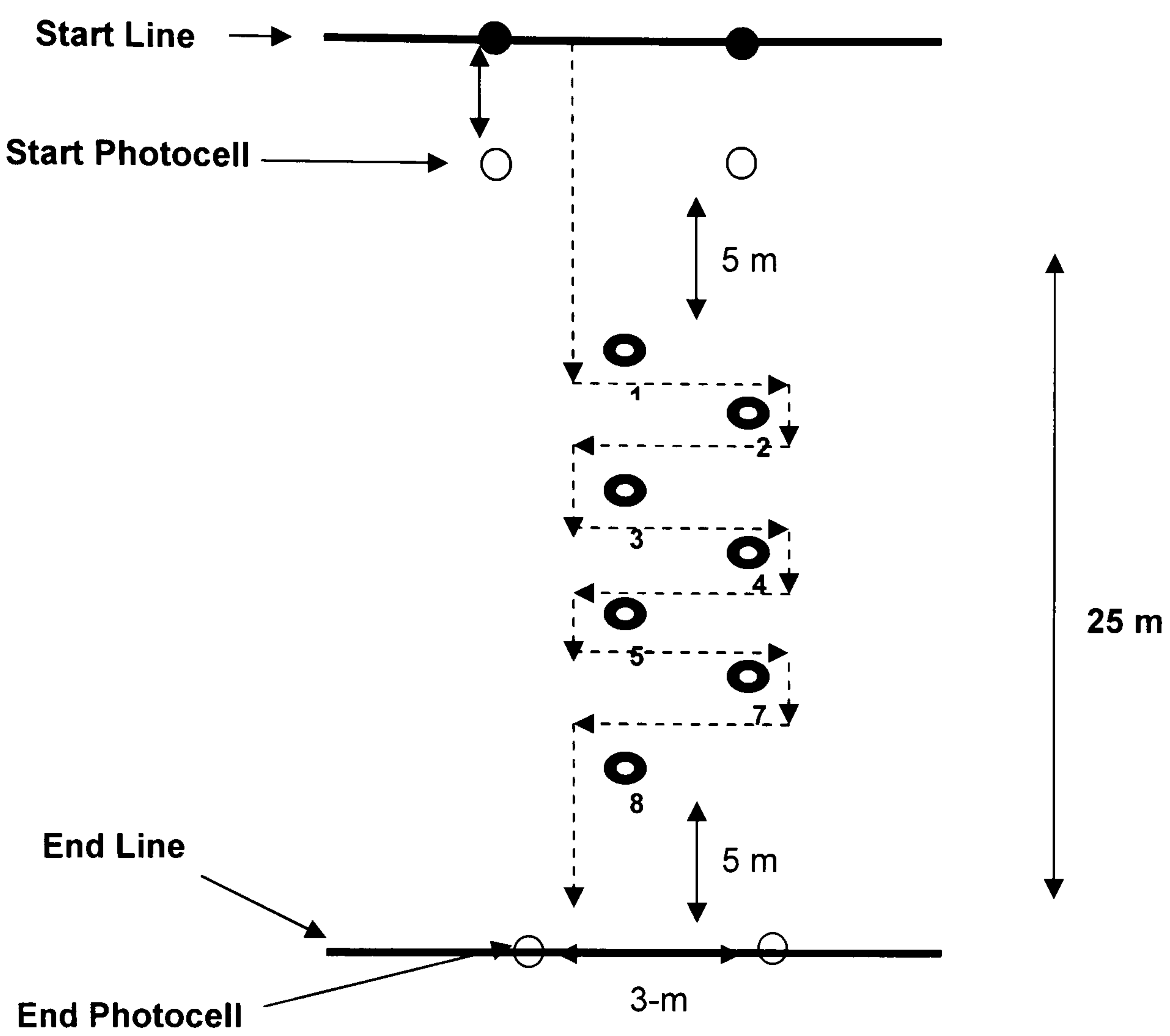


Figure 4.2.3. Diagrammatic representation of the contact platform.

Agility was measured by means of a Rotational Agility Test (R_{AT}). The R_{AT} is a measure of agility and body control that evaluates the ability to change direction rapidly while maintaining balance without losing speed. This test is a modified version of that adopted by Buttifant et al. (2002).

A 10-min warm-up period consisting of running and stretching, ad libitum, was allowed prior to the start of the test. During this time the subjects were reminded that the test was a maximal effort. Electronic photocells (Newtest, Norway) mounted on tripods were set approximately 0.75 m above the floor and were positioned 3 m apart facing each other at the start line and end line (see Figure 4.2.4). The subjects decided themselves when to start the sprint test from a static position 1 m behind the start line. At their own discretion, subjects sprinted to the 1st cone and then proceeded to weave through the course in a sequential manner (cones 1,2,3,4,5,6,7) without touching any of the cones. The test was repeated if the subjects failed to follow the appropriate course or touched any of the cones. Time was recorded when the subject intercepted the electronic photocell at the start line and terminated when the subject crossed the end photocell. Each subject had three trials separated by a 5-min rest. Trials were recorded to the nearest one-hundredth of a second. The fastest trial for each subject was used for statistical analyses.



Vertical Cone distances from Start Photocell	Horizontal cone distances
Cone 1= 5 m	Cone 1-2= 5 m
Cone 2= 7.5 m	Cone 2-3= 5 m
Cone 3= 10 m	Cone 3-4= 5 m
Cone 4= 12.5 m	Cone 4-5= 5 m
Cone 5= 15 m	Cone 5-6= 5 m
Cone 6= 17.5 m	Cone 6-7= 5 m
Cone 7= 20 m	

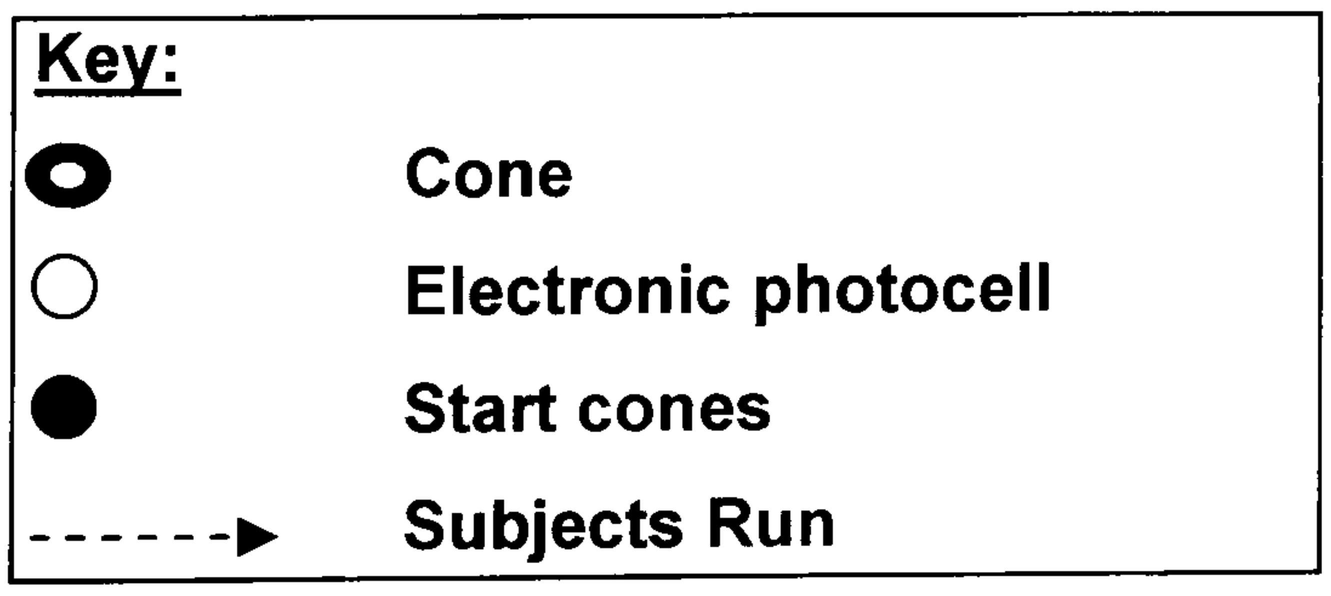


Figure 4.2.4. Diagrammatic representation of the Rotational Agility test.

Upper body strength was measured by means of a 'one repetition maximum' (1-RM) bench press performed with a competition standard Olympic style bar and plates (Eleiko, Sweden). A 10-min warm-up period consisting of specific bench-press activity was allowed prior to the start of the test. This activity consisted of performing the bench press with light resistance (40 kg). During the bench press, subjects lay with the back flat on a bench and their feet in full contact with the floor throughout the lift. Subjects grasped the bar with a thumb-lock grip at a position slightly greater than shoulder width. Trained spotters assisted the subjects in lifting the bar from the support rack. The subjects then lowered the bar to their chest in a controlled fashion and returned the bar to full arm extension. The test was repeated if the subjects bounced the bar on the chest or lifted the hips off the bench. The 1-RM value was taken as the maximum resistance the subjects could lift with a single attempt. Allometric equations were used to determine the relationship between maximal strength and body mass. Dimensional scaling suggests that comparisons between a small and a larger individual should be expressed by kg body weight raised to the power of 0.67 (Wisloff et al., 1998). This correction is based on the principle of 'geometric similarity' (all human bodies have the same shape, so they only differ in size) where muscle force is proportional either to body height squared (H^2) or to body mass to power two-thirds ($m^{2/3}$). Since muscular strength is proportional to muscle cross-sectional area, and body mass (m_b) varies directly with body volume, whole-body muscular strength measures will vary in proportion to $m_b^{0.67}$. In the present study, maximal strength is reported in absolute values (kg) and kg body mass raised to the power of 0.67 as kg $\cdot$ $m_b^{-0.67}$. The following equation was used to determine the relationship between maximal strength and body mass:

Maximal strength $= a \times m_b{}^{b}$ **(2)**

Where:

a = mass coefficient

m_b = body mass in kilograms

^{b} = reduced exponent 0.67

Intermittent recovery performance was measured by means of a 'Yo-Yo intermittent recovery test' (Bangsbo, 1993b). The aim of the Yo-Yo intermittent recovery test is to examine a subject's ability to recover from intense exercise. The test consists of 20 m bouts of running interspersed by regular short rest periods (5 s). All subjects had previous experience performing the Yo-Yo intermittent recovery test. A 10-min warm up period consisting of running and stretching, ad libitum, was allowed prior to the start of the test. During this time the subjects were reminded that the test was maximal and progressive and that they should continue to run at the required pace for as long as possible. During this test, all testing took place in a gymnasium environment.

During the Yo-Yo intermittent recovery test, subjects were required to complete 20 m shuttles at a progressively increasing intensity. The subjects followed the Yo-Yo intermittent recovery test protocol by running forward 20 m at the time of a first auditory signal. Running speed of the subjects was adjusted so that they reached a 20-m line exactly at the time of the next auditory signal. A turn was made at the 20-m line and the subjects ran back to the start line, which had to be reached in synchrony with an auditory signal. When the start line was reached the subjects continued forward at a lower tempo towards a marker positioned 2.5 m behind and slightly to the side of the start line (see Figure 4.2.5). The subjects proceeded around the marker and back to the start line. The time for this recovery period was exactly 5 s. The course was then repeated at a progressively increasing intensity. Subjects ran until they were unable to maintain the required pace and withdrew themselves, or were withdrawn by the investigator. The level attained and the distance reached when the subjects retired was recorded for statistical analyses. Each subject's heart rate was monitored during the test via short-range radio telemetry (SportTester™, PE3000, Polar Electro Fitness Technology) sampled at 5-s intervals.

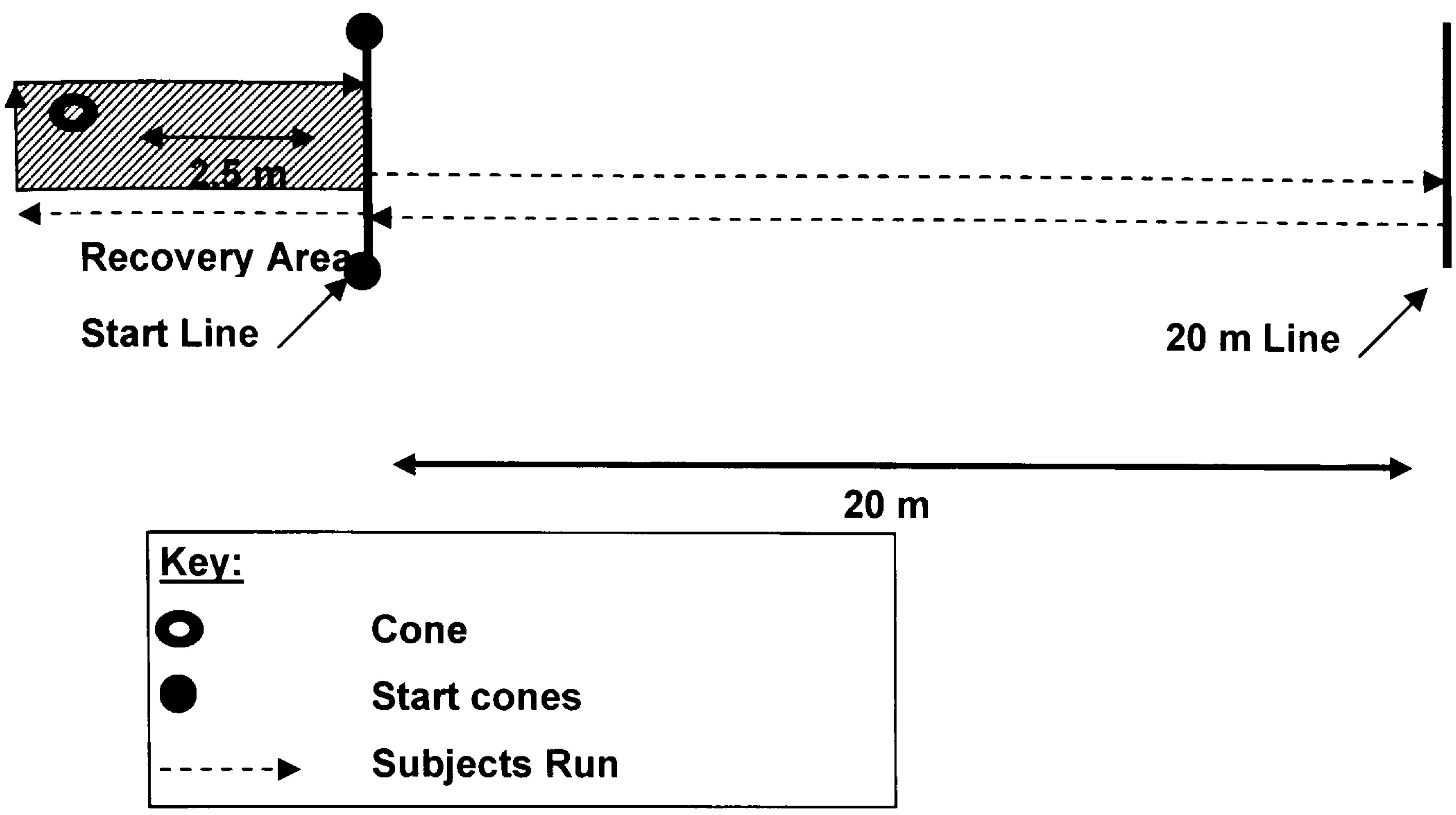


Figure 4.2.5. Diagrammatic representation of the Yo-Yo Intermittent Recovery Test.

Intermittent sprint capacity was measured by means of an Intermittent Sprint Test (IST) (Reilly, 2001) and a 'Bangsbo Sprint Test' (BST) (Bangsbo, 1994c). The aim of the IST and the BST is to examine a subject's capability to reproduce high-intensity sprints following a short recovery period. The IST consists of 7 x 30 m repetitions of sprint running interspersed by regular short rest intervals (15 s). All subjects had previous experience performing the IST. A 10-min warm-up period consisting of running and stretching, ad libitum, was allowed prior to the start of the test. During this time the subjects were reminded that the test was maximal and that a pacing strategy was not appropriate. All testing took place in an outdoor field setting. Electronic photocells (Newtest, Norway) mounted on tripods were set approximately 0.75 m above the floor and were positioned 3 m apart facing each other at the start line, 10 m and 30 m (see Figure 4.2.6). At their own discretion, subjects sprinted 30 m to the end line. When the end line was reached the subjects continued forward at a lower tempo into a 10-m deceleration zone. The subjects then proceeded around a marker (10 m from the 30-m line) and back to the start line to perform the next sprint. A recovery time of 15 s was permitted between sprints. The course was then repeated until seven sprints were completed. Times were recorded when the subjects intercepted the electronic photocell at the start line and terminated when the subjects crossed the end line. Times for 10 m and 30 m were recorded for statistical analyses. Each subject's heart rate was monitored during the test via short-range radio telemetry (SportTester™, PE3000, Polar Electro Fitness Technology) sampled at 5-s intervals. A fatigue index was calculated using equation (1) described above.

The BST test consists of 7 x 34.2 m intervals of sprint running interspersed by regular short rest periods (25 s). All subjects had previous experience of performing the BST. A 10 min warm-up period consisting of running and stretching, ad libitum, was allowed prior to the start of the test. During this time the subjects were reminded that the test was maximal and that a pacing strategy was not appropriate. All testing took place in an outdoor field setting. Electronic photocells (Newtest, Norway) mounted on tripods were set approximately 0.75 m above the floor and were positioned 3 m apart facing each other at the start line and 30 m (see Figure 4.2.7). At their own discretion, subjects sprinted 34.2 m to the end line. This sprint involved straight-line running with a change in direction. When the end line was reached the subjects continued forward at a lower tempo into a 10-m deceleration zone. The subjects then proceeded around a marker (10 m from the end line) and back to the start line to perform the next sprint. A recovery time of 25 s was permitted between sprints. The course was then repeated until seven sprints were recorded. The times were recorded when the subjects intercepted the electronic photocell at the start line and terminated when the subjects crossed the end line. Times for 34.2 m were recorded for statistical analyses. The mean time was calculated as the average of the seven sprint times. The fatigue time was recorded as the difference between the slowest and fastest time. Each subject's heart rate was monitored during the test via short-range radio telemetry (SportTester™, PE3000, Polar Electro Fitness Technology) sampled at 5-s intervals.

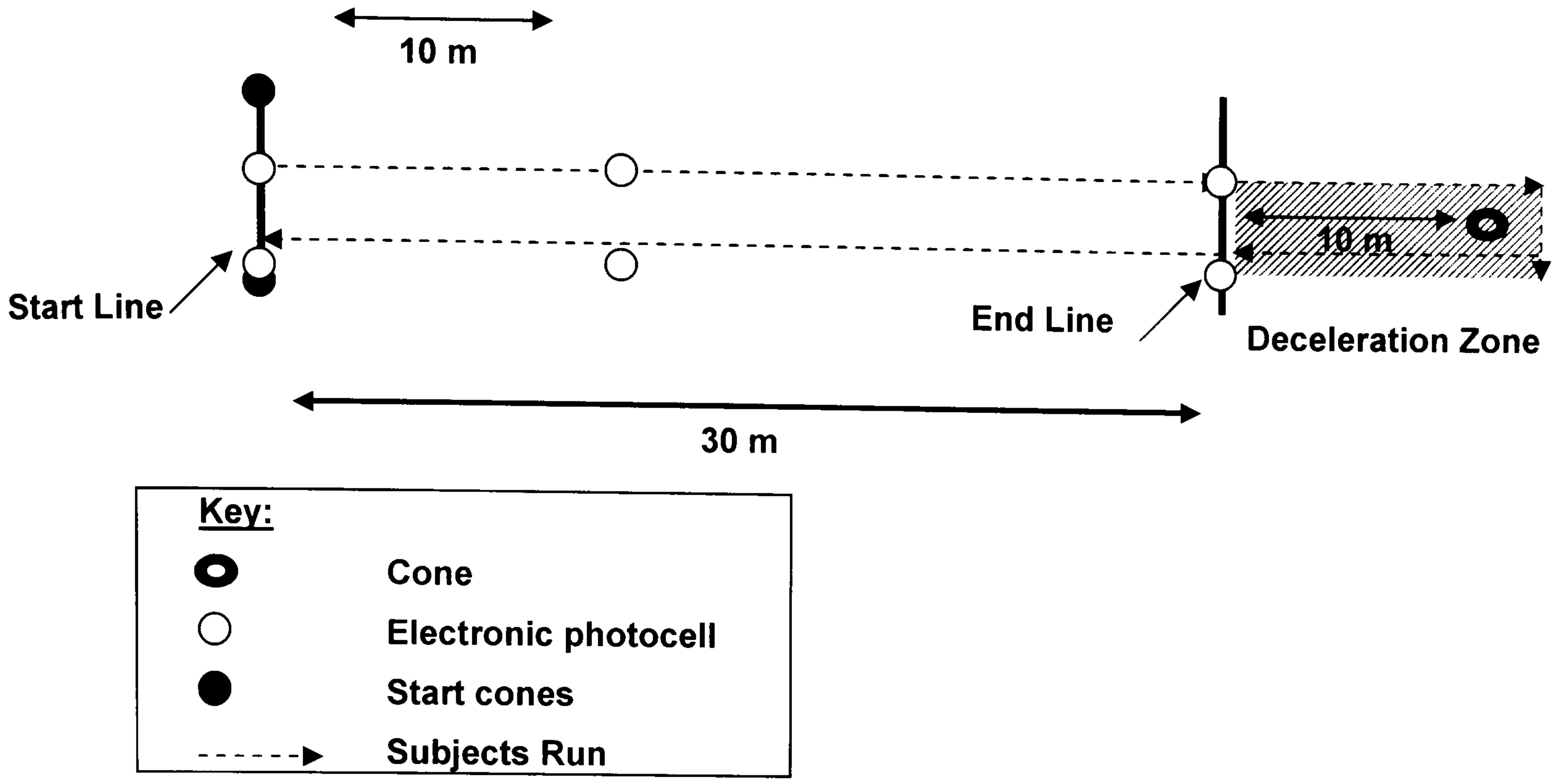


Figure 4.2.6 Diagrammatic representation of the Intermittent Sprint Test.

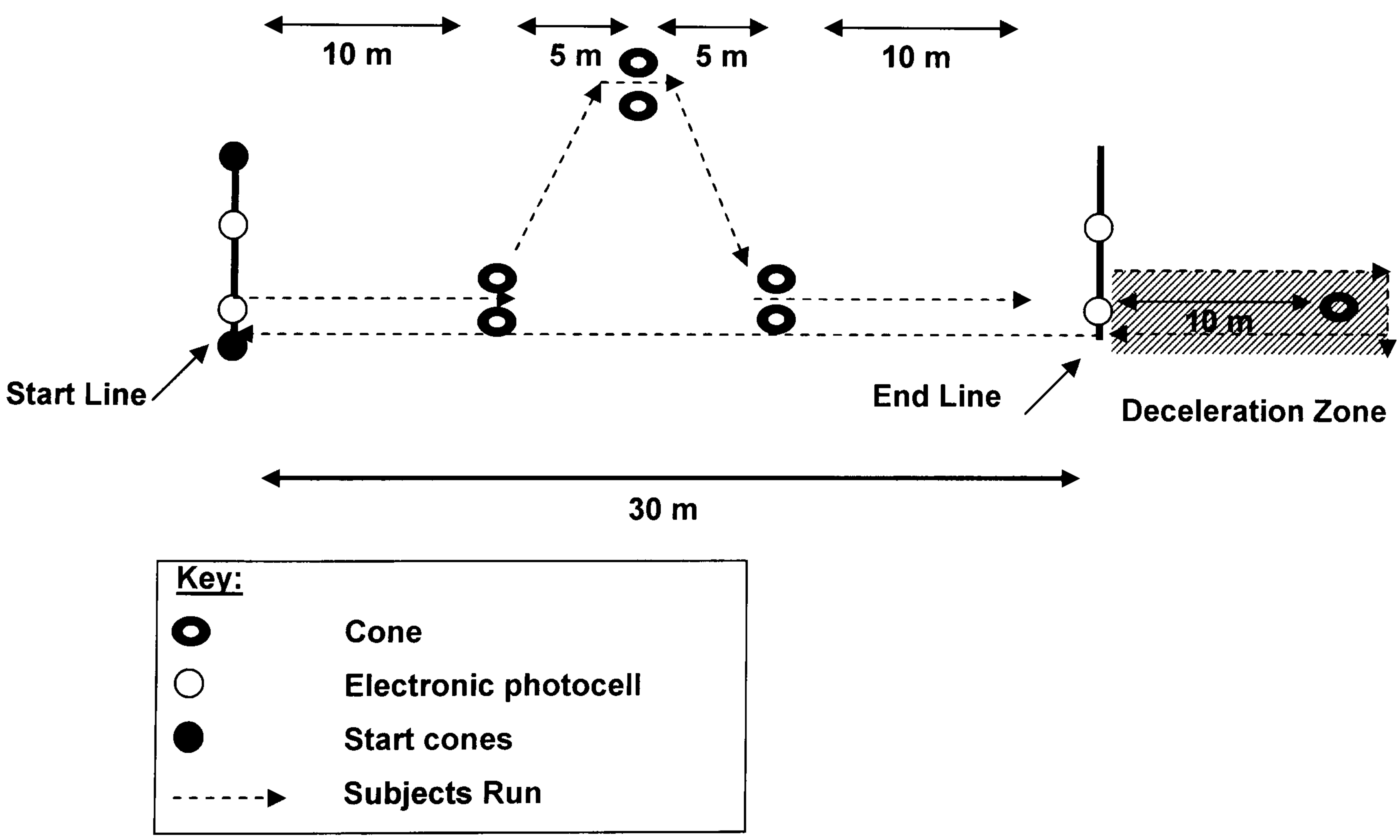


Figure 4.2.7. Diagrammatic representation of 'Bangsbo's Sprint Test'.

4.2.2.3 Statistical analyses

The statistical analyses of data were carried out using one-way analyses of variance (ANOVA). Post-hoc Tukey tests were used to identify where any differences that were found lay. The level of significance was accepted at $P<0.05$.

4.2.3 Results

The anthropometric characteristics of the subjects are presented in Table 4.2.2. The results of analyses of variance demonstrated significant differences in stature between the positions ($F_{4,35}$ = 14.337; P<0.001). Goalkeepers and central defenders were significantly taller in stature than full-backs, midfield players and forwards.

Differences between positions were further highlighted when examining the body mass of the players. Goalkeepers were significantly heavier than full-backs ($F_{4,35}$ = 3.151; P<0.026). Variability in body mass was greater in forwards compared to the other positions. The mean ± S.D body mass for all the positions combined was 79.7 ± 6.6 kg.

No significant differences were observed between the positions for adiposity, percent adiposity, muscle mass or percent muscle mass. The mean ± S.D. somatotype goalkeepers, central defenders, full-backs, midfield players and forwards was 2.5 ± 0.6 – 4.3 ± 0.5 – 3.0 ± 0.5; 2.2 ± 0.6 – 4.5 ± 1.4 – 3.1 ± 0.9; 2.4 ± 0.5 – 5.1 ± 0.5 – 2.0 ± 0.3; 2.6 ± 0.4 – 5.2 ± 0.9 – 2.1 ± 0.7; 2.4 ± 0.4 – 5.7 ± 0.6 – 2.0 ± 0.6 respectively. The somatotype for these players represents a trend towards mesomorphy or muscularity. Central defenders had a significantly higher rating of ectomorphy than full-backs, midfield players and forwards ($F_{4,35}$ = 5.170; P<0.002).

The mean estimated $\dot{V}O_{2max}$ for all players was 59.9 ± 1.6 ml·kg^{-1}·min^{-1} (Table 4.2.3). Estimated $\dot{V}O_{2max}$ of midfield players and full-backs were significantly higher than for goalkeepers ($F_{4,35}$ = 5.195; P<0.002). In addition, estimated $\dot{V}O_{2max}$ values of central defenders were significantly lower than for midfield players (P<0.033). Midfield players had the mean highest estimated maximal oxygen consumption with all players above 60.0 ml·kg^{-1}·min^{-1}.

Table 4.2.2. Anthropometric characteristics of elite male soccer players grouped according to their position in the team (mean ± S.D).

	Age (Years)	Stature (m)	Sitting Stature (m)	Body mass (kg)
	Mean ± S.D (Range)	Mean ± S.D (Range)	Mean ± S.D (Range)	Mean ± S.D (Range)
Goalkeepers	25.0 ± 5.0	1.90 ± 0.06	0.98 ± 0.04	86.6 ± 7.1
(n=4)	(20.0 – 34.0)	(1.82 – 1.97)	(0.94 – 1.03)	(76.0 – 91.0)
Central	26.0 ± 4.0	1.89 ± 0.04	0.97 ± 0.02	83.4 ± 3.9
Defenders (n=7)	(20.0 – 32.0)	(1.83 – 1.94)	(0.94 – 1.0)	(78.2 – 90.0)
Full-backs	25.0 ± 4.0	1.77 ± 0.04 †*	0.94 ± 0.01‡	75.9 ± 3.9‡
(n=8)	(21.0 – 30.0)	(1.73 – 1.82)	(0.91 – 0.95)	(71.0 – 81.1)
Midfield	25.0 ± 4.0	1.78 ± 0.03 †*	0.93 ± 0.02 †*	77.5 ± 5.4
players (n=11)	(20.0 – 33.0)	(1.73 – 1.82)	(0.89 – 0.96)	(70.1 – 86.0)
Forwards	24.0 ± 5.0	1.79 ± 0.05 †*	0.92 ± 0.02†*	79.8 ± 8.3
(n=10)	(17.0 – 31.0)	(1.73 – 1.90)	(0.89 – 0.94)	(67.5 – 88.0)
Mean ± S.D.	25.0 ± 4.0	1.81 ± 0.07	93.4 ± 3.6	79.7 ± 6.5

† P < 0.01 v Goalkeepers
* P < 0.01 v Central Defenders
‡ P < 0.05 v Goalkeepers

Average velocities in the H_IAIRT were slower in goalkeepers than all other positions [$F_{4,20}$ = 12.855; P<0.00 for 1200 m]; [$F_{4,20}$ = 11.130; P<0.00 for 800 m]. Central defenders were on average 0.1 $m.s^{-1}$ and 0.2 $m.s^{-1}$ slower than full-backs, midfield players and forwards for 1200 m and 800 m interval means respectively. Mean velocities for 1200 m and 800 m runs were identical for full-backs, midfield players and forwards (See Table 4.2.4.).

Fatigue Index during the 1200-m was higher in goalkeepers than all other positions (goalkeepers 19.1 ± 4.3; central defenders 8.9 ± 1.6; full-backs 7.8 ± 1.1; midfield players 8.0 ± 3.3; forwards 10.2 ± 2.8. ($F_{4,20}$ = 12.044; P<0.00). Forwards displayed a higher decrement in performance of 1200-m running than other outfield players. Midfield players and full-backs had lower values for Fatigue Index than all other positions demonstrating consistent performance during 1200-m and 800-m interval runs.

Variables related to A_nIRT performance are presented in Table 4.2.5. Fatigue Index was higher in goalkeepers than all other positions ($F_{4,20}$ = 6.826; P<0.001).

Variables related to Sprint and R_{AT} performance are presented in Table 4.2.6. No significant differences were found between the positions for rotational agility. Forwards were significantly faster than midfield players and central defenders over 5 m ($F_{4,33}$ = 3.154; P<0.027). Forwards were also significantly faster than central defenders over 30 m ($F_{4,33}$ = 4.596; P<0.05).

Table 4.2.3. Estimated $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) of elite male soccer players grouped according to their position in the team (mean ± S.D).

	Estimated $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) Mean ± S.D (Range)
Goalkeepers (n=4)	57.8 ± 1.3 (56.0 – 59.3)
Central Defenders (n=7)	59.2 ± 1.7 (57.4 – 62.7)
Full-backs (n=8)	61.1 ± 1.4† (59.8 – 63.7)
Midfield players (n=11)	61.9 ± 2.3‡* (60.2 – 67.5)
Forwards (n=10)	59.9 ± 1.6 (57.4 ± 61.1)
Mean ± S.D.	59.9 ± 1.6

† $P < 0.05$ v Goalkeepers
* $P < 0.05$ v Central Defenders
‡ $P < 0.01$ v Goalkeepers

Table 4.2.4. Performance of elite male soccer players in the High-intensity Aerobic Interval Running test (HIAIRT) grouped according to their position in the team (mean ± S.D)

	Average Velocity ($m.s^{-1}$)		Fatigue Index (%)	
	1200 m Mean ± S.D (Range)	800 m Mean ± S.D (Range)	1200 m Mean ± S.D (Range)	800 m Mean ± S.D (Range)
Goalkeepers (n=4)	4.1 ± 0.4 (3.8 – 4.6)	4.3 ± 0.5 (3.6 – 4.9)	19.1 ± 4.3 (16.4 – 25.5)	6.7 ± 8.2 (2.5 – 19.0)
Central Defenders (n=5)	4.7 ± 0.2† (4.4 – 5.0)	4.9 ± 0.2† (4.6 – 5.0)	8.9 ± 1.6† (6.9 – 11.1)	5.6 ± 2.9 (2.4 – 10.4)
Full-backs (n=5)	4.8 ± 0.1† (4.8 – 4.9)	5.1 ± 0.1† (5.1 – 5.2)	7.8 ± 1.1† (6.7 – 9.0)	2.3 ± 0.3 (2.0 – 2.6)
Midfield players (n=6)	4.8 ± 0.1† (4.8 – 5.0)	5.1 ± 0.1† (5.0 – 5.2)	8.0 ± 3.3† (3.0 – 13.2)	1.9 ± 3.0 (0.0 – 4.5)
Forwards (n=5)	4.8 ± 0.1† (4.7 – 4.8)	5.1 ± 0.1† (5.0 – 5.2)	10.2 ± 2.8† (6.3 – 13.8)	3.2 ± 2.4 (0.0 – 5.2)
Mean ± S.D.	4.7 ± 0.3	4.9 ± 0.4	10.4 ± 4.7	3.8 ± 4.0

† $P < 0.05$ v Goalkeepers

Table 4.2.5. Performance of elite male soccer players in the Anaerobic Interval Running test (A_nIRT) according to position in the team (mean ± S.D).

	Mean Run Times (s) Mean ± S.D (Range)	Fatigue Index (%) Mean ± S.D (Range)
Goalkeepers	115.5 ± 2.6	21.3 ± 10.1
(n=4)	(113.0 – 118.0)	(9.2 – 34.0)
Central Defenders	102.1 ± 2.5†	6.9 ± 4.2†
(n=5)	(99.3 – 105.7)	(2.0 – 11.7)
Full-backs	99.6 ± 1.8†	5.5 ± 2.8†
(n=5)	(97.0 – 102.0)	(2.0 – 8.6)
Midfield players	98.7 ± 2.4†	5.5 ± 3.9†
(n=6)	(94.7 – 101.0)	(0.0 – 10.6)
Forwards	97.7 ± 3.9†	5.5 ± 5.2†
(n=5)	(91.7 – 100.7)	(0.0 – 11.6)
Mean ± S.D.	102.1 ± 6.7	8.3 ± 7.7

† $P < 0.05$ v Goalkeepers

Table 4.2.6. Times (s) of elite male soccer players in the Sprint and Rotational Agility test (R_{AT}) grouped according to their position in the team (mean ± S.D).

	Time (s)			
	Agility	0 – 5 m	0 – 10 m	0 – 30 m
	Mean ± S.D (Range)	Mean ± S.D (Range)	Mean ± S.D (Range)	Mean ± S.D (Range)
Goalkeepers (n=4)	11.22 ± 0.17 (11.00–11.40)	0.98 ± 0.04 (0.94 – 1.04)	1.79 ± 0.04 (1.75 – 1.85)	4.35 ± 0.11 (4.19 – 4.45)
Central Defenders (n=6)	11.40 ± 0.24 (11.15-11.70)	1.05 ± 0.05 (0.97 – 1.09)	1.79 ± 0.03 (1.76 – 1.84)	4.40 ± 0.05 (4.31 – 4.48)
Full-backs (n=8)	11.21 ± 0.20 (11.01-11.48)	1.02 ± 0.05 (0.94 – 1.04)	1.74 ± 0.06 (1.65 – 1.82)	4.25 ± 0.11 (4.02 – 4.39)
Midfield players (n=10)	11.32 ± 0.13 (11.16-11.50)	1.05 ± 0.06 (0.95 – 1.17)	1.80 ± 0.11 (1.64 – 1.97)	4.31 ± 0.13 (4.09 – 4.49)
Forwards (n=10)	11.17 ± 0.23 (10.92-11.50)	0.98 ± 0.03†* (0.94 – 1.04)	1.74 ± 0.07 (1.60 – 1.81)	4.19 ± 0.09* (4.0 – 4.32)
Mean ± S.D.	11.27 ± 0.20	1.02 ± 0.05	1.77 ± 0.08	4.29 ± 0.13

* P < 0.05 v Central Defenders
† P < 0.05 v Midfield players

Variables related to vertical jump performance are presented in Table 4.2.7. Squat jump height of forwards was significantly greater than midfield players and central defenders ($F_{4,23}$ = 4.622; P<0.007). CMJ was also significantly greater in forwards than midfield players ($F_{4,23}$ = 3.149; P<0.033). These values demonstrate a trend towards a high leg power output of forward players compared to other positions.

Table 4.2.7. Vertical jump (cm) performance of elite male soccer players grouped according to their position in the team (mean ± S.D).

	Vertical Jump Height (cm)		
	Squat Jump	CMJ	CMJ_A
	Mean ± S.D (Range)	Mean ± S.D (Range)	Mean ± S.D (Range)
Goalkeepers (n=4)	41.8 ± 3.1 (39.0 – 46.0)	43.5 ± 2.4 (42.0 – 47.0)	49.5 ± 6.0 (44.0 – 58.0)
Central Defenders (n=6)	41.5 ± 2.3 (38.0 – 44.0)	43.5 ± 2.9 (41.0 – 48.0)	46.5 ± 3.1 (42.0 – 50.0)
Full-backs (n=5)	41.8 ± 2.4 (39.0 – 45.0)	44.0 ± 3.0 (40.0 – 47.0)	48.2 ± 7.9 (43.0 – 61.0)
Midfield players (n=6)	40.0 ± 1.1 (39.0 – 42.0)	42.7 ± 1.8 (40.0 – 45.0)	45.7 ± 2.9 (42.0 – 50.0)
Forwards (n=7)	46.0 ± 5.2†* (38.0 – 53.0)	47.3 ± 2.8‡ (42.0 – 50.0)	53.6 ± 5.4 (42.0 – 59.0)
Mean ± S.D.	42.5 ± 3.7	44.3 ± 3.0	48.8 ± 5.7

* P < 0.01 v Central Defenders
† P < 0.01 v Midfield players
‡ P < 0.05 v Midfield players

Performance variables for upper body strength are presented in Table 4.2.8. In terms of absolute maximal strength, no significant differences were found between the playing positions. No differences were observed when body mass was raised to the power of 0.67.

Table 4.2.8. Upper body strength performance of elite male soccer players grouped according to their position in the team (mean ± S.D).

	Bench Press 1 RM (kg) Mean ± S.D (Range)	1 RM (kg·$m_b^{-0.67}$) Mean ± S.D (Range)
Goalkeepers (n=4)	85.6 ± 14.3 (72.5 – 105.0)	3.1 ± 0.4 (2.7 – 3.6)
Central Defenders (n=5)	94.5 ± 13.0 (75.0 – 107.5)	3.3 ± 0.4 (2.7 – 3.9)
Full-backs (n=6)	78.3 ± 15.4 (65.0 – 100)	3.0 ± 0.6 (2.5 – 3.8)
Midfield players (n=9)	78.1 ± 18.5 (60.0 – 120.0)	3.0 ± 0.7 (2.5 – 3.8)
Forwards (n=7)	79.6 ± 8.8 (70.0 – 92.5)	3.1 ± 0.5 (2.6 – 3.9)
Mean ± S.D.	82.1 ± 15.0	3.1 ± 0.5

During the Intermittent Sprint Test, Fatigue Index over 10 m was significantly greater in goalkeepers and central defenders than in full-backs, midfield players and forwards ($F_{4,18}$ = 17.611; P<0.000). Fatigue index over 30 m was also higher in goalkeepers and central defenders compared to the other positions ($F_{4,18}$ = 17.465; P<0.000). When recovery time between intermittent bouts of sprint performance was increased to 25 s (Bangsbo Sprint Test) no significant differences between positions were identified ($F_{4,12}$ = 2.065; P<0.149). See Table 4.2.9.

No significant differences were found between the positions during the Yo-Yo Recovery Test although there was a trend for midfield players to obtain the highest levels and goalkeepers and central defenders the lowest levels ($F_{4,17}$ = 2.775; P<0.061). Midfield players recorded the greatest distances covered during the test.

Table 4.2.9. Intermittent sprint performance of elite male soccer players grouped according to their position in the team (mean ± S.D).

	Intermittent Sprint Test		Yo-Yo Recovery Test		Bangsbo Sprint Test	
	Fatigue Index (%) 0-10 m	Fatigue Index (%) 0-30 m	Level	Distance (m)	Best (s)	Fatigue (s)
	Mean ± S.D (Range)	Mean ± S.D (Range)	Mean ± S.D (Range	Mean ± S.D (Range	Mean ± S.D (Range	Mean ± S.D (Range
Goalkeepers (n=4)	18.2 ± 1.8 (16.9 – 19.4)	17.6 ± 0.1* (17.5 – 17.7)	21.3 ± 0.9 (20.4 – 22.2)	866.7 ± 281.0 (600 – 1160)	6.70 ± 0.18 (6.57 – 6.83)	1.01 ± 0.50 (0.66 – 1.37)
Central Defenders (n=6)	13.6 ± 3.9 (10.3 – 19.2)	13.2 ± 2.6 (10.7 – 16.3)	21.3 ± 0.1 (21.2 – 21.5)	880 ± 56.6 (840 – 960)	6.72 ± 0.14 (6.57 – 6.85)	0.87 ± 0.11 (0.75 – 0.96)
Full-backs (n=6)	6.9 ± 1.6†* (5.0 – 8.9)	9.1 ± 1.5†‡ (6.6 – 10.1)	21.7 ± 0.4 (21.5 – 22.2)	1026.7 ± 115.5 (960 – 1160)	6.67 ± 0.15 (6.50 – 6.84)	0.60 ± 0.19 (0.42 – 0.85)
Midfield players (n=8)	7.0 ± 1.8†* (5.4 – 9.8)	8.1 ± 1.6†‡ (6.4 – 9.8)	22.1 ± 0.5 (21.5 – 22.7)	1152.0 ± 153.4 (960 – 1360)	6.67 ± 0.18 (6.45 ± 6.89)	0.59 ± 0.17 (0.38 – 0.77)
Forwards (n=7)	5.3 ± 1.4†‡ (3.4 – 7.0)	9.4 ± 8.6†‡ (8.6 – 10.6)	21.7 ± 0.3 (21.3 – 22.1)	1005.7 ± 101.8 (880 – 1120)	6.49 ± 0.58 (6.31 – 6.62)	0.58 ± 0.21 (0.32 – 0.80)
Mean ± S.D.	8.8 ± 4.6	10.3 ± 3.3	21.6 ± 0.5	1000.0 ± 166.1	6.64 ± 0.16	0.68 ± 0.25

† $P < 0.01$ v Goalkeepers
‡ $P < 0.01$ v Central Defenders
* $P < 0.05$ v Central Defenders

4.2.4 Discussion

The aim of the present study was to establish fitness characteristics of elite soccer players prior to the competitive season. In terms of fitness characteristics, the Premier League soccer players in the current study constitute a relatively heterogeneous group. Similar observations have been obtained in other studies where physiological distinctions have been made between players based upon their playing position (Raven et al., 1976; Ekblom, 1986; Davis et al., 1992; Puga et al., 1993; Bangsbo, 1994b). Moreover, it would appear that there are specific roles required of players during competitive match-play and that these requirements may to some extent be reflected in their performance on field-based tests.

Several studies have determined the maximum oxygen uptake for elite soccer players and mean values between 56-69 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ have been reported (Reilly, 1996). These values are similar to those observed in the present study and support the belief that there is a large contribution from aerobic power during elite competitive match-play. More recently, individual values as high as 70 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ have been recorded (Wisloff et al., 1988).

There is evidence that $\dot{V}O_{2max}$ varies according to positional role and the variability observed in the present study reflects positional specificity. The $\dot{V}O_{2max}$ of 19 professional players in the Portuguese First Division was below 60 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ for goalkeepers and central defenders and above 60 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ for midfield players and forwards (Puga et al., 1993). Midfield players frequently have the highest $\dot{V}O_{2max}$ values in the team due to the higher endurance demands on the more active midfield position during match-play (see Table 4.2.10). When English League players were subdivided into positions according to their 4-3-3 configuration, the midfield players had significantly higher $\dot{V}O_{2max}$ values than those in the other positions. The central defenders had significantly lower relative values than the other outfield players while the full-backs and strikers had intermediate values (Reilly, 1990).

Midfield players cover greater distances during competitive match-play than other players (Reilly and Thomas, 1976; Withers et al., 1982; Ekblom, 1986; Rienzi et al., 2000). This greater distance may be attributed to tactical and/or physiological factors, or a combination of both. In theory, we expect to find that the most successful players have the physiological characteristics best suited to their particular roles, and that differences in physiological characteristics emphasise the important aspects of performance physiology. Given that midfield players are characterised by higher $\dot{V}O_{2max}$ levels than other players, coaches are more likely to select those individuals with a higher $\dot{V}O_{2max}$ than those players with lower $\dot{V}O_{2max}$ values. Moreover, such high $\dot{V}O_{2max}$ values would allow these players to sustain higher work-rates and make them less susceptible to the reduction in work-rate associated with fatigue (Reilly and Thomas, 1976; Rienzi et al., 2000). Indeed, the extent that players experience fatigue has been shown to be negatively related to $\dot{V}O_{2max}$ (Reilly, 1990). Self-selection of individuals into specific positional roles may be common when individuals possess the appropriate physiological characteristics.

In the present study, all midfield players had an estimated $\dot{V}O_{2max}$ value above 60 ml.kg^{-1} min^{-1}. This finding implies that for success in elite contemporary soccer, an individual midfield player must possess a $\dot{V}O_{2max}$ threshold above 60 ml.kg^{-1} min^{-1}. It follows that central defenders, forwards and to a lesser extent full-backs may not need an extraordinary endurance capacity but must possess a moderately high $\dot{V}O_{2max}$ (and likely also other sub-maximal indices of aerobic performance) that will influence work-rate and critical involvement during match-play.

In the present study the ability of individuals to sustain high-intensity bouts of aerobic running was measured by means of a High-intensity Aerobic Interval Running Test (H_IAIRT). During the H_IAIRT, distinctions were made between players based upon their playing position. Average velocities for 1200-m and 800-m runs were significantly slower in goalkeepers than all other positions. Fatigue decrement was also greater in goalkeepers than other positions.

These performances probably reflect the specific role requirements of goalkeepers during competitive match-play. Goalkeepers have been reported to cover approximately 4 km in the course of a match (Reilly, 1990). Critical involvement usually takes the form of quick reaction movements and bursts of muscular power. Such a work-rate profile implicates anaerobic power rather than any demands on the oxygen transport system. It follows that during the systematic preparation of goalkeepers, there is an emphasis on anaerobic training rather than training designed to improve the oxygen transport system. Evidence for the anaerobic profile of goalkeepers is supported in the literature with several reports that goalkeepers tend to be the most powerful of all positions (Cochrane and Pyke, 1976; Verma et al., 1979; Bhanot, 1988).

When considering anaerobic performance, a distinction has to be made between anaerobic power and anaerobic capacity. Anaerobic power represents the highest rate of anaerobic energy release, whereas anaerobic capacity reflects the maximal anaerobic energy production an individual can obtain in any exercise bout to exhaustion (Reilly et al., 2000). The Wingate anaerobic power test is considered the most common test of anaerobic fitness (Bar-Or, 1987). However, questions concerning muscle and activity pattern specificity and accessibility of the Wingate test to games players have led to the development of both running (Rusko et al., 1993, Semenick, 1994) and jumping (Bosco et al., 1983) tests. As yet no validated physiological measurement exists for determining anaerobic capacity (Bangsbo, 1998b). The Anaerobic Interval running Test (A_nIRT) used to measure anaerobic capacity in the present study may be an appropriate field test for differentiating between players in different positions in elite soccer players. Mean run times and fatigue index during the A_nIRT were significantly higher in goalkeepers than all other positions denoting a reduced anaerobic capacity in these positions. Differences in protocols make comparisons of these test results within the literature difficult. However, it is plausible to suggest that the ability to maintain exercise without appreciable accumulation of lactate is a key determinant in performance on the A_nIRT.

When Danish elite soccer players were tested during treadmill running, the oxygen uptake corresponding to a given blood lactate concentration was lower for central defenders and goalkeepers than for midfield players and full backs (Bangsbo, 1998a). The lower $\dot{V}O_{2max}$ displayed by the goalkeepers means that these players are unable to exercise at a high percentage of their $\dot{V}O_{2max}$ without the accumulation of lactate. This is especially the case in soccer where the systematic preparation of goalkeepers does not include extensive steady-state exercise, which would enable goalkeepers to operate at a higher percentage of their $\dot{V}O_{2max}$ without lactate accumulation in the blood. Based on findings of high blood lactate concentrations approaching 8-10 $mmol.l^{-1}$ in outfield players during competitive match-play (Ekblom, 1986), it is reasonable to suggest that outfield players have well developed physiological systems in maintaining exercise without accumulation of lactate. Since the work-rate profile of goalkeepers is characterised by explosive bouts of exercise lasting <6 s, energy for these brief bouts of activity can be obtained from alactic sources, namely the creatine kinase and adenylate kinase systems. Certainly, short sprints and explosive movements are an integral part of the goalkeeper's work-rate profile. It may be that the anaerobic glycolytic system plays a less dominant role during competitive match-play for goalkeepers, resulting in a reduced ability to clear lactate when compared with outfield players. This difference is reflected in their performance during the A_nIRT. Discrete differences were also observed between central defenders and other outfield players, supporting the view that the work-rate profiles of players in these positions are characterised by frequent static pauses and a reduced emphasis upon sustained periods of critical involvement.

Agility, leg power, and leg speed are believed to be necessary physical components for successful performance in contemporary soccer (Buttifant et al., 2002). It is not surprising then that a strong interest exists for developing field tests that can effectively measure these components. In the present study, agility was measured by means of a Rotational Agility Test (R_{AT}). This test is a modified version of the test adopted by Buttifant et al. (2002) which was shown to be a reliable measure of agility. No significant positional variations were found between players in the present study, suggesting that agility is an important quality across all positions in elite soccer. However, forward players were found to be the fastest and central defenders the slowest during the R_{AT}. Measurements of agility are difficult to compare across studies due to the different test protocols used. In a study by Raven et al. (1976), agility was measured using the Illinois agility run (Cureton, 1970), and the faster times for forward players support the observations in the present study. This finding is not surprising given the specific role requirements of forwards during competitive match-play. The forward's work-rate profile is characterised by sudden bursts of high-intensity activity in order to facilitate the creation of space or receive a pass from a team mate or to move on to a goal-scoring opportunity (Rienzi et al., 2000). Clearly, quickness when changing direction over a relatively short distance is a critical component of successful performance.

There are many factors that influence agility. These include the ability to anticipate, react quickly, decelerate quickly, mechanical efficiency and eccentric leg strength. Given that the central defenders recorded the slowest times during the R_{AT}, their larger body size may have resulted in a reduced bio-mechanical efficiency. However, no such observations were reported for goalkeepers with comparable body structure. Moreover, the systematic preparation of goalkeepers involves a considerable amount of time devoted to agility, leg power and anticipation. The implication of these observations is that during the training of elite central defenders, greater emphasis should be placed on optimising agility components so that they can compete more readily with their forward counterparts.

Sprint times of elite soccer players have been determined in several studies (see Table 4.2.10). It has been reported that 96% of all sprint bouts are shorter than 30 m and 49% are less than 10 m (Valquer et al., 1998). These points were kept in mind when choosing appropriate test regimens. In the present study, mean ± S.D. sprint times for 0-5 m, 0-10 m and 0-30 m were 1.02 ± 0.05, 1.77 ± 0.08 and 4.29 ± 0.13 s, respectively. These values are similar to those reported for German, French and Norwegian elite soccer players (Kollath and Quade, 1993; Cometti et al., 2001; Wisloff et al., 2002).

Forwards were significantly faster over 0-5 m than central defenders and midfield players, reflecting a higher acceleration and thus force production over short distances. On this basis, maximal mobilisation of force in shorter distances may be an important determinant of match winning actions for contemporary forward players. Moreover, the ability to produce as much force as possible in the shortest possible time is one of the characteristics that distinguish forwards form other players. In terms of comparing the rankings between the five position categories, goalkeepers were comparable with forwards over 0-5 m but only 4th fastest over 0-30 m. This suggests that the profile of the goalkeeper is more dependent on acceleration over short distances as opposed to the ability to attain high velocities in the transition phase between initial acceleration and maximum running speed (Delecluse, 1997).

Few studies in the literature have compared sprint times across different positions. Kollath and Quade (1993) found no significant differences between offensive and defensive German 1st division soccer players. Due to the narrow categorisation between offensive and defensive players, much of the qualitative data that can be used for comparative purposes was omitted. In line with the results of the agility test, central defenders were the slowest players over 0-5 m and 0-10 m suggesting that a greater emphasis should be placed on optimising acceleration over short distances during the elite preparation of players in these positions. It may be that central defenders rely more on stature, body mass and an increased absolute upper body strength as reflected in higher 1-RM values, during competitive play when attempting to prevent opponents from creating goal scoring opportunities.

The vertical jump has frequently been used as a test of 'explosive power'. According to Gauffin et al. (1989), vertical jump is sensitive enough to differentiate between levels of play, thus supporting the importance of this characteristic as a measure of explosive power for elite soccer players. Mean values reported in this study are similar to those in the literature (see Table 4.2.11). In the present study, positional variations were observed in vertical jump performance as measured by the squat jump. Squat jump height was significantly greater in forwards than midfield players and central defenders. Similar observations have been obtained in other studies where distinctions have been made between vertical jump height and playing position (Raven et al., 1976; Wisloff et al., 1998). According to Wisloff et al. (1998), the higher values for vertical jump height of forwards compared with midfield players may be explained by the tendency for forward players to be involved in more jumping compared with midfield players. Given that taller individuals with longer limbs will have an advantage in contesting high balls, and the fact that the average forward in the present study was approximately 0.09 m shorter than the average central defender, it seems reasonable to suggest that forward players have to rely on maximal mobilisation of force during aerial contests.

Muscular strength is one basic quality that influences power output. An increase in maximal strength is usually associated with an improvement in relative strength and therefore with improvement of power abilities (Wisloff et al., 2004). Muscular strength of players appears from the literature to be related to the position in the team. In a study of elite Danish players (Bangsbo, 1988), muscular strength in isokinetic movements was the lowest for the midfield players at all angular velocities of movement, while full-backs generated lower forces than goalkeepers, forwards and central defenders at high velocities (3.1 rad s^{-1}). Similar findings were reported during knee extension torgue at 0.52 rad s^{-1} (Oberg et al., 1984). In the present study, there was a performance trend in upper body strength, as measured by 1-RM bench press, for midfield players to have the lowest absolute strength values, thereby supporting previous findings (Wisloff et al., 1998). According to Bangsbo (1998a), the differences in muscular strength are likely to be due to selection of a specific type of player for a position, rather than to a more pronounced strength development as a result of playing in the position. While we expect to find that the most successful players have the physiological characteristics best suited to their particular roles, the nature of the competitive programme and the training regimen adopted are fundamental to the development of the physiological differences between outfield players.

In several studies with elite soccer players, muscle morphological analysis has been performed on biopsies taken from m. vastus lateralis or m. gastrocnemius. The mean percentage of type I fibres ranged from 40 to 61% for m. vastus lateralis and from 48% to 61% for m. gastrocnemius (Bangsbo and Mizuno, 1988; Bangsbo, 1998a). According to Bangsbo and Mizuno (1988), the profile of mitochondrial enzyme activities in the gastrocnemius of the players was closer to that of endurance athletes than to strength-trained individuals. However, as with many observations on elite soccer players, a large variability was reported between players. Parente et al. (1992) reported that players in different positions exhibited different muscle characteristics. Midfield players had a higher percentage of type I fibres (67%), than defenders (44%) and forwards (38%). In light of such findings, it is plausible to suggest that genetic variations in muscle morphology may be reflected in performance on field-based physiological tests. Moreover, the positional heterogeneity observed in the present study in muscular strength and endurance might be due to the higher percentage of type I fibres in the midfield players.

The ability to sprint repeatedly during competitive match-play is of great importance in soccer (Bangsbo, 2003). This ability can be evaluated by having the players perform a number of sprints each separated by a break that is so short that the players are unable to recover fully before the next sprint. In the present study, intermittent sprint performance was measured during the IST (Reilly, 2001) and the BST (Bangsbo, 1994c). During the IST, fatigue index was significantly greater in goalkeepers and central defenders than in full-backs, midfield players and forwards. Midfield players were also capable of sustaining repeated 30-m sprints with the lowest decrement in performance compared with all other positions. Given that midfield players had the highest $\dot{V}O_{2max}$ values, these players are less likely to suffer from the detrimental effects of fatigue during repeated bouts of high-intensity exercise.

Hamilton et al. (1991) compared the aerobic response of endurance-trained athletes and games players during repeated bouts of 6-s treadmill sprints (endurance-trained athletes, $\dot{V}O_{2max}$ 60.8 ± 4.1 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$; games players, $\dot{V}O_{2max}$ 52.5 ± 4.9 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$). While both groups attained similar peak power values, the endurance-trained athletes consumed significantly more oxygen during repeated intervals of maximal sprinting and demonstrated a significantly smaller percentage decrement in power over the 10 sprints compared with games players. Similar observations were reported in female soccer players grouped according to high aerobic power (HAP) and low aerobic power (LAP), during repeated 6-s maximal cycle sprints (Tomlin, 1998). These findings along with the observations of Bogdanis et al. (1996) and Balsom et al. (1994), suggest that consuming more oxygen during repeated bouts of sprinting results in less reliance on anaerobic glycolysis and thus lactic acid production. The net results are less H+ accumulation and thus better maintenance of power. In line with these observations, Reilly and Doran (2001) reported an increased tolerance to fatigue in the IST following improvements to the oxygen transport system of games players.

In the present study, when recovery time between intermittent bouts of sprint performance was increased to 25 s in the BST, no significant differences between positions were identified. Clearly, the length of recovery interval between repeated bouts of high-intensity exercise will affect performance. Wootton and Williams (1983) reported that although power output decreased during repeated 6-s sprints with either 30 s or 60 s recovery, the decrement in power output was less when 60 s of recovery was permitted. A longer recovery interval ensures more complete renewal of the physiological indices related to performance.

According to Bogdanis et al. (1993), PCr availability during the initial seconds of a sprint is critical for power generation. These observations were supported by Greenhaff et al. (1993), who reported enhanced performance during repeated bouts of high-intensity exercise with oral creatine supplementation. Moreover, a lower blood lactate accumulation with creatine supplementation suggests a change in the source of energy production (Balsom et al., 1993). During a 6 s sprint, PCr contributes to approximately 50% of the total anaerobic ATP production (Gaitanos et al., 1993). Although PCr has been shown to have a rapid rate of resynthesis (Harris et al., 1976) a recovery interval of short duration will not be sufficient to replenish PCr levels. It follows that during the BST, the increased recovery interval was sufficient for resynthesis of PCr to take place. Therefore, the increased recovery interval may not be sensitive enough to differentiate between elite players according to position. In addition, it has been suggested that PCr resynthesis is a two-component process (Sahlin et al., 1979). The initial fast phase of PCr resynthesis is limited by the availability of O_2, whereas the subsequent slow phase is limited by H^+ ion transport out of the muscle (Harris et al., 1976). Since O_2 supply and H^+ clearance are dependent upon the effectiveness of the oxygen transport system, the difference observed between players when the recovery interval was shortened may be linked to this phenomenon. This process may have been magnified in the IST where the combination of a shorter recovery period and a superiority in the midfield players to provide O_2 resulted in significant performance differences.

An important consideration when examining the recovery of PCr following intense exercise is the possible difference in PCr resynthesis between the two major fibre types. In a study by Tesch et al. (1989), PCr was resynthesised to 50% (Type II) and 68% (Type I) of resting levels following 60 s of maximal knee extensions. It may be that the differences in the muscle characteristics of the midfield players and the goalkeepers in the present study were reflected in performance in the IST. Moreover, such performance characteristics reflect the role requirements of players during competitive match-play.

Whilst field-based tests enhance the specificity of the evaluation (Svensson and Drust, 2005), the methods employed must be valid and reliable (Atkinson and Nevill, 2001). In the present thesis, reliability measures were not undertaken to determine the consistency or reproducibility of the field tests employed. Clearly, a test with poor reliability is unsuitable for tracking changes in performance, and it lacks precision for the assessment of performance in a single trial (Hopkins, 2000). Reliability measures were not conducted within this thesis due to the inability to repeat maximal tests on players in such a short period of time. Nevertheless, reliability measures have been reported in the literature for the vertical jump tests (Aragon-Vargas, 2000), rotational and 20 m sprint tests (Buttifant et al., 2002) and the Yo-Yo intermittent recovery test (Krustrup et al., 2003b).

A major tenet of the research provided in this section is the need to generalise the findings to the elite soccer population at large. In doing so, universal statements can be constructed. However, the extent to which this is achieved can be questioned due to the inherent problems with sampling sizes. Moreover, a larger sample size may have shown positional differences more clearly at the statistical level.

Table 4.2.10. The $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) of elite players according to positional roles (mean ± S.D).

Source	Players	Combined Mean (mean ± S.D)	Goalkeepers (mean ± S.D)	Central defenders (mean ± S.D)	Full-backs (mean ± S.D)	Midfield players (mean ± S.D)	Forwards (mean ± S.D)
Present study	English Premier	59.9 ± 1.6 (n=40)	57.8 ± 1.3 (n=4)	59.2 ± 1.7 (n=7)	61.1 ± 1.4 (n=8)	61.9 ± 2.3 (n=11)	59.9 ± 1.6 (n=10)
Bangsbo (1994b)	Danish 1st Division	60.5 (n=65)	51.0 (n=5)	56.4 (n=13)	61.9 (n=12)	62.4 (n=21)	60.2 (n=14)
Matkovic et al. (1993)	Croatian 1St Division	52.1 ± 10.7 (n=44)					
Puga et al. (1993)	Portuguese 1st Division		52.7 (n=2)	54.8 (n=3)	62.1 (n=2)	61.9 (n=8)	60.6 (n=6)
Wisloff et al. (1998)	Norwegian 1st Division	63.7 ± 5.0 (n=29)			61.5 ± 3.3 (n=13)	66.4 ± 5.7 (n=7)	63.5 ± 3.5 (n=9)
Casajus (2001)	Spanish 1st Division	65.5 ± 8.0 (n=15)					
Al-Hazzaa et al. (2001)	Saudi National	56.8 ± 4.8 (n=23)		52.3 ± 7.3	57.7 ± 5.1	59.9 ± 0.93	56.9 ± 2.5
Chin et al. (1992)	Hong Kong National	59.1 ± 4.9 (n=24)					
Raven et al. (1976)	USA 1st Division	58.4 ± 0.83 (n=18)	53.7 ± 1.0 (n=2)		59.3 ± 1.3 (n=9)	56.1 ± 1.4 (n=2)	59.6 ± 1.2 h (n=5)
Cochrane and Pyke (1976)	Australian National		54.7 (n=1)		56.8 (n=3)	57.2 (n=3)	55.0 (n=4)
Apor (1988)	Hungarian 1st Division	66.3 ± 3.8 (n=10)					
Davis et al. (1992)	English 1st /2nd Division	60.4 ± 3.0 (n=122)	56.4 ± 3.9 (n=13)	59.5 ± 3.2 (n=24)	60.7 ± 2.3 (n=22)	61.4 ± 3.4 (n=35)	60.1 ± 4.2 (n=41)

Table 4.2.11. Sprint times (s) of elite players in a sample of reports in the literature (mean ± S.D).

Source	Players	Sprint times (s)			
		0-5 m	0-10 m	0-20 m	0-30 m
		Mean ± S.D	Mean ± S.D	Mean ± S.D	Mean ± S.D
Present study	English Premier (n=28)	1.02 ± 0.05	1.77 ± 0.08		4.29 ± 0.13
Wisloff et al. (2002)	Norwegian 1st Division (n=17)		1.82 ± 0.3	3.0 ± 0.3	4.0 ± 0.2
Cometti et al. (2001)	French 1st Division (n=29)		1.80 ± 0.1		4.22 ± 0.2
Dowson et al. (2002)	New Zealand National (n=21)			2.91 ± 0.1	
Kollath and Quade (1993)	German 1st Division (n=20)	1.03 ± 0.1	1.79 ± 0.1	3.03 ± 0.1	4.19 ± 0.1
Dunbar and Power (1995)	English Premier (n=18)				3.94 ± 0.2

Table 4.2.12. Vertical jump (cm) of elite players in a sample of reports in the literature (mean ± S.D).

		Vertical Jump (cm)		
Source	Players	Squat Jump Mean ± S.D	CMJ Mean ± S.D	CMJ_A Mean ± S.D
Present study	English Premier (n=28)	42.5 ± 3.7	44.3 ± 3.0	48.8 ± 5.7
Wisloff et al. (1998)	Norwegian 1st Division (n=14)			56.7 ± 6.6
Raven et al. (1976)	USA 1st Division (n=18)			53.0 ± 2.5
Casajus (2001)	Spanish 1st Division (n=18)	39.2 ± 3.1	41.4 ± 2.7	47.8 ± 2.9
Cometti et al. (2001)	French 1st Division (n=29)	38.5 ± 3.8	41. 6 ± 4.2	
Reilly and Thomas (1977)	English 1st Division (n=31)			58.0 ± 6.2
Dowson et al. (2002)	New Zealand National (n=21)			48.1 ± 4.6
Thomas and Reilly (1979)	English 1st Division (n=31)			55.6 ± 6.0

Table 4.2.13. Position rankings on tests of anaerobic power (modified from Tumilty, 1993)

Source	Players	Test	Goalkeeper	Defence	Midfield	Forward
Present study	English Premier	0-5 m sprints (s) Vertical jump (cm)	2	3	4	1
Wisloff et al. (1998)	Norwegian 1st Division	Vertical Jump (cm)		2	3	1
Cochrane and Pyke (1976)	Australian National	36-m Sprints (s) Vertical jump (cm)	1	3	4	2
Raven et al. (1976)	USA 1st Division	Vertical jump (cm)	3	2	4	1
Withers et al. (1977)	South Australian representative	Margaria stair climb (kgm/kg/s)		2	3	1
Verma et al. (1979)	Indian National	Margaria stair climb (kgm/kg/s)	1	3	4	2
Bhanot (1988)	Indian Players	Margaria stair climb (kgm/kg/s)	1	4	3	2

In summary, the Premier League soccer players in the current study constitute a relatively heterogeneous group in terms of fitness profiles. Fitness characteristics allow players to best meet the demands imposed upon them by their position. Each position demands specific tasks during different phases of the game and players have to meet these requirements with a demonstration of appropriate fitness characteristics. It may be that genetic predisposition and participation in competitive match-play contribute to the variability that exists in field-based physiological testing. Whether self-selection into specific positional roles occurs according to the appropriate physiological characteristics remains unclear. It may be that the heterogeneity in fitness profiles is a reflection of contemporary training regimens and competitive fixtures. That is, training regimens that emphasise the playing of matches as the main physiological demand on the body's energy systems are more likely to result in inter-positional differences in physiological measures. Fitness profiles may be genetically determined, complicated in structure or subject to environmental conditions. As a consequence the contemporary search for elite soccer players may move towards the selective recruitment of players based on physical and physiological characteristics matched to positional roles, once a certain level of skill is attained

Therefore the following hypothesis was rejected:

B. H_O: At an elite level of play, fitness characteristics do not vary according to different playing positions.

4.3 ANTHROPOMETRIC AND PHYSIOLOGICAL PREDISPOSITIONS FOR UNDERAGE ELITE MALE SOCCER PLAY

4.3.1. Introduction

Soccer players have to adapt to the requirements of the game to compete at an elite level of play. These characteristics were quantified in sections 4.1 and 4.2. It is possible that success in soccer can be achieved despite rather moderate fitness if an individual has a well-developed tactical sense and a high technical standard. Therefore the individual capacity at elite level may not in all cases reflect the overall physical demands in competitive match-play (Reilly et al., 2000). Nevertheless, if large numbers of players are observed, mean values yield important information about activity and fitness profiles and how these vary with different team configurations.

An alternative approach is to identify the anthropometric and physiological characteristics of elite young players who have already been selected and exposed to systematised training. Knowledge of these individuals, and in particular those who have already been successful, can give clues as to the prerequisites for playing at the highest level. For this thesis, therefore, the emphasis was switched from studying elite mature players to younger talented groups.

Professional soccer clubs began to place emphasis on the systematic development of their young players when the Football Association formally established Football Academies in 1998. In soccer, identifying, developing and nurturing talented players have become increasingly important. The spiralling costs of purchasing players on the transfer market have reinforced the need for professional soccer clubs to put appropriate talent identification and development structures into place. Identifying soccer potential at an early age ensures that players receive specialist coaching to accelerate the talent development process. With the need to develop young talented players, it is essential to identify the key physiological and anthropometric characteristics that are required for elite performance participation.

There have been few contemporary investigations on the anthropometric and physiological profiles of elite young professional soccer players. The purpose of this study was to establish anthropometric and physiological characteristics of elite underage players and perform a retrospective analysis, whereby players were categorised as successful or less successful, prior to comparing their profiles on various measures. Such data may also facilitate a better understanding of the anthropometric and physiological predispositions for success in elite contemporary male soccer play.

4.3.1.1 Statement of hypotheses

C. H_O: At an elite level of play, anthropometric and physiological characteristics do not vary between successful and less successful players.

4.3.2 Methods

4.3.2.1 Subjects

Subjects were 50 full-time male soccer scholars of a Premier League Academy squad (age 16.5 ± 0.5 years). For the purpose of the study, only subjects who were full-time scholars were included. Four separate yearly cohorts spanning the years from 1998 to 2001 were selected for this study. The yearly cohorts comprised of 14 players in the first group and 12 players in each group thereafter.

4.3.2.2 Procedures

Anthropometric and fitness profiles were obtained on all players during a period of intensive pre-season training (September to November). Profiles were collected on yearly cohorts in their 1st respective season as a full-time scholar. Subjects were categorised retrospectively according to their eventual level of success. Success was determined on the basis of whether the individual received a professional contract following his scholarship. Those who received a professional contract following their scholarship were classified as 'successful' (n=15), whilst those who did not receive a professional contract were categorised as 'less-successful' (n=35).

All procedures were approved by the Human Ethics Committee of Liverpool John Moores University. Subjects were fully informed about the aims, procedures and the demands that the tests would place upon them, together with any possible risks and discomfort before written consent was obtained. All of the tests undertaken were familiar to the subjects as part of their ongoing fitness assessment. The test battery included a number a field tests designed to measure anaerobic and aerobic performance. The fitness variables included maximal oxygen uptake (Ramsbottom et al., 1988), intermittent sprint capacity (Reilly, 2001), sprint speed and leg power. Anthropometric variables included estimated muscle mass (Martin et al., 1990), body mass, adiposity (Durnin and Womersley, 1974, Reilly et al., 1996), stature and somatotype calculated by the Heath-Carter (1967), anthropometric method. Methods used to determine these characteristics were described in section 4.1.2.2 and 4.2.2.2.

4.3.2.3 Statistical analyses

The statistical analyses of data were carried out using t-tests. The separate univariate analyses were complemented by discriminant function analysis in order to consider all of the variables together. The significance of the discriminant function was determined using Wilks' Lambda. The χ^2 significance test was used to investigate the distribution of birth dates between successful and less successful players. Data were analysed using SPSS software (version 11.0). The level of significance was accepted at $P<0.05$ for all statistical procedures.

4.3.3 Results

The anthropometric characteristics of the subjects are presented in Table 4.3.1. The results demonstrated significant differences in stature ($P<0.05$) between the groups. Successful players were significantly taller in stature than less-successful players ($P<0.048$). Successful players were heavier than less-successful players but these differences were not found to be statistically significant.

Variables related to the body composition of subjects are presented in Table 4.3.2. No significant differences were observed between the groups for adiposity, percentage adiposity, muscle mass or percentage muscle mass. The mean ± S.D. somatotype of successful and less-successful players was 2.5 ± 0.5 – 4.6 ± 1.0 – 2.7 ± 1.0; and 2.8 ± 0.4 – 4.4 ± 0.9 – 2.7 ± 0.8 respectively. The somatotype for the successful players represents a greater trend towards mesomorphy or muscularity compared with the less-successful players ($P=0.094$). There was also a trend for the less-successful players to have a higher level of endomorphy rating ($P=0.066$).

Variables related to the aerobic and anaerobic performance of the subjects are presented in Table 4.3.3. There were no significant differences between the groups for estimated $\dot{V}O_{2max}$, vertical jump or sprint times. No differences were observed between the groups for intermittent recovery, as expressed by the fatigue index for the 10-m and 30-m sprint times

Table 4.3.1. Anthropometric characteristics of elite young male soccer players grouped according to eventual level of success (mean ± S.D).

	Age (Years) Mean ± S.D (Range)	Stature (m) Mean ± S.D (Range)	Sitting Stature (m) Mean ± S.D (Range)	Body mass (kg) Mean ± S.D (Range)
Successful	16.7 ± 0.3	1.81 ± 0.08†	0.94 ± 0.04	76.9 ± 7.4
(n=15)	(16.1 – 17.0)	(1.72 – 1.97)	(0.93 – 1.03)	(67.0 – 92.0)
Less-	16.7 ± 0.3	1.77 ± 0.06	0.93 ± 0.03	72.1 ± 5.7
successful	(16.1 – 17.0)	(1.70 – 1.93)	(0.87 – 0.99)	(62.5 – 83.0)
(n=35)				
Mean ± S.D.	16.5 ± 0.5	1.79 ± 0.07	0.93 ± 0.03	73.6 ± 6.6

† $P < 0.05$ v Less-successful

Table 4.3.2. Body composition of elite young male soccer players grouped according to eventual level of success (mean ± S.D).

	Adiposity Mean ± S.D (Range)	% Adiposity Mean ± S.D (Range)	Muscle mass (kg) Mean ± S.D (Range)	Muscle mass (%) Mean ± S.D (Range)
Successful	34.2 ± 6.1	11.4 ± 1.7	46.4 ± 5.3	60.3 ± 3.2
(n=15)	(26.7 – 44.0)	(9.4 – 13.8)	(38.6 – 54.8)	(55.7 – 66.9)
Less-	37.5 ± 6.3	12.6 ± 2.0	43.0 ± 4.3	59.6 ± 3.3
successful	(25.4 – 50.2)	(8.4 – 16.9)	(33.1 – 52.5)	(52.3 – 63.8)
(n=35)				
Mean ± S.D.	36.5 ± 6.4	12.3 ± 1.9	44.0 ± 4.8	59.8 ± 3.3

Table 4.3.3. Aerobic and anaerobic performance of elite young male soccer players grouped according to eventual level of success (mean ± S.D).

			Sprint times (s)		
	Estimated $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) Mean ± S.D (Range)	Vertical Jump (cm) Mean ± S.D (Range)	0 – 5 m Mean ± S.D (Range)	0 – 10 m Mean ± S.D (Range)	0 – 30 m Mean ± S.D (Range)
Successful (n=15)	59.7 ± 2.3	46.7 ± 3.7	1.01 ± 0.04	1.70 ± 0.05	4.28 ± 0.13
	(57.4 – 66.5)	(42.0 – 58.0)	(0.95 – 1.08)	(1.68 – 1.84)	(4.08 – 4.43)
Less-successful (n=35)	58.5 ± 2.0	44.8 ± 4.4	1.03 ± 0.03	1.80 ± 0.05	4.39 ± 0.10
	(55.4 – 64.6)	(36.0 – 55.0)	(0.98 – 1.08)	(1.69 – 1.86)	(4.26 – 4.47)
Mean ± S.D.	58.9 ± 2.1	45.3 ± 4.4	1.02 ± 0.03	1.77 ± 0.05	4.35 ± 0.12

Table 4.3.4. 'Intermittent sprint' performance of elite young male soccer players grouped according to eventual level of success (mean ± S.D).

	Fatigue Index (%) 0-10 m Mean ± S.D (Range)	Fatigue Index (%) 0-30 m Mean ± S.D (Range)
Successful (n=15)	9.3 ± 6.6 (3.2 – 16.8)	12.8 ± 7.3 (3.4 – 20.7)
Less-successful (n=35)	10.5 ± 5.8 (4.9 – 17.9)	13.7 ± 3.6 (8.8 – 22.1)
Mean ± S.D.	10.4 ± 6.1	13.9 ± 5.0

Discriminant function analysis identified three variables for distinguishing between successful and less-successful soccer players. The main variables contributing to group separation were body mass, endomorphy and estimated $\dot{V}O_{2max}$. The standardised canonical discriminant function coefficients were 0.792 for body mass, 0.587 for endomorphy and 0.568 for estimated $\dot{V}O_{2max}$. Wilks' Lambda value was 0.735, [$P<0.002$], and Rao's V was 11.94, [$P<0.02$). The canonical correlation was $r=0.515$. Further, 11 of the subjects were deemed to be wrongly classified, 3 from the successful group and 8 from the less-successful group.

4.3.4 Discussion

The purpose of this study was to establish anthropometric and physiological characteristics of elite young players and identify any variations that exist between players according to eventual success in professional soccer. Successful players were taller in stature and heavier than players who were deemed less-successful. Successful players also had a lower rating of endomorphy and higher estimated $\dot{V}O_{2max}$ values compared to their less-successful counterparts. Similar observations have been obtained in other studies where anthropometric and physiological characteristics have distinguished between soccer players of different levels of success (Garganta et al., 1993; Jankovic et al., 1997; Panfil et al., 1997).

At an elite level of play, adult athletes have the physiological and anthropometric characteristics specifically suited to their sport (see sections 4.1 and 4.2). It is not clear whether these characteristics arise because of training or whether the individual with the appropriate characteristics is selected for the sport. According to Damsgaard et al. (2001), young athletes in competitive sports are selected due to constitutional factors. These authors conducted a cross-sectional study of 183 boys and girls aged 9-13 years participating in swimming, tennis, handball and gymnastics. Analysis revealed no effect of training on height, body composition or pubertal development, which suggests that children in competitive sports may be selected due to constitutional factors. In the present study, the elite young soccer players had already undergone selection processes and been exposed to systematised training regimens. It is therefore likely that both environmental and constitutional factors influence the anthropometric and physiological characteristics reported.

Tanner (1964), studying the physique of Olympic athletes, concluded that athletes were both 'born' and 'made', suggesting that the required body structure for each sport had to be present at birth and that the required training then had to be undertaken in order to achieve sporting success. Clearly, predispositions for success in soccer, and even a particular position within the game, start with heredity. It follows that the genetic base for the presence of an ideal body structure will contribute to achievement potential. Opportunities, guidance, appropriate training and minimal interference of profound injuries will then influence the ability to realise this potential proficiency (Singer and Janelle, 1999).

Stature is strongly influenced by genetic factors with a heritability coefficient of 0.85 (Reilly et al., 2000). A coefficient of 1 indicates a total independence on genetic factors, whereas a value of 0 indicates no genetic influence. Shields (1962) reported correlations for stature of 0.96 for monozygotic (MZ) twins raised together and 0.82 for those raised apart. The available evidence indicates that a significant portion of the variation in stature, skeletal lengths and breadths is genetically determined, presuming healthy and adequately nourished individuals (Bouchard et al., 1997).

In the present study, successful players were significantly taller than less-successful players suggesting that tallness per se may bestow individuals an advantage during elite competitive match-play. Furthermore, the mean stature for successful young players in this study was similar to those values reported for elite adult males in section 4.1 (successful young professional players 1.81 ± 0.08 m; elite adult professional players 1.81 ± 0.07 m). Such findings give credence to the view that successful soccer players may be moving away from the midpoints of the general population and toward the 'expanding athlete' concept (Norton and Olds, 2001). Further support for the relationship between stature and success in contemporary soccer is provided by data from the Premier League. Figure 4.3.1 illustrates the difference between a successful Premier League team (Champions) and a less-successful team (relegated). Analysis reveals that on average, individuals from the successful team were 0.02 m taller than their less-successful counterparts. These observations imply that in team sports that involve jumping and aerial contests, tallness is advantageous. Similar observations have been reported in Rugby Union Football where significant correlations between final ranking and average stature were reported ($r = -0.59$ $P < 0.005$) (Olds 2001).

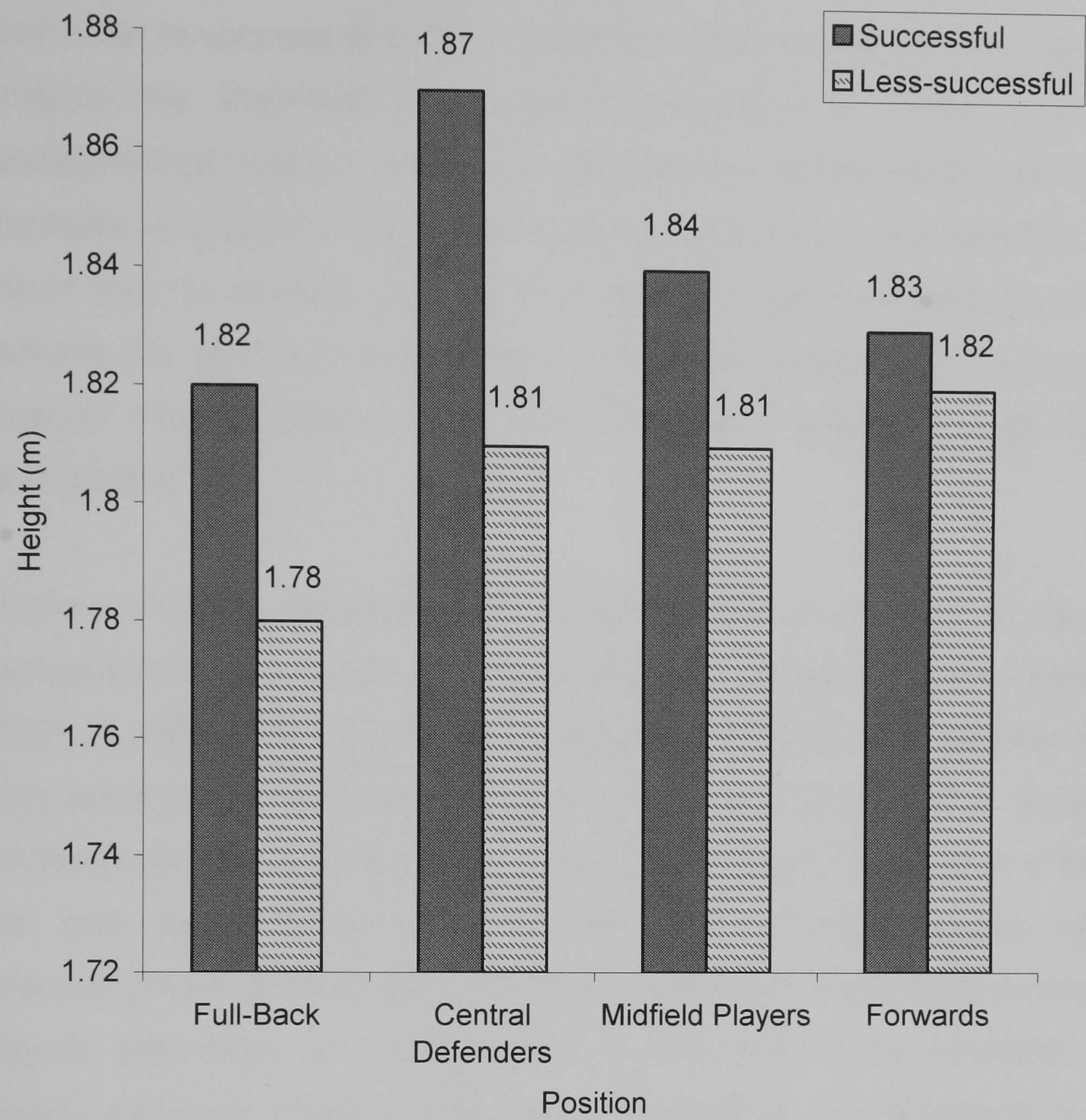
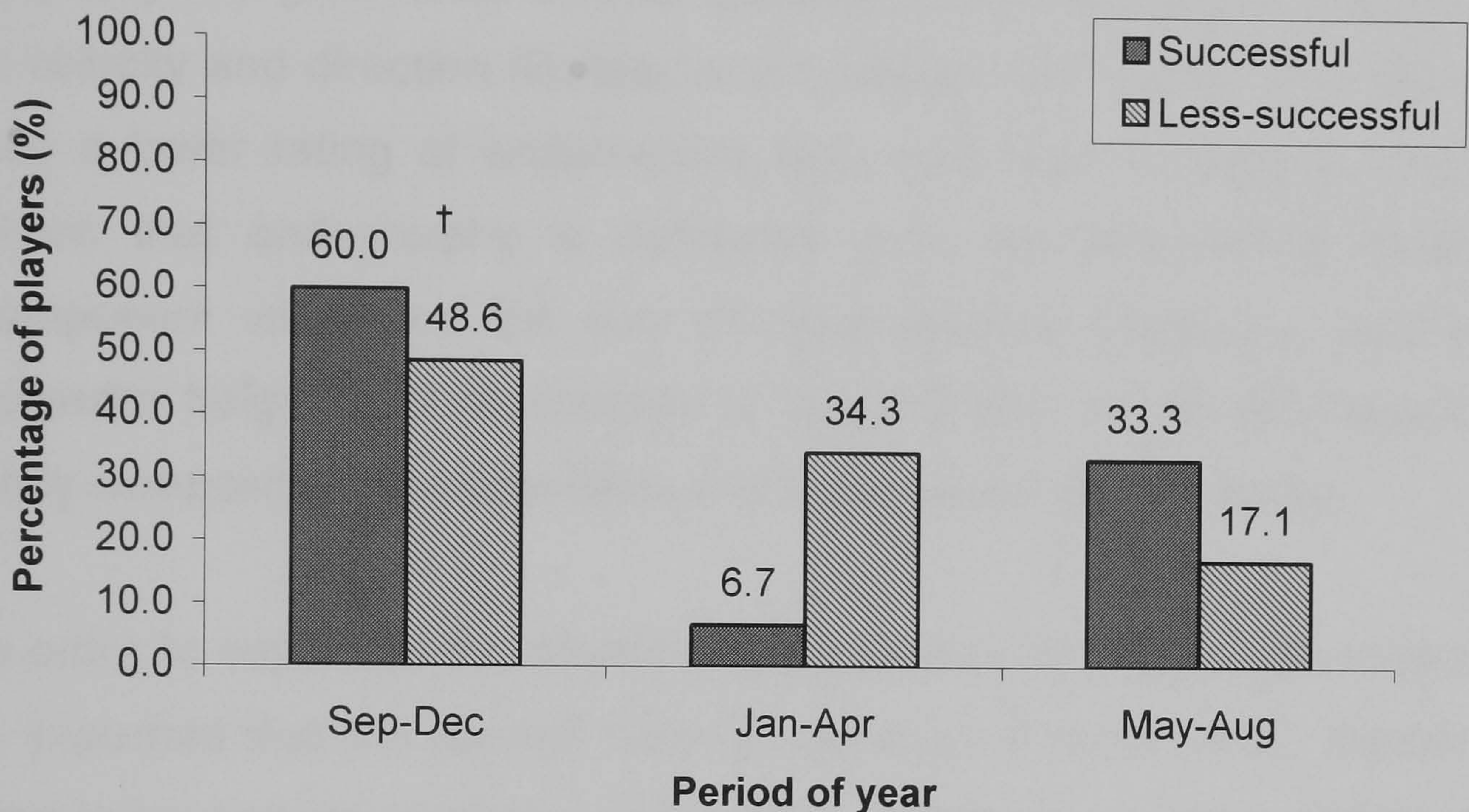


Figure 4.3.1. Average height values by position of a successful and less-successful Premier League team (Source Touch-Line Data Systems).

The successful players had a greater body mass than less successful players. These values were lower than those reported for male adult soccer players in section 4.1, but similar to those reported in other age-related studies of soccer (Dunbar and Power, 1995; Franks et al., 1999; Dowson et al., 2002). The relative importance of body mass in predisposing to success in soccer becomes more apparent when the demands of the game are considered. Soccer is a contact sport in which shoulder-to-shoulder charging, tackling and aerial contests are all commonplace. For successful performance, players must cope with these physical demands. It follows that the greater the body mass, the greater the advantage when contesting possession of the ball. Moreover, the greater the body mass, the greater the benefits during body contact situations with respect to stability, inertia and momentum, provided that there is no adverse effect on speed. While smallness in body size is not in itself a bar to success in soccer, a disadvantage during physical contests may increase the likelihood of missed opportunities at critical points in the developmental stages. That is, in a competitive training environment where an emphasis is placed on physical contests, smallness may result in a lack of opportunity to develop due to an inability to gain possession of the ball. Perhaps the sport is moving toward a Darwinian selection process in terms of physical characteristics where only the 'fittest' reach the highest level of participation.

Studies of male athletes have indicated that a number of sports have participants who are average or advanced in biological maturity (Malina et al., 1982). A study of Mexican soccer players suggested that there was a trend for boys advanced in sexual maturation to be more successful in soccer in late adolescence (Pena Reyes et al., 1994). In addition, Panfil et al. (1997) found that elite youth soccer players had a higher morphological age (more physically mature) than their less elite counterparts and that coaches favoured players advanced in morphological growth during the selection process. Clearly, an early onset of maturation can bestow an advantage in selection due to the greater than average body size and the aforementioned effects on soccer performance. It is therefore not surprising that the successful players in the present study demonstrated larger body sizes when compared to their less-successful counterparts.

The advantage of advanced biological maturity for selection into certain sports is highlighted by the observation that in some sports, individuals who are born at the start of the selection year have a distinct advantage of being selected over those born later in the year (Baxter-Jones et al., 1995; Brewer et al., 1995). An interesting feature to emerge from the present study was the trend in the successful players towards a higher number of births during the early phase of the selection year (September to December) (see Figure 4.3.2.). A 12-month difference in age can have enormous implications for performance capabilities. It is therefore not surprising that players with birth dates early in the eligibility season tend to be over-represented in England World Cup squads (Richardson, 1998). While late maturers are not necessarily smaller as adults, they may have missed opportunities for training at critical time points. Young players who mature early biologically may be given specialist coaching which late maturers are denied at the same chronological age (Reilly et al., 2000).



†P < 0.05 v Less-successful

Figure 4.3.2. Seasonal birth distribution of elite young male soccer players grouped according to eventual level of success. (Successful = 15, Less-successful = 35).

Body composition is more amenable to environmental and training factors than are linear anthropometric variables. Mean heritability coefficient for skinfold thickness is 0.55, but there is a large standard deviation (Reilly et al., 2000). Coefficients for somatotypes range from 0.35 to 0.50 suggesting that these characteristics may be a greater reflection of the demands imposed on athletes during training and competition (Reilly et al., 2000). Clearly, the ability to perform well in soccer requires continual physical training and responsiveness to the various types of training and competitive regimens (Bouchard et al., 1997). While responsiveness to training appears to be individualistic, it reflects both genetic variation and the exposure to regular training.

Body composition and its relationship with athletic performance, is of considerable importance in soccer. Evidence from the athletic population has demonstrated an inverse relationship between adiposity and performances of physical activities requiring translocation of the body mass either vertically, as in jumping, or horizontally as in running (Boileau and Lohman, 1977; Pate et al., 1989). Excess adiposity is detrimental in activities such as soccer because it adds mass to the body without additional capacity to produce force. Since acceleration is proportional to force but inversely proportional to mass, excess adiposity at a given level of force application will also result in slower changes in velocity and direction (Boileau and Lohman, 1977). The successful players had a lower rating of endomorphy than their less successful counterparts. Given that endomorphy is estimated from the relationship between the component value and the sum of three skinfold measures, relative to the subject's height, it is reasonable to suggest that successful players display body composition characteristics that favour good performances.

In order to cope with the physical requirements for elite soccer match-play, it is important that the players have a high level of muscularity. Soccer players tend to be well developed in muscularity, reflected in a characteristic physique (Reilly, 1990). The overall somatotype of successful and less-successful players was 2.5 ± 0.5 – 4.5 ± 1.2 – 2.7 ± 1.0; and 2.8 ± 0.6 – 4.4 ± 0.9 – 2.7 ± 0.8 respectively. These observations are similar to those obtained for elite young Portuguese soccer players (Garganta et al., 1993). The somatotype for the successful players represents a greater trend towards mesomorphy or muscularity compared with the less-successful players. Such a muscular profile would be of benefit to the successful players in game contexts with respect to withstanding external forces, turning and accelerating away from opponents. Given that a large body mass is also beneficial with respect to momentum in body contacts, musculo-skeletal robustness is essential to meet the successful requirements of the game.

In the present study, a mean difference of 3.4 kg was observed for muscle mass in successful and less successful players (successful 46.4 ± 5.3 kg; less-successful 43.0 ± 4.3 kg). A significant positive relationship between muscle mass and total distance covered during soccer match-play has been observed in adult players (Rienzi et al., 2000). This relation implies that individuals with a higher muscle mass can maintain a higher overall work-rate throughout competitive match-play. The advantage of having greater active muscle mass to recruit during exercise is also potentially useful in providing enhanced functional capacities during physical pursuits requiring strength, speed and power (Armstrong and Welsman, 1997). In young players the greater muscle mass may reflect a relative-age effect from being born in the early part of the competitive year.

Discriminant analysis separated the successful and unsuccessful players on the basis of estimated $\dot{V}O_{2max}$. Moreover, subjects from the successful group achieved all of the outstanding performances in the physiological measures (see Table 4.3.3). When the goalkeepers were removed from the sample, the mean $\dot{V}O_{2max}$ of the successful players increased to 60.1 ml.kg^{-1} min^{-1}. It may be that the consistent observation of mean $\dot{V}O_{2max}$ values exceeding 60 ml.kg^{-1} min^{-1} in elite male teams suggests the existence of a threshold below which an individual player is unlikely to perform successfully in top-class contemporary soccer (Reilly et al., 2000).

Physiological measures have been used in previous research in an attempt to identify key predictors of performance in soccer. Jankovic et al. (1997) compared successful and less successful 15 to 17-year olds using measures of anaerobic power, grip and trunk strength, heart volume and $\dot{V}O_{2max}$. The successful players were taller and heavier, had higher $\dot{V}O_{2max}$ and anaerobic power values, and greater heart volume than their less successful counterparts. Janssens et al. (1998) demonstrated that performance in short and prolonged 'shuttle' running discriminated between successful and less-successful young soccer players. Similarly, Panfil et al. (1997) reported that elite 16-year-olds recorded better performance in running and jumping than their less elite counterparts.

While these findings led Jankovic et al. (1997) to conclude that physiological measures could be useful in predicting later success, the possibility remains that the superiority of the successful players in the above studies was due in part to a more systematic approach to training before their induction into the specialised squads. In the present study, the elite young soccer players had already undergone selection processes and been exposed to long term systematised training regimens. It follows that in a sample of elite soccer players already exposed to systematised training, talent becomes harder to predict due to interrelated physiological, biomechanical and psychological factors (Franks et al., 1999). Nevertheless, statistical procedures may yield group distinctiveness in physiological parameters such as $\dot{V}O_{2max}$.

Endurance training of sufficient duration and intensity induces increases in $\dot{V}O_{2max}$ (Tabata et al., 1996; Helgerud et al., 2001). Changes in aerobic performance caused by participation in an endurance training programme can be characterised by considerable individual differences (Lortie et al., 1984). The initial phase of the training response is more related to environmental and training factors, while the later phase, that is when getting closer to maximal trainability, is more related to heredity (Hamel et al., 1986). Therefore, a high level of aerobic performance will be the result of prior endowment, an adequate training programme, and genetic characteristics associated with the status of a high responder to training (Bouchard and Malina, 1983).

There are limited data on the anaerobic power of young soccer players. Caru et al. (1970) tested 95 soccer players aged 14-18 years. The soccer players had higher values than non-athletes of similar ages. Anaerobic performance profiles have also incorporated short all-out runs. Sena et al. (1997) used five 30-m sprints with a recovery of 90 s between repetitions when assessing young players at Porto F.C. Speed increased with age providing evidence for age-related developmental improvements. In a sample of 64 players who attended the National School, no differences were observed between those who were deemed to be more or less successful (Franks et al., 1999). However, given the emphasis on speed and power in contemporary soccer, small differences in anaerobic qualities may be influential in determining successful performance.

Contemporary soccer is now played at a higher 'tempo' than 10 years ago (Williams et al., 1999). It is likely therefore, that speed of movement has gained in importance in the context of fitness for the game in contemporary professional soccer. While differences in sprint times did not reach the required level of significance, small but discrete differences may afford successful players an advantage over less-successful players during competitive match-play. The successful players were on average approximately 0.5 m ahead of the less-successful after 10 m. This difference is similar to those observed between professional and amateur German soccer players (Kollath and Quade, 1993). Such an advantage over 10 m may make the difference between winning and losing possession of the ball. On this basis, maximal mobilisation of force over short distances may be an important determinant of successful soccer performance. Moreover, the ability to produce as much force as possible in the shortest possible time is one of the characteristics that distinguish successful players from less-successful players.

Anaerobic power remains a critical performance variable relevant to accelerating the body during short movements, in jumping to win the ball or contest its possession in the air. The importance of power output during these explosive bouts of the game becomes readily apparent when the increasing influence of set plays and aerial contests during contemporary soccer is considered. Set plays are becoming increasingly important in international, European and domestic soccer (Taylor et al., 2002). The key principle for consideration, however, is the availability of individual players for these particular circumstances. Players who maximise their power during aerial contests ultimately increase their chances of success over their 'less explosive' counterparts. In the present study, the vertical jump heights of the successful players were on average approximately 2 cm higher than the less-successful players. Such a performance difference may determine the players' relative success in elite soccer and afford the successful players an advantage during critical moments of the game.

The ability to sprint repeatedly during competitive match-play is important in soccer (Bangsbo, 2003). This ability can be evaluated by having the players perform a number of sprints each separated by a break that is so short that the players are unable to recover fully before the next sprint. In the present study, no differences were observed between successful and less-successful players, suggesting that this test was not sensitive enough to differentiate between players who have already been exposed to systematic training. Such similarities are probably a reflection of environmental and training factors and a result of the long-term exposure of players to intermittent type exercise.

Various factors predispose towards a successful career in professional soccer. Foremost among these are excellent technical and tactical abilities. According to Reilly et al. (2000), in view of the heterogeneity observed in anthropometric and physiological characteristics among top teams, it is not possible to isolate individual prerequisites for success with great confidence. Nevertheless, the present findings suggest that successful young soccer players have a somewhat above average height and mass, a favourable body composition, moderate to high aerobic power and are capable of generating high power output during fast movements. Although no factors have been identified as markers of potential in soccer, the ability to respond to systematic training is important. It follows that for successful players, the presence of an ideal body structure contributes to achievement potential. This is reflected in the present study in the anthropometric differences observed between successful and less-successful players. In addition, estimated $\dot{V}O_{2max}$ plays a prominent role in determining a player's employability as a professional. Moreover, a greater sample population may yield significant differences at the statistical level. Indeed the numbers of players in the current study may weaken inferences that can be drawn regarding the differences in physiological measures between successful and less-successful players.

Clearly, more research is required encompassing a greater sample population.

While the H_O could be partially accepted on the grounds of anthropometric characteristics, the following hypothesis was accepted:

C. H_O: At an elite level of play, anthropometric and physiological characteristics do not vary between successful and less successful players.

4.4 ANTHROPOMETRIC AND FITNESS PROFILES OF ELITE PLAYERS IN TWO FOOTBALL CODES

4.4.1 Introduction

Within the football codes there has been an increasing emphasis on work-rate during competitive play with a requirement for mobility around the field. This trend is thought to apply not just to professional soccer but also to Gaelic Football, which though still largely an amateur game, makes heavy commitments on its elite players. In the first two studies in this thesis, the subjects were professional soccer players in the Premier League. In the next study, talented young soccer players were observed. The approach in this study was to return to the Premier League players who might be compared with top performers in another football code.

Gaelic Football is the national game in Ireland and is played by Irish communities overseas. Fifteen players represent each team, and the ball can be played with the hands or the feet. The playing field is over 40% larger than a soccer pitch. A point is scored when the ball crosses between the two goal-posts and over the bar, a goal (equal to 3 points) when the ball crosses the goal-line beneath the cross-bar. The main skills of the game include high catching, long-distance kicking, passing the ball quickly and accurately by hand or foot, agility in side-stepping opponents whilst holding possession of the ball, and blocking an opponent's kick or hand-pass. Current tactics require continuous movement off-the-ball and marking opposing players tightly. The relative intensity of competitive match-play is roughly equivalent to that observed for soccer although the duration of inter-county matches is 20 min less than in soccer (Florida-James and Reilly, 1995). The physiological demands on a player are governed by the irregular changes of pace and anaerobic efforts that are superimposed on a backdrop of sustained light to moderate aerobic activity. These demands are accentuated by the practice of man-to-man marking.

Apart from the method of scoring, the main differences between Gaelic Football and Rugby Union are that in the former tackling is restricted to shoulder-to-shoulder charges, set plays are limited to free kicks and sideline kicks, and a maximum of four steps may be taken without playing the ball. County teams represent elite performance and players typically train or compete 5-6 days each week.

The physiology of soccer has been reviewed in the past (e.g. Bangsbo, 1994a; Reilly, 1997: Shephard, 1999). The game is considered to place demands on the aerobic system with intermittent calls on anaerobic metabolism. A broadly similar view has been reported for Gaelic Football, the game being played on a larger field than soccer and play lasting for 70 min at inter-county level (Reilly and Doran, 2001). A direct comparison of the elite level players in each of the football codes has not hitherto been conducted. Consequently, the purpose of the present study was to examine the anthropometric and fitness profiles of players at an elite level in each of those football codes with a view to making comparisons between them. Such data may also facilitate a better understanding of the anthropometric and physiological requirements for success in elite male soccer play.

4.4.1.1 Statement of hypotheses

D. H_O: Anthropometric and physiological characteristics do not vary between soccer and Gaelic football players.

4.4.2 Methods

4.4.2.1 Subjects

Subjects were 19 professional soccer players (age 22 ± 2.0 years) and 33 inter-county Gaelic Football players (age 23 ± 5.0 years). The soccer players were members of a Premier League squad and were studied throughout an entire competitive season. Anthropometric and fitness profiles were obtained on all soccer players during a period of intensive pre-season training (July to August). These subjects were also used in Chapter 4.1 and 4.2. The Gaelic footballers were members of the Mayo squad preparing for the 1999 All-Ireland championship.

4.4.2.2 Procedures

All procedures were approved by the Human Ethics Committee of Liverpool John Moores University. Subjects were fully informed about the aims, procedures and the demands that the tests would place upon them, together with any possible risks and discomforts before written consent was obtained. All of the tests undertaken were familiar to the subjects as part of their ongoing fitness assessment. The test battery included a number a field tests designed to measure anaerobic and aerobic performance. The fitness variables included maximal oxygen uptake (Ramsbottom et al., 1988), intermittent sprint capacity (Reilly, 2001), sprint speed and leg power. Anthropometric variables included muscle mass (Martin et al., 1990), body mass, adiposity (Reilly et al., 1996, Durnin and Womersley, 1974), stature and somatotype (Heath and Carter, 1967). The methods used to determine these characteristics are described in sections 4.1.2.2 and 4.2.2.2. The data for Gaelic footballers were collected by a research team from Liverpool John Moores University and made available for comparable analysis. In addition, a change in the method for determining vertical jump was employed. Vertical jump was measured as the rise height of the centre of mass using a jump dynamometer (Takei, Japan). Such a method employs a measuring tape around the athlete's waist that unreels with the distance jumped vertically. Subjects were instructed to take off and land within a marked area on a jump mat. Prior to the jump the subjects performed a fast counter-movement. Throughout the jump, the subjects were allowed to swing their arms freely.

4.4.2.3 Statistical analyses

The statistical analyses of data were carried out using t-tests. No corrections were made for the use of multiple t-tests. The level of significance was accepted at $P<0.05$.

4.4.3 Results

The anthropometric characteristics of the subjects are presented in Table 4.4.1. There were no significant differences between the groups for stature, body mass, estimated percent body fat or percent muscle mass. A variance ratio test indicated that the variability in stature was significantly greater in the soccer players compared to the Gaelic footballers (P<0.01).

Table 4.4.1. Anthropometric characteristics of elite players in two football codes (mean ± S.D). (Soccer players = 19, Gaelic Football players = 33).

	Stature (m)	Body mass (kg)	% Adiposity	Muscle mass (%)
	Mean ± S.D	Mean ± S.D	Mean ± S.D	Mean ± S.D
Soccer	1.77 ± 0.07	77.9 ± 8.9	11.2 ± 1.8	62.4 ± 3.3
Gaelic Football	1.79 ± 0.07	79.2 ± 8.2	12.3 ± 2.9	60.7 ± 2.4

The mean ± S.D. somatotype of soccer and Gaelic Football players was 2.5 ± 0.4 – 5.7 ± 0.8 – 2.0 ± 0.6 and 2.7 ± 0.5 – 5.7 ± 0.8 – 1.9 ± 0.6 respectively. The somatotype for the Gaelic Football players represents a trend towards medium endomorphy compared with the soccer players.

Variables related to the performance characteristics of the subjects are presented in Table 4.4.2. There were no significant differences between the groups for estimated $\dot{V}O_{2max}$. The mean value for the two groups combined was 59 $ml \cdot kg^{-1} \cdot min^{-1}$. Vertical jump was significantly greater in the soccer players compared to the Gaelic Football group (P<0.01). Performance in the 10-m and 30-m components of the sprint was significantly faster among members of the soccer group compared to the Gaelic footballers (P<0.01)

(Table 4.4.3.). No differences were observed between the groups for recovery, as expressed by the fatigue index for the 10-m and 30-m sprints.

Table 4.4.2. Performance characteristics of elite players in two football codes (mean ± S.D).

	$\dot{V}O_{2max}$ ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$)	Vertical jump (cm)
Soccer (n=19)	59.4 ± 6.2	63.4 ± 5.7†
Gaelic Football (n=33)	58.8 ± 3.8	58.3 ± 6.7

† P < 0.01 v Gaelic Football

Table 4.4.3. Sprint performance over 10 and 30 m and fatigue profiles for elite players in two football codes (mean ± S.D).

	10 m Sprint (s) Mean ± S.D	Fatigue Index (%) 0-10 m Mean ± S.D	30 m Sprint (s) Mean ± S.D	Fatigue Index (%) 0-30 m Mean ± S.D
Soccer (n=19)	1.75 ± 0.08†	8.92 ± 6.6	4.28 ± 0.12†	9.74 ± 3.2
Gaelic Football (n=33)	1.89 ± 0.17	10.5 ± 5.2	4.60 ± 0.30	9.72 ± 0.3

† P < 0.01 v Gaelic Football

4.3.4 Discussion

The soccer players and Gaelic footballers can be described as lean and muscular with a reasonably high level in all areas of physical performance. The anaerobic performance characteristics of the professional soccer players were superior to those of Gaelic Football players and reflect a greater requirement for speed over short distances at an elite level of soccer play.

Body composition is an important aspect of fitness for football as superfluous body fat acts as dead weight in activities where body mass is lifted repeatedly against gravity in running or jumping during play (Reilly, 1994b). It appears that low adiposity and high muscularity is advantageous because of the need to be mobile around the field and contest for possession of the ball. The Gaelic footballers were no different in anthropometric characteristics from either the current Premier League players or the South American international soccer players reported by Rienzi et al. (2000).

A comprehensive anthropometric profile of 95 international soccer players at the Copa America Championships in Uruguay yielded estimated adiposity values of 11% and muscle mass values averaging 62% (Rienzi et al., 1998). These figures are close to those observed in the present study for both groups and those reported for international rugby sevens players (Rienzi et al., 1999). The muscle mass estimates reported in the present study for Gaelic Football players are considerably higher than the estimates for Lancashire League U21 players (41.9 ± 5.4%) whose values were below those reported for University soccer players (Florida-James and Reilly, 1995). In this instance, the small proportionate muscle mass could be due to a combination of age and a lack of systematic training at the sub-elite level of play.

The muscular make-up of elite players in either code is evidenced in their somatotype. In both football codes shoulder-to-shoulder charging and tackling are permitted by the rules of play. A high degree of muscularity is therefore likely to be of benefit in a competitive setting. The physiques of the players in the present study represent a trend towards mesomorphy. Such a physique becomes beneficial when the demands of competitive match-play are considered. The leg muscles of players in either code will clearly be employed in kicking and punting, the arm muscles used in hand-passing and holding off opponents, while whole-body musculature can be deployed in shoulder-to-shoulder contact and in tackling. The somatotypes reported in the present study for soccer and Gaelic Football players are close to the values described for international Rugby Union seven-a-side representatives (Reilly et al., 2000).

In the present study, no differences were observed between players in either code for estimated $\dot{V}O_{2max}$. This suggests that elite players in both codes must possess a reasonably high $\dot{V}O_{2max}$, which will influence work-rate and critical involvement during match-play. Keane et al. (1997) employed Cooper's 12-min run test (Cooper, 1968) as a measure of aerobic fitness for Gaelic Football players. They reported higher values for distance run by 35 inter-county squad members (2990 ± 182 m) than by 34 senior club players (2866 ± 207 m). Reilly and Keane (2002) demonstrated changes in inter-county players in performance of this test from January (2633 ± 151 m) to May (3028 ± 114 m) at the start of the championship season. No measurements were obtained during the championship campaign in which the team became All-Ireland champions so the peak performance capabilities of the team are likely to have been missed. However, the highest mean values exceed the mean of 2976 m reported for professional soccer players in the U.S.A. (Raven et al., 1976). Comparative data are not available for contemporary professional soccer players. Nevertheless, this comparison reflects that elite Gaelic Football teams with systematic training programmes can reach high levels of endurance fitness in preparation for the All-Ireland title (Reilly and Doran, 2001).

Whilst aerobic fitness is important in the football codes, speed over short distances is influential in beating an opponent to the ball and avoiding tackles. Muscular strength and power are also relevant in many games contexts and in particular, tackling, kicking the ball and jumping to win possession of the ball.

In order to cope with the physical requirements for elite match-play, it is important that the players have a high level of speed, agility, muscular strength and anaerobic power. The anaerobic characteristics of professional soccer players in the current study are superior to those of Gaelic Football players. This would suggest a greater requirement for speed at an elite level of soccer match-play. Whilst both groups were similar on the aerobic test, the soccer players were distinguished by their greater abilities in jumping and sprinting.

There has not been a systematic approach towards testing components of speed and muscular power in Gaelic Football players. Nevertheless some common laboratory-based and field-based tests have been employed. The mean values of inter-county Gaelic Football players for vertical jump are comparable with the observations on professional soccer players. Reilly (1979) reported mean values of 219 cm for English League soccer players. These values are comparable to those reported by Young and Murphy (1994) for 21 inter-county Gaelic football players (229 ± 16 cm). The vertical jump performances of the inter-county players studied by Keane et al. (1997) were 58.4 ± 6.4 cm, similar to those reported for Gaelic Football players in this study and higher than those reported for first-class Rugby Union players monitored by Rigg and Reilly (1988) prior to the professionalisation of the sport.

Laboratory-based tests of anaerobic power have rarely been reported in the assessment of Gaelic Football players within Ireland. Both the stair-run test (Margaria et al., 1966) and the Wingate anaerobic test (Bar-Or, 1987) have been employed in the assessment of English-domiciled club players. The values recorded for the stair-run test (1049 ± 99 W), and for mean power and peak power in the Wingate test (518 ± 59 W; 838 ± 88 W respectively), were significantly lower than those values reported for age-matched University soccer players (Kirgan and Reilly, 1993). Indeed, much higher values would be expected for leg power, and upper-body power output at an elite level of play in light of the demands for quick bursts of activity and the ability to break free of tackles (Reilly and Doran, 2001).

The conditioning programme for football players will also impact upon their physical characteristics. The emphasis of conditioning for Gaelic Football players may be placed more on aerobic endurance training than explosive strength development. Indeed, there is some evidence to suggest an inhibition of explosive leg strength (Vertical jump) during an aerobic conditioning period (Reilly and Thomas, 1977). The comprehensive preparation for professional soccer players involves the development of speed and explosive leg strength in the form of 'plyometric' and 'complex' training methods. The former engages stretch-shortening cycles of muscle action whilst 'complex' training involves a combination of resistance training and 'plyometric' work replicating sport-specific movements. While the conditioning programme for Gaelic Football players may be effective for the development of aerobic power, it seems that more emphasis should be placed on explosive strength development and improvements in speed over short distances in order to equal the fitness profiles of the soccer players.

The ability to sprint repeatedly during competitive match-play is of great importance in the football codes. In the present study, no differences were observed between soccer and Gaelic Football players suggesting that this test was not sensitive enough to differentiate between the football codes. Such similarities are probably a reflection of environmental and training factors and a result of the long-term exposure of players to intermittent type exercise. Moreover, given that an increased tolerance to fatigue in the IST is associated with improvements to the oxygen transport system (Reilly and Doran, 2001), and the fact that the $\dot{V}O_{2max}$ values were similar in soccer and Gaelic Football players, these findings were expected.

In summary, differences between players in each of the football codes in anthropometric and performance measures are likely to be due to the specificity of positional roles within the codes. Therefore, the physical capacity of the players in the present study may indicate the physiological demands of each sport. While the present thesis is concerned with soccer, a comparison with top performers in another football code adds valuable information to the holistic picture of the demands of elite soccer participation. The combined groups could be described as lean and muscular with a reasonably high level in all areas of physical performance. However, the anaerobic performance characteristics of the professional soccer players were superior to those of the Gaelic Football players and reflect a greater requirement for speed over short distances at an elite level of soccer match-play.

Therefore the following hypothesis was rejected:

D. H_O: Anthropometric and physiological characteristics do not vary between soccer and Gaelic Football players.

4.5 SUMMARY

The aim in this chapter was to investigate the anthropometric characteristics of elite soccer players. A further aim was to identify unique characteristics that are exclusive to soccer players. These aims were explored by means of comparison with other sports and a comprehensive analysis of the characteristics of successful young players.

The soccer players in this thesis can be described as lean and muscular with a reasonably high level in all areas of physical performance. This profile has implications for the demands of soccer, as the players need to meet these demands with appropriate physiological characteristics. The findings also have implications for subject selection in laboratory investigations, as such characteristics must be matched if inferences can be drawn to the soccer playing population. Analysis of positional differences revealed that soccer players constitute a relatively heterogeneous group in terms of physiological specificity. It would appear that there are specific role requirements of players during competitive match-play and that these demands are reflected in their performance on field-based physiological tests. Underage players were discriminated on the basis of eventual success on the basis of physiological measures. Moreover, factors related to body size, physique and aerobic endurance performance play a prominent role in determining success in soccer match-play. In addition, comparison with another football code namely Gaelic Football, highlighted the importance of quickness over a short distance as a distinguishing feature of professional soccer players.

In conclusion, the principal findings of the studies in this chapter were:

Anthropometric characteristics of soccer players varied according to different playing positions. Goalkeepers and central defenders were significantly taller than full-backs, midfield players and forwards. Goalkeepers were also significantly heavier than full-backs and midfield players. Each position demands specific tasks during different phases of the game and players have to meet these requirements with a demonstration of appropriate anthropometric characteristics.

Fitness profiles varied according to different playing positions. Midfield players and full-backs demonstrated greater performance profiles in aerobic tests of fitness than players in other positions. Forward players on the other hand demonstrated better performances in speed and power-related tests than all other players. Reasons for these differences will be further addressed in the next chapter where work-rate profiles will be investigated.

Discriminant function analysis identified three variables for distinguishing between successful and less-successful soccer players. The main variables contributing to group separation were body mass, endomorphy and estimated $\dot{V}O_{2max}$. These results suggest that appropriate anthropometric characteristics such as stature and body mass play a prominent role in determining success in soccer.

A variance ratio test indicated that the variability in stature was significantly greater in soccer players compared to Gaelic footballers. Fitness profiles varied between soccer and Gaelic football players. Such differences in terms of anaerobic sprint and jump performance suggest that the power demands are greater in soccer than Gaelic Football. Moreover, anaerobic power is one quality that differentiates soccer from other football codes.

The assessment of players revealed a general picture of the characteristics required for performance. To clarify the picture, an assessment of the demands of the game of soccer is required. This topic will be explored in the next chapter.

CHAPTER 5

CHAPTER V

5. THE DEMANDS OF ELITE SOCCER

This chapter contains three studies, which combined provide information relating to the physiological stresses of playing at an elite level of soccer. The purpose of the first study was to quantify the physiological stresses associated with elite competitive match-play and identify any positional variations between players. The purpose of the second study was to utilise the techniques of motion analysis to determine the work-rate profiles of elite players. The final study was focused on the physiological stresses imposed on elite players during intensive training pre-season and in-season. Such strategies were combined to provide an overall indicator of the physiological demands of elite competition.

5.1 AN ESTIMATION OF PHYSIOLOGICAL STRAIN IMPOSED ON ELITE MALE SOCCER PLAYERS DURING COMPETITIVE MATCH-PLAY

5.1.1 Introduction

The physiological demands of soccer can be examined by making relevant observations during competitive match-play. With the advancement of technology, physiological measurements have been made less invasive and easier to use in a field setting. The relative metabolic loading during competitive match-play could be indicated if direct measurements are available for both energy expenditure during competition and the maximal aerobic power (Reilly, 1994a). Direct measurements of oxygen uptake ($\dot{V}O_2$) made from collections of expired air have been employed to calculate energy expenditure rates during aspects of match-play (Ogushi et al., 1993). However, these measurements are likely to underestimate energy expenditure due to the restrictions placed on the players by the gas collection apparatus. An alternative research strategy has been to measure heart rate during match-play and juxtapose the observations on heart rate-$\dot{V}O_2$ regression lines determined during incremental running on a treadmill (Reilly, 1997). The estimate of $\dot{V}O_2$ from observations of heart rate in theory would overstate the actual O_2 consumption due to the factors (heat, stress, static exercises) that cause heart rate but not $\dot{V}O_2$ to rise (Astrand and Rodahl, 1986). The error is thought to be small in soccer because of the high exercise intensity and the dominant use of large muscle groups (Bangsbo, 1994a). Nevertheless, the heart rate in itself provides a useful index of the overall physiological strain, quite apart from its use in estimating $\dot{V}O_2$ (Reilly and Thomas, 1979).

A number of studies confirm that the circulatory strain during match-play is relatively high. Seliger (1968) reported the mean heart rate during a competitive game for Czech players to be 165 beats$\cdot$min^{-1}, or 80% of maximal heart rate. Rhode and Esperson (1988) reported that the heart rate response for Danish players participating in 1st division games was below 73% of maximal heart rate for 11% of the total playing time, between 73% and 92% of maximal heart rate for 63% of the playing time, and greater than 92% of maximal heart rate for 26% of the total playing time.

Heart rate varies with exercise intensity and may differ between playing positions and between first and second halves. Van Gool et al. (1988) reported mean figures of 155 beats$\cdot$min^{-1} for defenders, 170 beats$\cdot$min^{-1} for a midfield player, and 168 beats$\cdot$min^{-1} for a forward player. This pattern was closely related to the distances covered by players and provides evidence that the physiological stresses of soccer match-play vary with positional roles. The same research group reported mean values for a Belgian University team during a friendly match of 169 beats$\cdot$min^{-1} in the first half and 165 beats$\cdot$min^{-1} in the second half. Again, the physiological responses reflected a drop in the work-rate during the second half.

While reasearchers have compared work-rates between first and second halves (Bangsbo et al., 1991), the deterioration in work-rate towards the end of the game may not occur in all players. Clearly, more research is required to establish the physiological stresses associated with elite soccer participation. Such a requirement has led to the formulation of the following hypotheses:

5.1.1.1 Statement of Hypotheses

A. H_O: At an elite level of play, heart rate profiles do not vary according to different playing positions.

B. H_O: At an elite level, heart rate profiles do not vary between time periods of the game.

There have been few contemporary investigations of heart rate profiles during competitive match-play. The purposes of this study was to establish an estimation of the physiological strain imposed on elite Premier League players and identify any positional variations between players. Such data may also yield important information concerning the design of laboratory-based soccer protocols.

5.1.2 Methods

5.1.2.1 Subjects

Subjects were twenty-eight (7 central defenders, 7 full-backs, 7 midfield players and 7 forwards) full-time professional male soccer players of a Premier League squad (age 25 ± 6 years). For the purpose of the study, only subjects who had represented the 1st team in the Premier League were included.

5.1.2.2 Procedures

Anthropometric and fitness profiles were obtained on all players during a period of intensive pre-season training (August). All of the tests undertaken were familiar to the subjects as part of their ongoing fitness assessment. The fitness variables included maximal oxygen uptake (Ramsbottom et al., 1988), agility, sprint speed and leg power. Methods for the determination of these variables are described in section 4.2.2.2. Anthropometric variables included muscle mass (Martin et al., 1990), body mass, adiposity (Durnin and Womersley, 1974, Reilly et al., 1996), stature and somatotype calculated by the Heath-Carter (1967), anthropometric method. Methods for the determination of anthropometric variables are described in section 4.1.2.2.

Each subject's heart rate was monitored during competitive match-play via short-range radio telemetry (SportTester^{TM}, PE3000) sampled at 5-s intervals. Heart rates were randomly monitored during competitive 1st team fixtures. These included English Cup competitions and Premier League fixtures. For the purpose of this study, no more than two players were monitored for the same competitive match. In total, twenty two matches were used for analysis during the study period.

Following each competitive match, heart-rate data were downloaded into a computer software package for analysis (Polar Precision Performance SW, 2000). This software computed maximum and mean heart rates for the entire competitive match. Such software also allowed for calculation of time spent in categories of intensity as well as the distribution of heart rates over time intervals.

The heart rate responses were divided into four categories of intensity: Maximal (>90 % HR_{max}), High Intensity (80-90 % HR_{max}), Moderate Intensity (60-79 % HR_{max}) and Low Intensity (<60 % HR_{max}). Maximal heart rate (HR_{max}) was recorded as the highest attained during the 20 m shuttle run (Ramsbottom et al., 1988).

5.1.2.3 Statistical analyses

Differences between time periods within a match were determined using one-way analyses of variance with repeated measures. Bonferroni multiple comparisons were carried out to identify where any differences that were found lay. Significance was accepted at $P<0.05$.

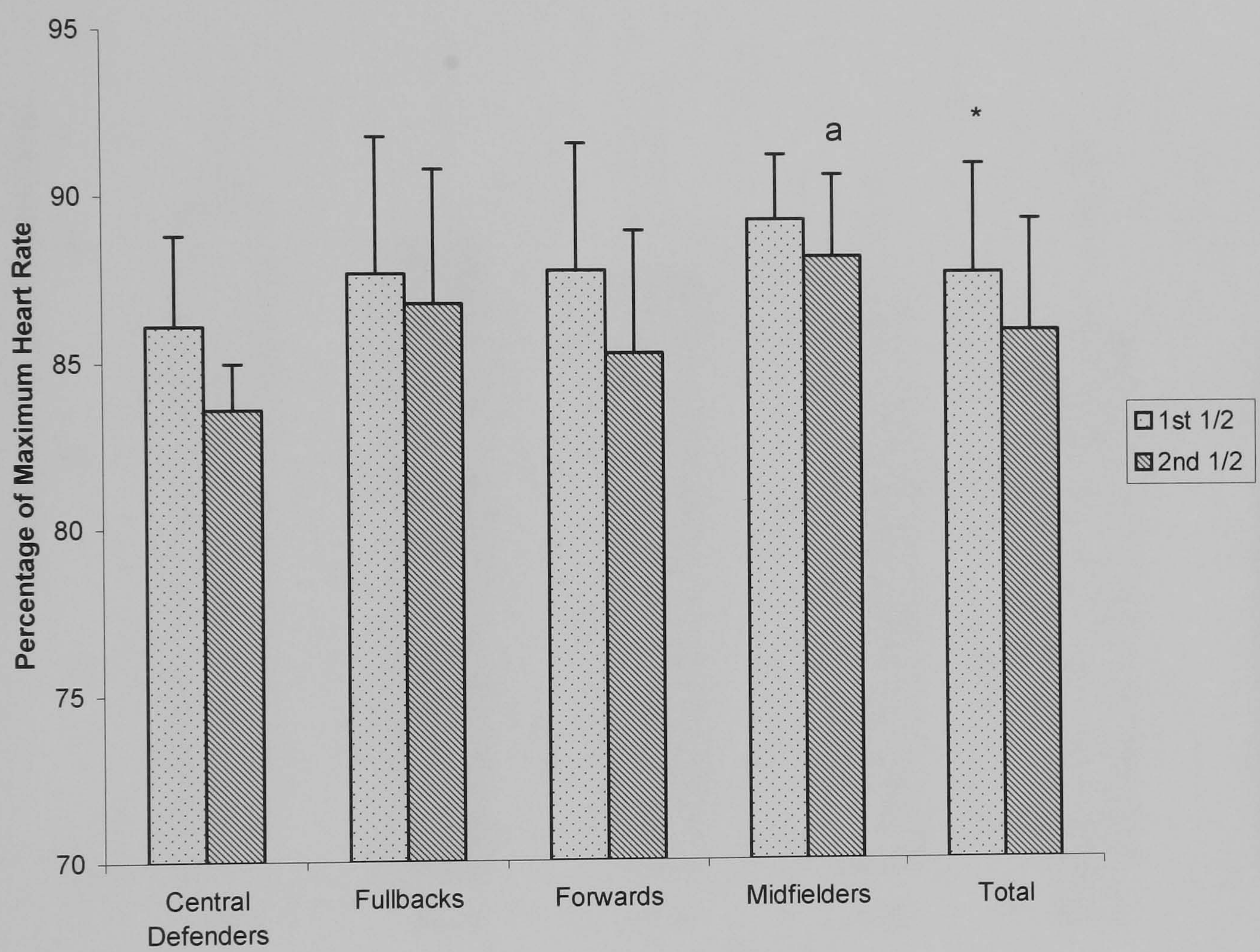
5.1.3 Results

The anthropometric and performance characteristics of the subjects are presented in Table 5.1.1. The ranges for stature, body mass, and adiposity are in line with the figures reported in Chapter IV for elite soccer players. The mean ± S.D. somatotype for the subjects was 2.5 ± 0.4 – 5.7 ± 0.8 – 2.0 ± 0.6.

Table 5.1.1. Anthropometric and performance characteristics of elite male soccer players (mean ± S.D). (n = 28).

Stature (m)	1.81 ± 0.06
(Range)	(1.73 – 1.94)
Body mass (kg)	79.9 ± 7.0
(Range)	(67.5 – 90.0)
Muscle mass (%)	61.5 ± 2.4
(Range)	(57.0 – 66.2)
Adiposity (mm)	32.6 ± 6.3
(Range)	(30.9 – 34.7)
Maximum heart rate (beats·min^{-1})	196 ± 7.0
(Range)	(179 – 208)
Estimated $\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	59.9 ± 1.7
(Range)	(58.2 – 67.5)

The mean heart rates during competitive match-play are shown in Figure 5.1.1. The mean heart rate response for all positions during competitive match-play was 171 ± 9 beats·min^{-1} corresponding to 87.2% of HR_{max}. The mean heart rate response for forwards, defenders, full-backs and midfielders was 86.5%, 84.9%, 87.3% and 88.7% of HR_{max} respectively. No significant differences were observed between positions for heart rate responses during the first half of match-play. However, midfielders had significantly higher heart rates compared to central defenders in the second half of the games ($F_{3,24}=2.896$; $P=0.046$). A significant reduction in heart rate was noted in the second half compared to the first half when the sample was taken as a whole ($F_{23,32}=2.139$; $P=0.023$).

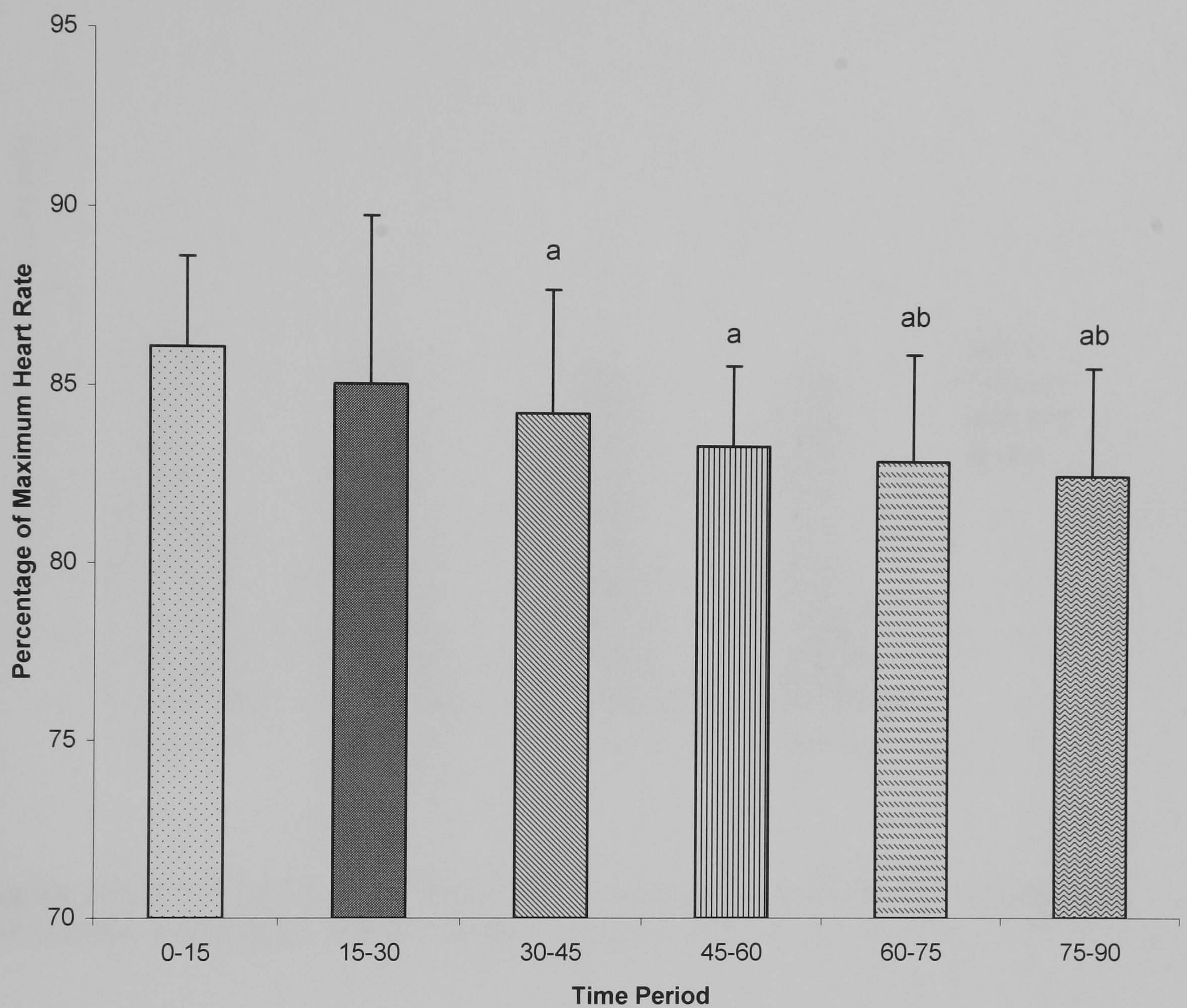


[a] $P < 0.05$ v Central Defenders

* $P < 0.05$ v 2nd ½

Figure 5.1.1. Mean heart rate response (percentage of HR_{max}) during competitive match-play for elite male soccer players grouped according to their position in the team (mean ± S.D) (n = 28).

Heart rate responses over the entire match, as expressed in 15-min periods are shown in Figure 5.1.2. Peak heart rate responses were recorded in the first 30 min of matches. Thereafter, significant reductions in heart rate responses were observed ($F_{2.2,135}$ =11.802; P<0.0001).



[a] P < 0.001 v 0-15 min
[b] P < 0.01 v 15-30 min

Figure 5.1.2. Mean heart rate (percentage of HR_{max}) during different 15-min periods of competitive match-play (mean ± S.D). (n = 28).

During competitive match-play, 32.5%, 46.0%, 21.1% and 0.5% of the time was spent in the maximal, high-intensity, moderate intensity and low intensity zones, respectively. The relative intensities indicate a high cardiac strain with heart rate exceeding 80% of the individual maximal value for over 78% of the event. The heart rates suggested higher exertion in midfield players and full-backs than forwards and central defenders (Figure 5.1.3.). The relative time spent in the maximal zone for forwards, defenders, full-backs and midfielders was 26.8%, 20.1%, 35.8% and 36.2% of HR_{max} respectively. These variations in exertion, were not significantly different according to one-way analysis of variance ($F_{3,24}$ =1.260; P<0.310).

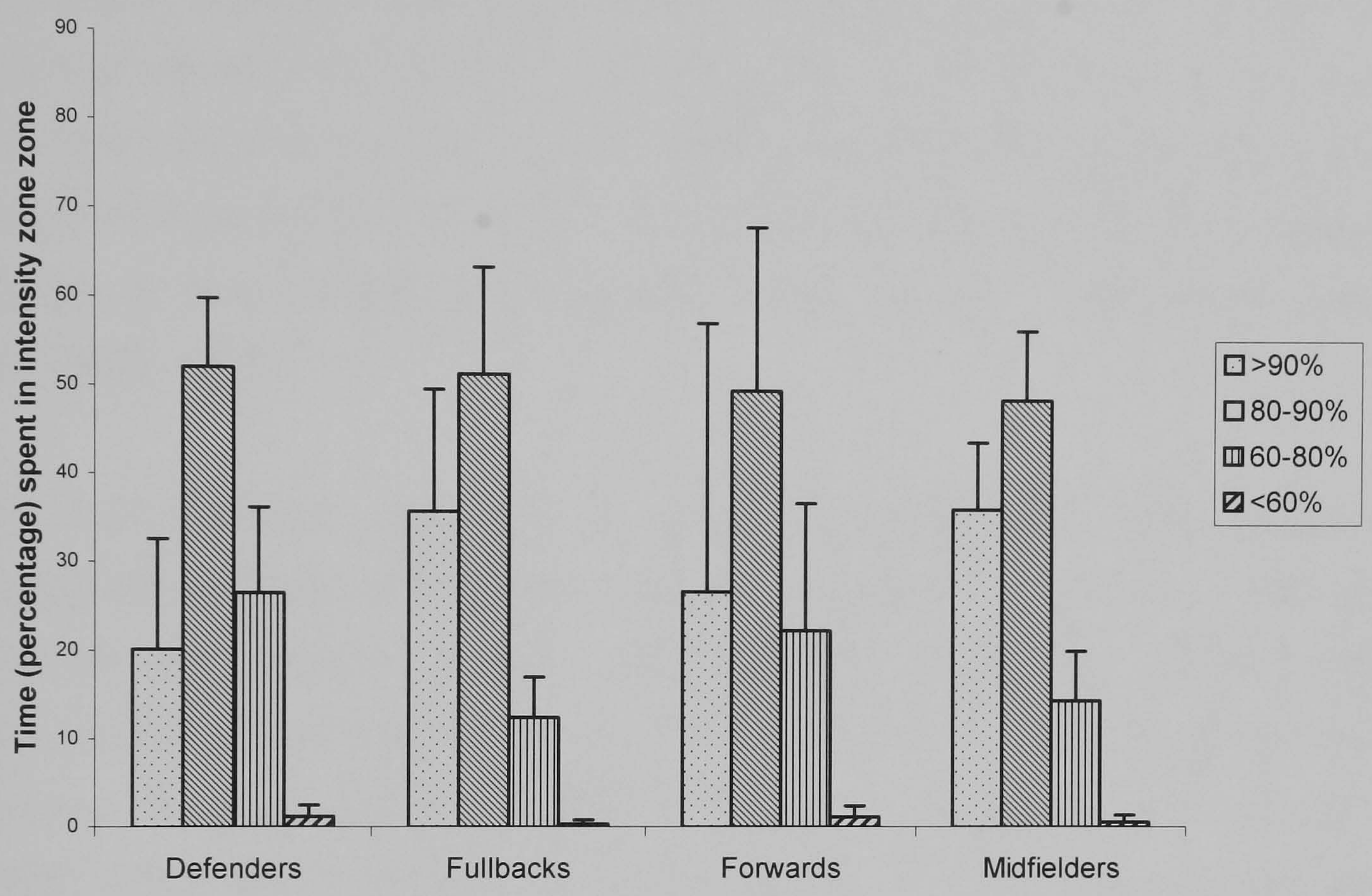


Figure 5.1.3. Percentage of time spent in various intensity zones during elite competitive match-play (mean ± S.D). (n = 28).

5.1.4 Discussion

The mean heart rate response during competitive match-play was 171 ± 9 beats$\cdot$min^{-1} corresponding to 87.2% of HR_{max}. In terms of relative time spent in exercise intensity zones, 32.5%, 46.0%, 21.1% and 0.5% of the time was spent in the maximal, high-intensity, moderate intensity and low intensity zones respectively. These relative intensities indicate that the strain on the circulatory system is high with heart rate exceeding 80% of the individual maximal value for over 78% of the competition. A similar heart rate response has been reported in elite soccer, Gaelic Football and Rugby Union where repeated high-intensity bouts of exercise elevate heart rates for prolonged periods of time (Rhode and Esperson, 1988; McLean, 1992; Florida-James and Reilly, 1995).

The high exercise intensities observed in the present study reflect the physiological stress associated with soccer-specific movement patterns as well as the orthodox running and walking. Reilly and Bowen (1984) documented the additional energy costs of changes in directional modes of running. Running backwards and sideways produced energy expenditure levels which were significantly greater than running forwards at the same speed. Reilly and Ball (1984) also observed that dribbling a ball significantly increases the energy cost of motion by approximately 7.2 to 10.8% when compared to running at a given speed. Accelerating, stopping, turning, jumping and irregular/feigned movements all determine the exercise intensity observed during a game (Ekblom, 1986; Shephard, 1992; Reilly, 1997). Such unorthodox modes of motion and game-specific activities increase the physiological strain during soccer compared with linear motion exercise and offer some explanation of the relatively high work-rate associated with competitive match-play.

Characteristic work-rate profiles have emerged in relation to playing position. Midfielders and full-backs cover greater distances during competitive match-play than forwards and central defenders (Reilly and Thomas, 1976; Withers et al., 1982; Van Gool et al., 1988; Bangsbo et al., 1991; Rienzi et al., 2000; Mohr et al., 2003). Clearly, these work-rate profiles reflect the tactical demands of elite competition associated with playing positions and determine the physiological responses to match-play .

The greatest work-rate in soccer is imposed on midfield players who serve as a link between defence and attack. Such duties require a greater distance to be covered during match-play, as there is an emphasis on sustained running (Reilly and Thomas, 1976). Such a work-rate profile is characterised by less static pauses and a greater percentage of the total distance covered jogging (Drust, 1997; Rienzi et al., 2000). The central defender's work-rate profile is characterised by sudden bursts of high-intensity exercise interspersed with recovery periods at low intensity that seem to indicate a limited involvement in the play. This work-rate profile contains an increased number of static pauses during competitive match-play (central defenders 285 ± 79; midfield players 255 ± 31; forwards 260 ± 41) (Drust, 1997). Moreover, central defenders cover less total distance and perform less high-intensity running than players in other positions (Mohr et al., 2003). The forward player's work-rate profile is reflected by sudden bursts of high-intensity activity, usually into space to receive a pass from a supporting player. These intensive bouts of activity are usually interspersed with periods of low-intensity recovery, when players have no direct involvement with the play. This is in line with the observation that forward players perform more sprints than defenders and midfield players during a game (Mohr et al., 2003).

The results of the present study indicate that the physiological responses to competitive match-play are associated with the position in the team. The greatest work-rate is imposed on midfield players due to their linking role between defence and attack, which requires more sustained running. On the other hand, central defenders have more periods of exercise at low intensity, which may allow for longer recovery periods. This was further pronounced during the second half of games. What requires further analysis is the length of the recovery periods and the exercise: rest ratio of the different positions during match-play. These factors will be addressed in section 5.2.

In the present study, the individual physiological response (as measured as a percent of HR_{Max}) to match-play was highly variable. Moreover, within each playing position, there was considerable variation in the relative strain as indicated by percent of HR_{Max}. Similarly, Mohr et al. (2003) found a significant variation in the distance covered at high-intensity running within each playing position. There was a variation of 1.9 km in the distance covered at high-intensity running among midfield players in the same game. Such intra-positional variation could be attributed to the tactical role assigned to the players and/or their physical capacity.

In terms of physiological response to match-play, a large intra-group variance was observed in the forwards. This observation is in line with the large intra-group variances reported for anthropometric and physical performance capacities of the forward players in Chapter IV. Clearly the game places unique demands on players occupying the various positional roles. Anthropometric and physical characteristics allow players to meet the demands imposed upon them by their positions. Moreover, these characteristics influence the tactical role given to the player by the coach. Such tactical and physical considerations influence work-rate profiles and provide an explanation to the large degree of variance observed in heart rate responses. The question remains, is it the game per se that determines exercise intensity or is it due to the physical qualities the players bring to competition? Given a reduction in the exercise intensity over time, it may well be that the physical capacity of all players is fully taxed during the 90 min of competition.

As $\dot{V}O_{2max}$ varies according to positional role, the variability observed in heart rate responses in the present study may be a result of position-specific fitness characteristics. Midfield players and full-backs most frequently have the highest $\dot{V}O_{2max}$ values in the team (see Chapter IV). Given that midfield players and full-backs are characterised by higher $\dot{V}O_{2max}$ values than other players, a well developed aerobic system allows these players the opportunity to sustain higher work-rates and make them less susceptible to the reduction in work-rate associated with fatigue (Reilly and Thomas, 1976; Rienzi et al., 2000; Mohr et al., 2003). Indeed, the extent to which players experience fatigue is negatively related to $\dot{V}O_{2max}$ (Reilly, 1990).

More recently Helgerud et al. (2001) showed that increasing $\dot{V}O_{2max}$ by 11% gave a 20% increase in distance covered during a game, a 23% increase in involvements with the ball, and 100% increase in number of sprints, demonstrating the causal link from aerobic endurance capacity to soccer-related performance. These authors used a high-intensity interval training protocol (4 x 4 min at 90-95% HR_{max}, 2 x week for 8 weeks) and reported an increase in work intensity during competitive match-play from 82.7% to 85.6% of HR_{max}. Improved work intensity as a result of the training intervention may explain the differences observed in the present study, as the players possessing the highest $\dot{V}O_{2max}$ should have the greatest number of sprints and take part in more decisive situations that elevate heart rates (Smaros, 1980).

There was a significant reduction in heart rate towards the end of matches. Peak heart rate responses were recorded in the first 30-min of matches. Thereafter, significant reductions in heart rate responses were observed. These effects were noted independent of playing position within the team. Such a reduction in heart rate may be a manifestation of fatigue, defined as a decline in the ability to continue performing (Reilly, 1997).

It is unclear to what extent the players experience fatigue during elite soccer match-play. Several researchers have provided evidence that the players' ability to perform high intensity exercise is reduced towards the end of games in both elite and non-elite soccer players (Reilly and Thomas, 1976; Bangsbo et al., 1991: Mohr et al., 2003: Mohr et al., 2004: Krustrup et al., 2005). Moreover, it has been observed that the amount of high intensity running is reduced in the last 15-min period of an elite soccer game (Mohr et al., 2003) and that jump, sprint and intermittent exercise performance is lowered after compared with before a soccer game (Rebelo et al., 1998; Mohr et al., 2004;

Mohr et al., 2005). Given that frequent bouts of high-intensity work significantly elevate heart rate, a decline in the number of sprints performed may indicate the development of fatigue in the second half of matches and lead to a reduced exercise intensity over time. This aspect will be further explored in section 5.2.

In a study by Mohr et al. (2003), the greatest distance covered in high-intensity running was observed in the first 15-min of the game. It is likely that the tempo and continuous activity in the first 15-min period of competition, along with the increased high-intensity running would significantly elevate heart rates. In addition, there is a higher incidence of engagement in activities of injury risk (e.g. tackling) in the first 15-min than in other periods of the game (Rahnama et al., 2002). It may well be that thereafter, the high-intensity bouts of activity are reduced which results in a significant decline in exercise intensity. Such a decline may be more pronounced in central defenders and forwards, and less pronounced in midfield players and full-backs, who tend to have the higher $\dot{V}O_{2max}$ values (see Chapter IV).

In the present study, the decline in exercise intensity was attenuated in midfield players who possessed the higher $\dot{V}O_{2max}$ values and was more pronounced in central defenders who had the lower $\dot{V}O_{2max}$ values. On the whole, exercise intensity peaked in the first 30-min of the game and was significantly reduced towards the later stages of a game. Such data imply that the pooling of mean heart rate data over the whole 90-min may result in a substantial loss of specific information during competitive match-play.

In summary, the physiological demands of elite match-play (as measured as a percent of HR_{Max}) are high, with heart rates exceeding 80% of the individual maximal value for prolonged periods during competition. Expressing exercise intensity as a mean heart rate over 90 min discards specific information about changes within the game. Soccer matches have high-intensity periods where players are exposed to a number of unorthodox modes of action and game-specific activities. Moreover, each position demands its own set of specific requirements and these are reflected in the work-rate profiles of players. Evidence from the present study suggests a considerable variation in relative exercise response within each positional category. Such a variation could be attributed to the tactical role assigned to the players and/or the physical capacity of the players. Nevertheless, heart rate profiles are sensitive enough to monitor such variations in exercise response. An elite player should ideally be able to maintain a high intensity of exercise throughout the whole game. Evidence from the present study suggests a significant reduction in heart rate occurs towards the later stages of a game. Such a reduction may be a manifestation of the phenomenon of fatigue.

Therefore the following hypotheses were both rejected:

A. H_O: At an elite level of play, heart rate profiles do not vary according to different playing positions.

B. H_O: At an elite level, heart rate profiles do not vary between time periods.

5.2 A MOTION ANALYSIS OF WORK-RATE IN PREMIER LEAGUE SOCCER

5.2.1 Introduction

Soccer match-play is characterised by intermittent activity involving the anaerobic and aerobic energy systems (Reilly, 1996). In order to gain a correct impression of the physiological load imposed on soccer players, observations have to be made during competitive match-play. Motion analysis has been used to determine the work-rate profiles of players during a soccer game. Activities may be classified according to mode, intensity, duration and frequency. Motion analysis has helped identify the performance demands of different positions, fitness requirements for play and the intensities of discrete activities during match-play.

According to Reilly and Thomas (1976) the total distance covered provides information about the physiological load associated with soccer match-play. Several authors have determined the individual distance covered during a game, which can then be used as an indicator of the total work performed. Several methods have been used to determine distance covered during a soccer game, including the use of hand notation systems (Knowles and Brookes, 1974), coded commentary (Reilly and Thomas, 1976), video recordings (Bangsbo et al., 1991) and computerised techniques (Ohashi et al., 1988). The differing techniques have meant that varying distances covered by players have been reported in the literature. Nevertheless, there is a general consensus that elite players cover a distance of 9-12 km during match-play.

The physiological responses of soccer players to match-play indicate that a combination of demands is imposed on players during competition (Reilly, 1996). The energy demands are largely aerobic in nature with only a small contribution coming from anaerobic sources. High-intensity efforts are important since the timing of these anaerobic efforts are critical to the outcome of the game. The high correlation between aerobic power ($\dot{V}O_{2max}$) and distance covered per game indicates the importance of a well-developed oxygen transport system (Smaros, 1980). The total distance covered during soccer match-play varies according to level of play (Ekblom, 1986) and between elite playing populations (Drust et al., 1998). Differences in work-rate profiles have also been observed between positional roles, indicating positional specificity in the demands of the game (Ekblom, 1986).

According to Williams et al. (1999) the work-rate of elite soccer players increased after the establishment of the Premier League. Moreover, if contemporary soccer places higher demands on players than in previous decades, research is required to update early literature (i.e. Reilly and Thomas, 1976). There still remains a shortage of data describing the physiological and movement demands imposed on contemporary elite players during domestic Premier League competition. Clearly, information regarding the work-rate profiles during competitive match-play will further our understanding of the demands of elite soccer participation. Such a proposition has led to the formulation of formulation of the following hypotheses:

5.2.1.1 Statement of hypotheses

A. H_O: At an elite level of play, work-rate profiles do not vary according to different playing positions.

B. H_O: At an elite level of play, work-rate profiles do not vary between time periods.

5.2.2 Methods

Twenty-four full-time professional male soccer players were filmed for the determination of work-rate profiles. None of the players had any knowledge that he was being filmed. One player per game was filmed for analysis. The activities of one player during the 90 min of match-play were recorded using a video camera (Sony TR 75E, Taiwan). The camera was positioned in a gantry overlooking the pitch and close to the half-way line. When filming, the camera focused on each individual player so as to enable footsteps and stride patterns to be identified for subsequent analysis. Videotapes were replayed on a television monitor and video (Sony Trinitron, Taiwan; Panasonic NV-F77) and analysed on a personal computer using a soccer-specific motion analysis system (Generic System, David Whitby, 1996). Activities were separated into four categories based on the intensity of action. The classification of activity was based upon the claculation of stride frequencies per second. These were walking (forward and backward movements), jogging (forward, backward and sideways), cruising and sprinting. Static pauses were also recorded. During data collection, each individual action was recorded in terms of the number of strides taken and time taken to complete the action. The number of strides and the time spent in each activity category were then calculated for the whole match by means of the motion analysis system's software. The total distance covered in each activity classification was estimated using information derived from movement trials. To enable this calculation to be made the players were filmed in each activity over 10 m at the training ground. The total number of strides taken to cover 10 m was recorded for each player. The stride length was then determined by dividing 10 by the number of steps taken to cover 10 m and the resultant was the distance covered per stride in metres.

Repeatability was assessed using a method established by Drust et al. (1997). Such a procedure involved re-analysing one 45-min period of a Premier League game. Repeatability was initially assessed 3 days after completion of the first analysis and was repeated after analysis of every 7 games throughout the data collection period. This was done to determine the effects of any practice or learning effects on the classification of activities. The level of agreement between the activity classifications for repeatability was determined using the number of exact agreements observed. A second-by-second breakdown of the results was obtained for each repetition of the 45-min period analysed, to calculate the exact number of agreements between data sets for category classification. The observations obtained for each analysis were compared manually and noted in the form of a contingency table to allow the calculation of the exact number of agreements to be compared. This approach was then supplemented by the calculation of the number of agreements that could be expected by chance (Rienzi et al., 2000).

This measure of agreement is known as Kappa. Kappa statistics relate the number of agreements observed to those expected by chance. Kappa has a maximum value of 1.00 when agreement is perfect and a value of 0 when there is no agreement better than chance. Table 5.2.1. shows the number of exact agreements, Kappa values and the strength of the agreement according to Altman (1991) for all the repeatability assessments.

Table 5.2.1. Number of exact agreements and Kappa values for repeatability assessments for the soccer motion system.

	Exact agreements (%)	Kappa Value	Strength of Agreement
Initial repeatability	86	0.82	Good
Second Assessment	85	0.80	Good
Third Assessment	83	0.77	Good
Final Assessment	84	0.78	Good

5.2.2.1 Statistical analyses

Differences between time periods within a match were determined using one-way analyses of variance with repeated measures. Bonferroni multiple comparisons were carried out to identify where any differences that were found lay. Significance was accepted at $P<0.05$.

5.2.3 Results

The total distance covered during first and second half match-play was 11065 ± 920 m. There was a significant reduction in the total distance covered in the second half compared to the first (first half 5708 ± 530 m; second half 5357 ± 456 m) [$F_{1,46}$ =6.07; P<0.018]. Activity for the total distance covered during match-play consisted of 40% jogging, 36% walking, 9% cruising, 2% sprinting and 13% utility movements (see Figure 5.2.1.). Utility movements were comprised of walking backwards (8%), jogging backwards (3%) and jogging sideways (2%). The categories of cruising and sprinting can be combined to represent high-intensity activity. In terms of actual distance covered, high-intensity running accounted for 1213 ± 424 m, consisting of 956 ± 321 m cruising, and 257 ± 111 m sprinting. A total distance of 9852 ± 752 m was covered at low intensity. This distance consisted of jogging 4457 ± 573 m and walking 4000 ± 237 m. A further 860 ± 108 m; 356 ± 53 m; 221 ± 68 m was covered walking backwards, jogging backwards and jogging sideways, respectively.

The total number of activities performed during the game was 1606 ± 171. This figure amounts to a change in activity approximately every 3.5 s. During match-play, 261 ± 54 static pauses were observed. Walking was the most frequently performed action with 695 ± 124 discrete bouts. High-intensity activities were the least frequently performed actions with sprinting and cruising accounting for 20 ± 10 and 74 ± 28 discrete bouts respectively. This figure represents a high-intensity bout of activity approximately every 60 s and a maximal effort every 4 min.

Midfield players and full-backs covered a significantly greater distance than central defensive players (midfield players 11830 ± 683 m; full-backs 11540 ± 343 m; central defenders 10266 ± 714 m) [$F_{1,46}$ =6.07; P<0.018]. The total distances covered for all positions are shown in Figure 5.2.2. A significant difference was also noted for playing positions for each half. Midfield players and full-backs covered a greater distance than central defenders in the first half of competition ($F_{3,20}$ =5.39; P<0.007). In the second half of competitive games midfield players covered a significantly greater distance than central defenders and forwards ($F_{3,20}$ =5.96; P<0.005) [See Figure 5.2.3.].

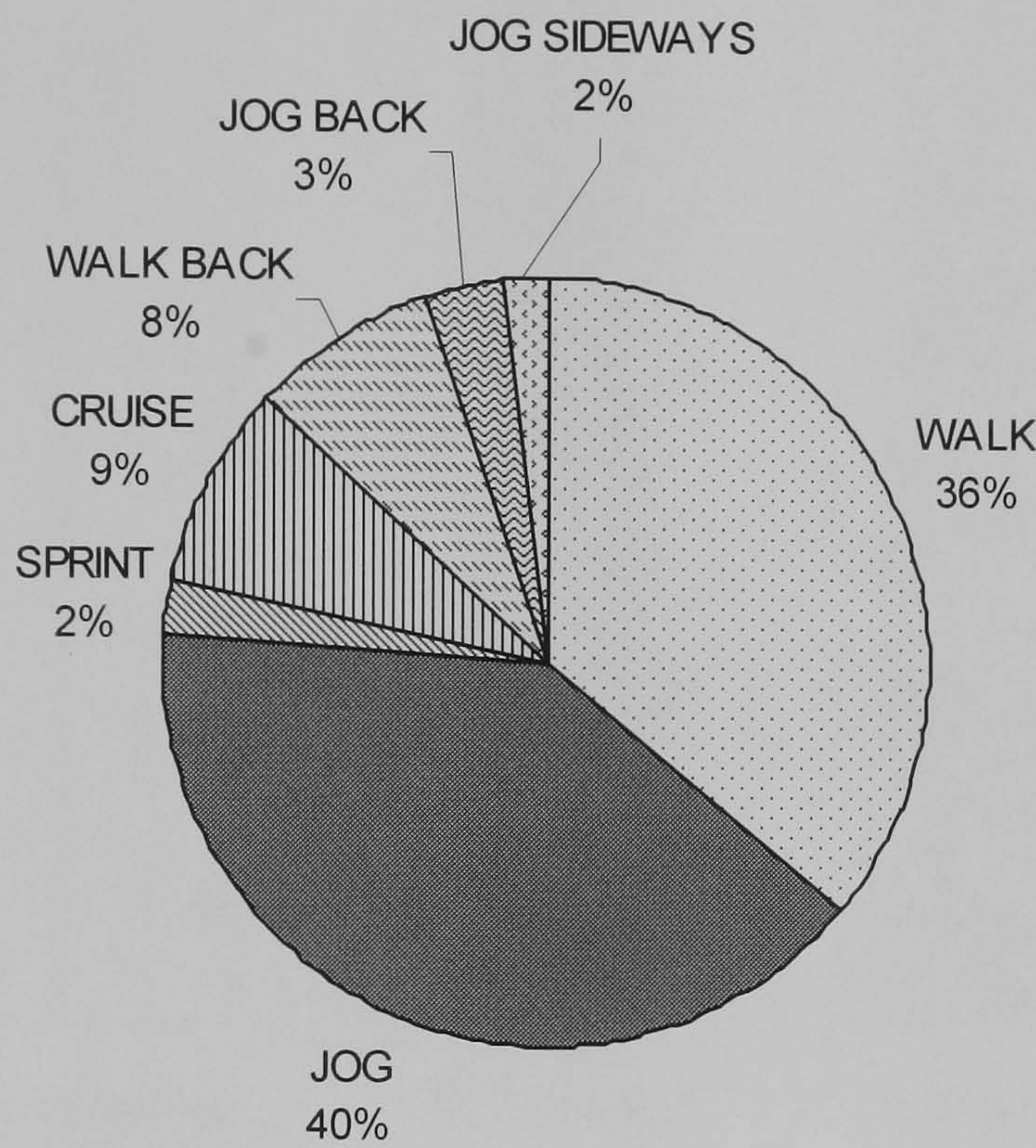
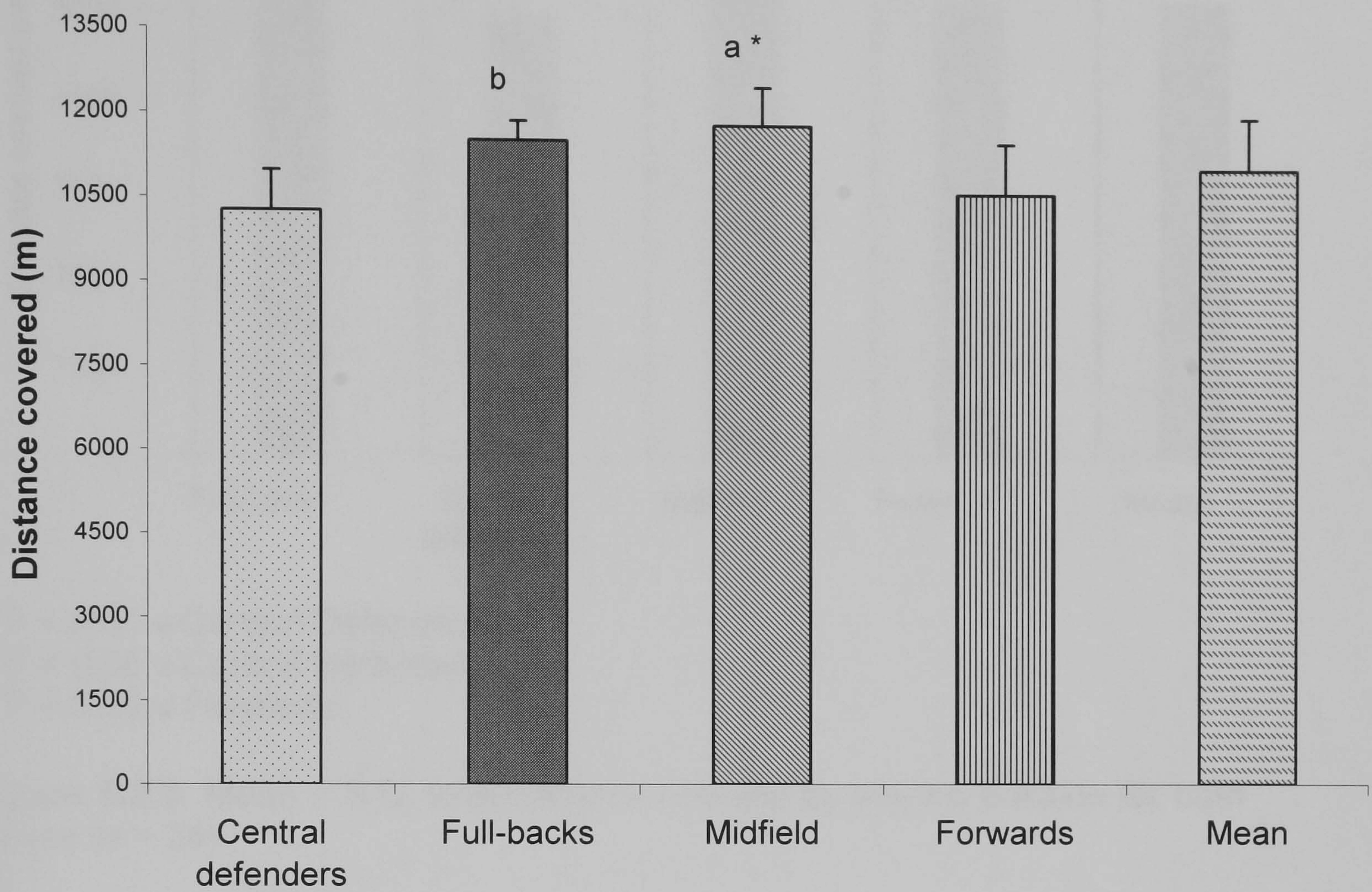


Figure 5.2.1. Categories of activity for the total distance covered during elite match-play (n=24).

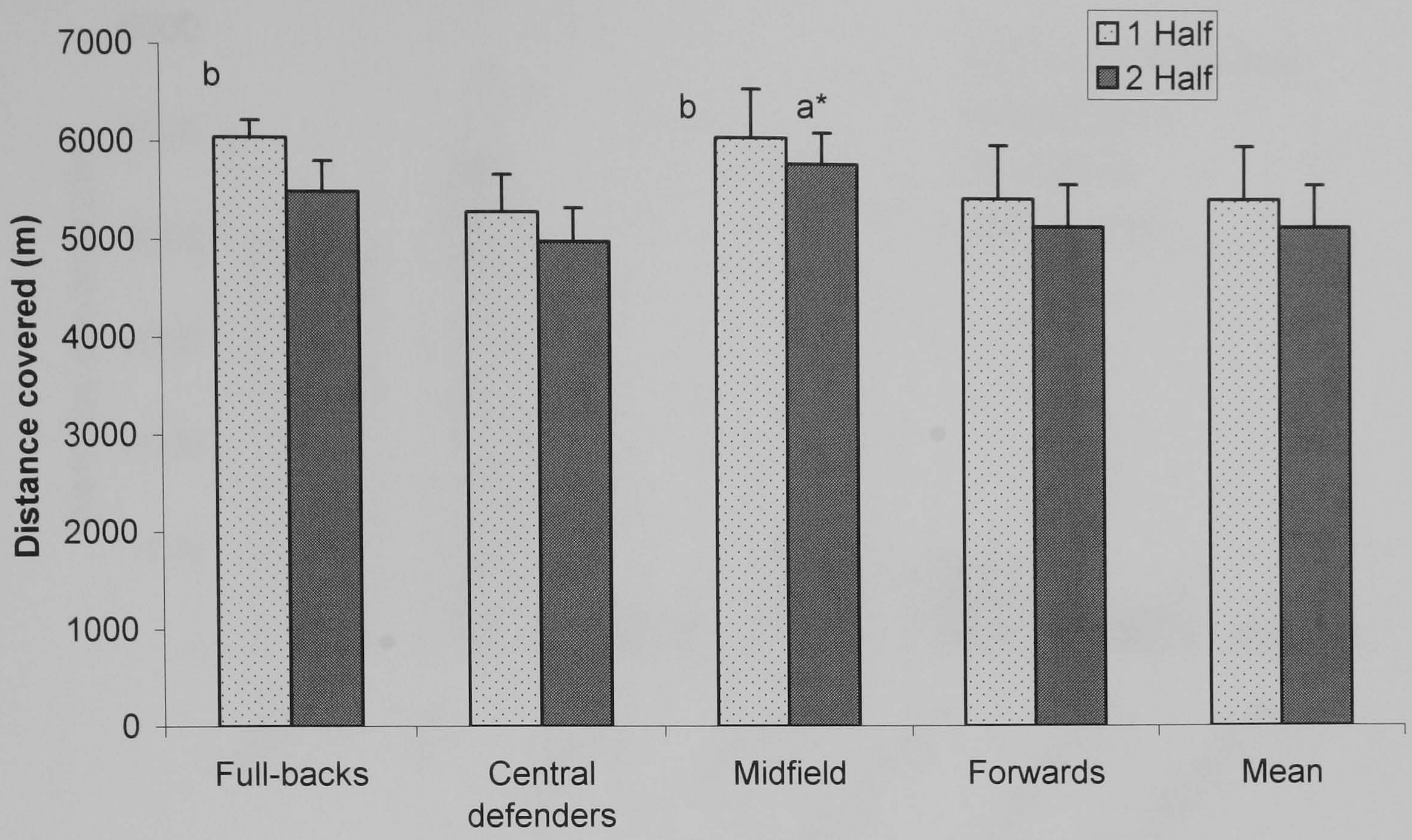
Midfield players and full-backs covered a significantly greater distance jogging than central defensive players (midfield 4793 ± 440 m; full-backs 4789 ± 491 m; central defenders 4059 ± 392 m) [$F_{3,20}$ =5.46; P<0.007]. Forward players covered a significantly greater distance sprinting than central defenders (forwards 313 ± 49 m; central defenders 164 ± 123 m) [$F_{3,20}$ =3.587; P<0.032]. Significant differences were also found between positions for the total distance covered cruising. Forwards and midfield players covered a greater distance cruising than central defenders (forwards 1061 ± 85 m; midfield players 1065 ± 237 m; central defenders 651 ± 356 m) [$F_{3,20}$ =4.46; P<0.015]. Central defenders covered a significantly greater distance jogging backwards than forwards [$F_{3,20}$ =3.99; P<0.022]. No differences were found between the positions for walking (See Figure 5.2.4.).



[a] P < 0.01 v Central Defenders
[b] P < 0.05 v Central Defenders
* P < 0.05 v Forwards

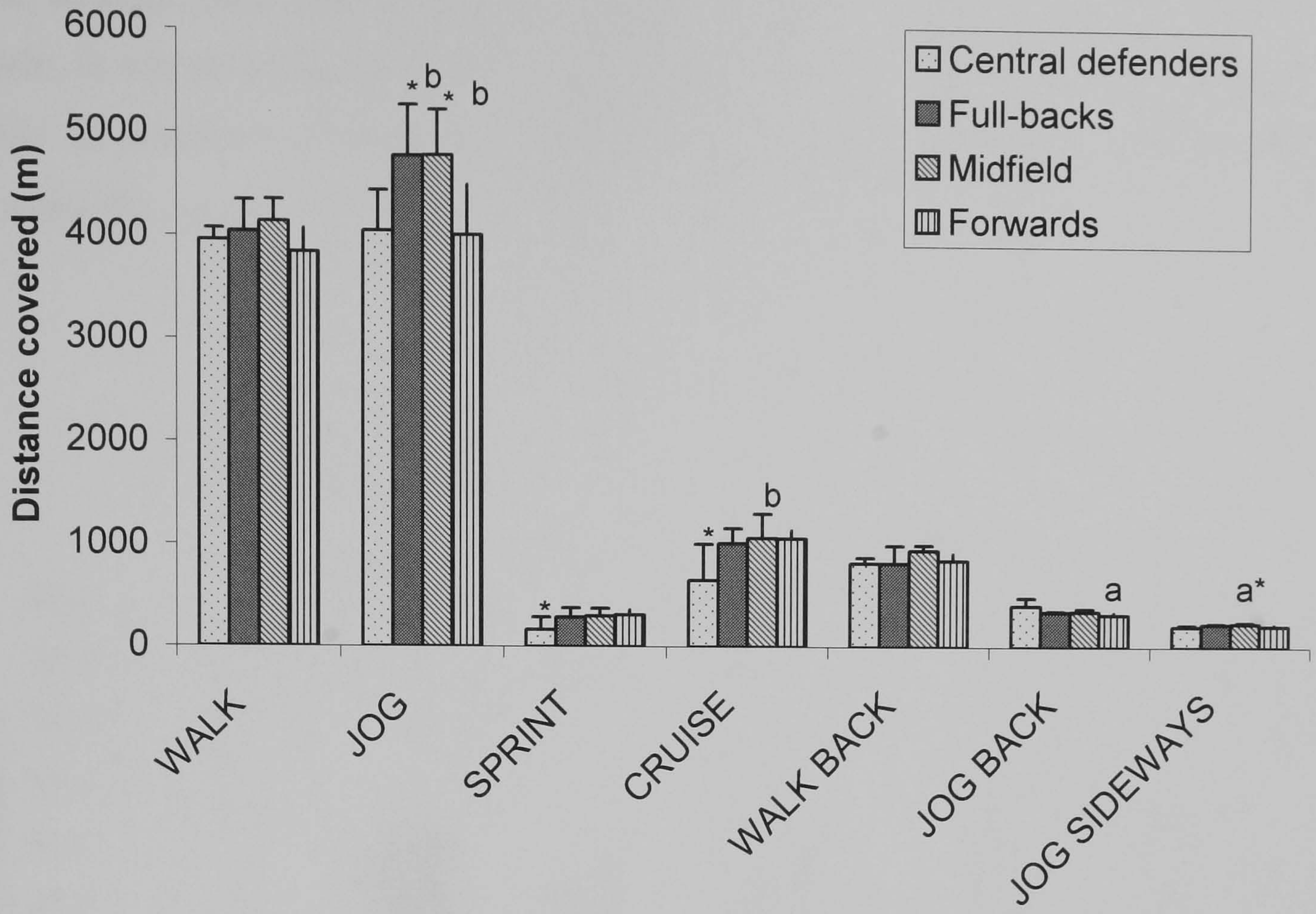
Figure 5.2.2. Mean ± S.D. total distance covered by playing position for all players (n = 24).

Low-intensity work accounted for 80% of the total time spent on activities with walking (forwards and backwards) and jogging (forwards, backwards and sideways) making up 48% and 32% respectively. Cruising and sprinting accounted for 4% and 1% of the total time. The remaining 15% of the total time was spent static (see Figure 5.2.5.). The ratio of work in terms of high:low:rest was 1:16:3.



[a] P < 0.01 v Central Defenders
[b] P < 0.05 v Central Defenders
* P < 0.05 v Forwards

Figure 5.2.3. Mean ± S.D. total distance covered by playing position for both halves (n = 24).



[a] P < 0.01 v Central Defenders
[b] P < 0.05 v Central Defenders
* P < 0.05 v Forwards

Figure 5.2.4. Mean ± S.D. total distance covered in each activity with respect to playing position (n = 24).

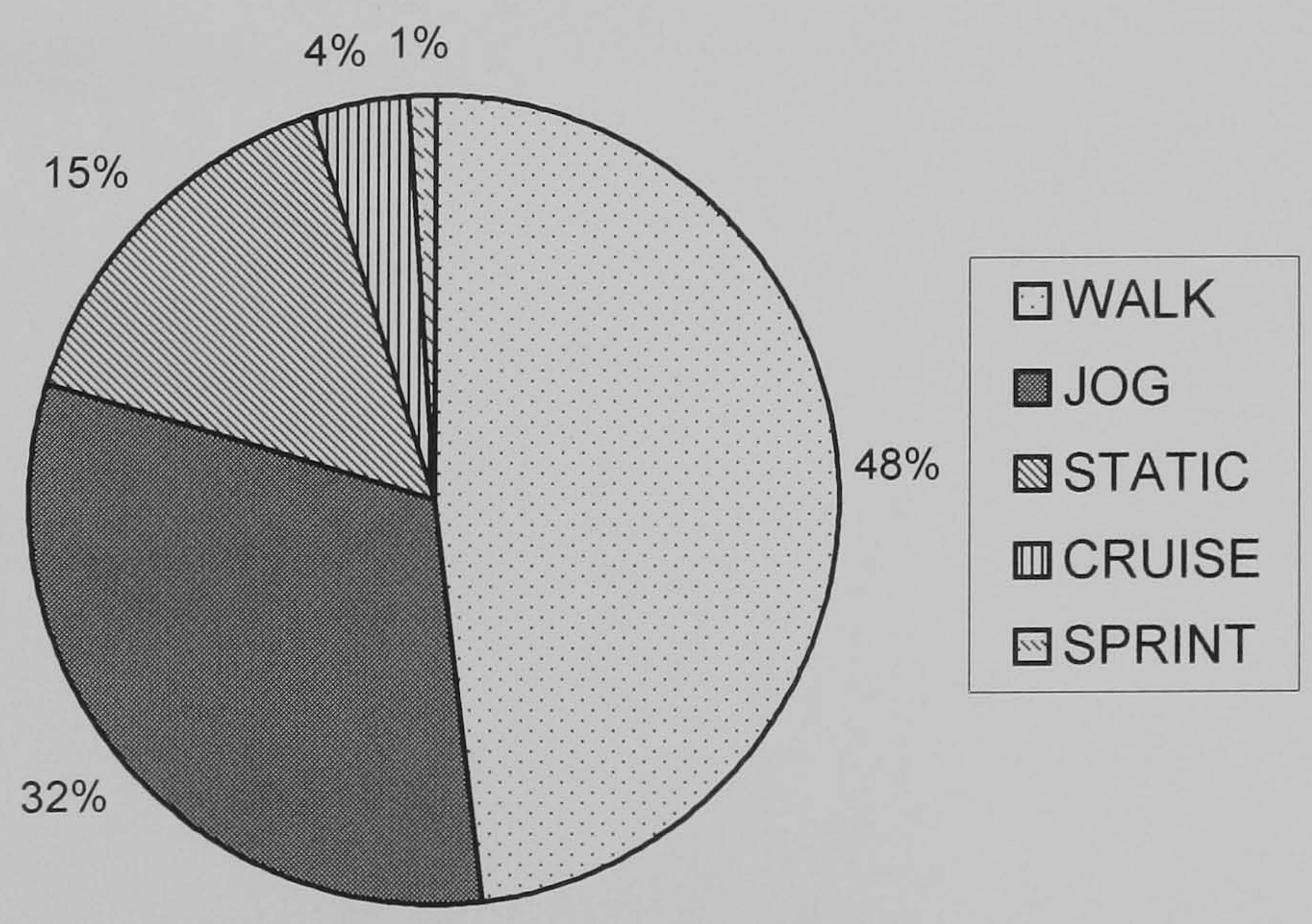
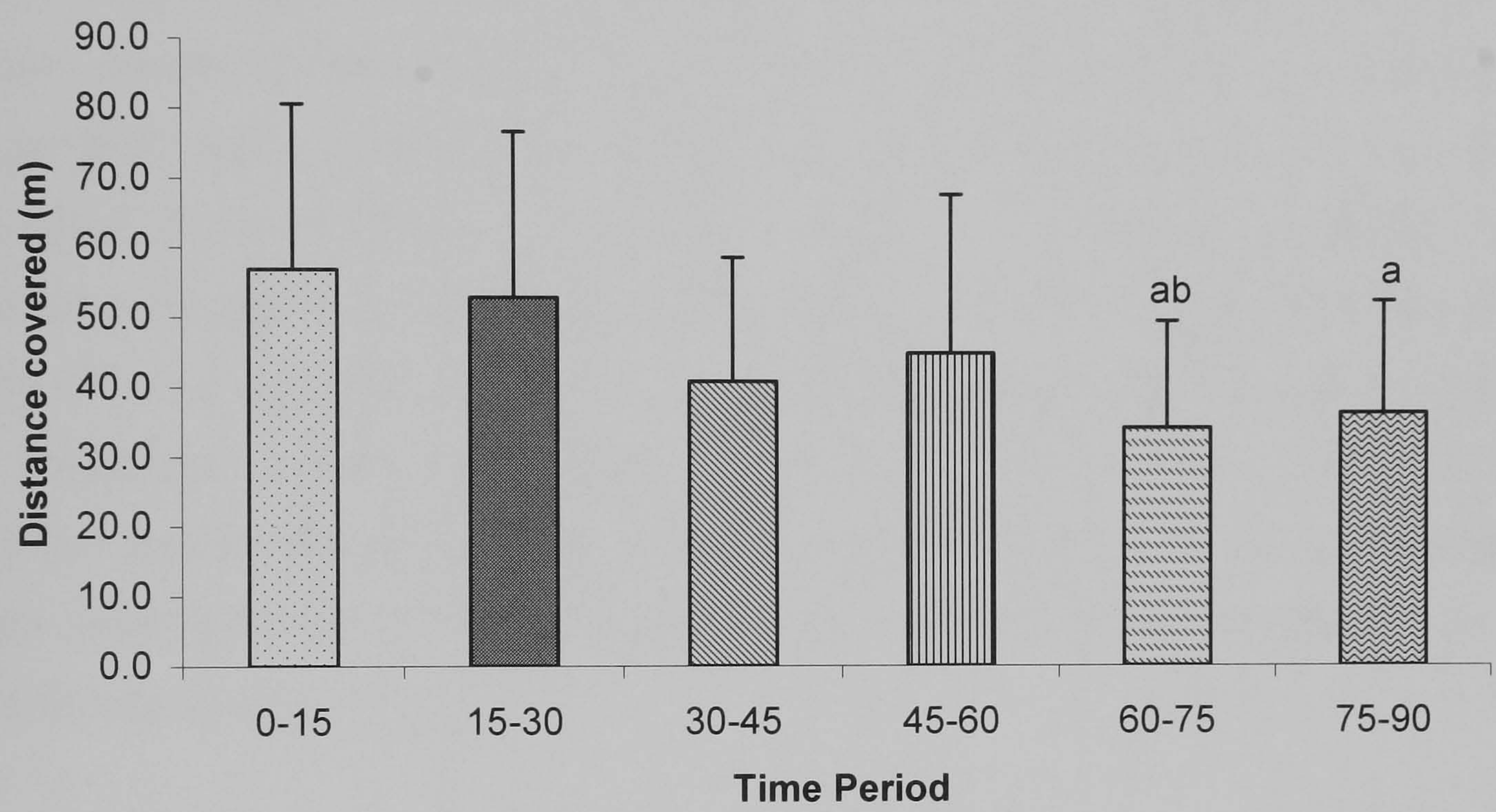


Figure 5.2.5. Percentages of the total time spent in each category during elite match-play (n = 24).

Sprint activity over the entire competitive match, as expressed in 15-min periods, is shown in Figure 5.2.6. Peak sprint activity was recorded in the first 15-min of matches. Thereafter, a significant reduction in sprint activity was observed ($F_{5,138}$ =4.74; P<0.00).



[a] P < 0.01 v 0-15 min
[b] P < 0.05 v 15-30 min

Figure 5.2.6. Mean sprint activity during different 15-min periods of competitive match-play (mean ± S.D) (n = 24).

5.2.4 Discussion

The primary aim of the current investigation was to determine the work-rate profiles of elite Premier League soccer players. The total distance covered during match-play provides a global representation of the severity of the exercise and the individual contribution towards the total team effort (Reilly, 1994a). The distances covered by the players in the present study are considerably higher than those that have been observed in the top English division in previous decades (Reilly and Thomas, 1976; Rienzi et al., 2000). Such data suggest that contemporary Premier League players are placed under greater stresses than players in previous decades since the energy expended during competitive match-play is directly related to the total distance covered (Reilly and Thomas, 1976). It is generally accepted that soccer in England is characterised by a fast pace and requires individuals to perform at a high level of activity in order to receive the ball from team mates or pressurise opponents to regain possession (Rienzi et al., 2000). The current data reinforce the notion that the inception of the Premier League has had a profound effect on the work-rate profiles of its participants and hence on the fitness needs of players.

The activity during match-play consisted of 40% jogging, 36% walking, 9% cruising, 2% sprinting and 13% utility movements. These findings support previous research suggesting the energy demands are aerobic in nature with only a small contribution coming from anaerobic sources (Drust et al., 1997; Mohr et al., 2003). High-intensity activities were the least frequently performed actions with sprinting and cruising accounting for 20 ± 10 and 74 ± 28 discrete bouts respectively. These values constitute a high-intensity bout of activity approximately every 60 s and a maximal effort every 4 min. Low-intensity work accounted for 80% of the total time spent on activities with walking (forwards and backwards) and jogging (forwards, backwards and sideways) making up 48% and 32%, respectively. Cruising and sprinting accounted for 4% and 1% of the total time. The remaining 15% of the total time was spent static. The ratio of high:low:rest was 1:16:3. These findings have implications for experimental investigations, since any protocol designed to replicate elite competitive match-play must incorporate the work-rate profiles of actual elite performance.

In the literature, characteristic work-rate profiles have emerged in relation to playing position. Midfielders and full-backs were observed to cover greater distances during competitive match-play than forwards and central defenders (Reilly and Thomas, 1976; Withers et al., 1982; Van Gool et al., 1988; Bangsbo et al., 1991; Rienzi et al., 2000; Mohr et al., 2003). In the present study, the distance covered was dependent upon the position in the team. Clearly, these work-rate profiles are a reflection of the tactical demands of elite competition and determine the physiological responses to match-play. The work-rate profile of the midfield players in the present study was characterised by a greater percentage of the total distance covered jogging and a lower percentage of the total distance covered walking than other positions respectively. These observations are in line with other research findings (Drust, 1997; Rienzi et al., 2000). Midfield players generally have a higher level of aerobic fitness than other positions as reflected by results in Chapter IV. A higher level of aerobic fitness may thus make these players less susceptible to a reduction in the work-rate associated with fatigue (Reilly and Thomas, 1976). In the present study, midfield players suffered the least reduction in work-rate as reflected in the differences in distances covered between the first and second than all other positions.

The forward players' work-rate profile in the present study was associated with a larger contribution of anaerobic work than other positions. Moreover, the forward players' profile was characterised by a greater percent of the total distance covered sprinting and cruising than players in other positions. The forward players' work-rate profile is characterized by sudden bursts of high-intensity activity, usually into space to receive a pass from a supporting player. These intensive bouts of activity are usually interspersed with periods of low-intensity recovery, when they have no direct involvement with the play. This pattern is in line with the observation that forward players perform more sprints than defenders and midfield players during a game (Mohr et al., 2003). Furthermore, it was demonstrated in Chapter IV that forwards were significantly faster over 0-5 m than central defenders and midfield players, reflecting a higher dependence on acceleration and thus force production over short distances. Clearly, analysis of work-rate profiles confirms a direct link between physiological characteristics (as described in Chapter IV) and activity patterns of competitive match-play.

The work-rate profile of the central defenders in the present study demonstrated that these players are placed under less stress than other positions. The total distance covered for central defenders was lower and the relative amount of high-intensity running was lower than players in other positions. These findings were reinforced in section 5.1 where the heart rate response during competition suggested higher exertion in midfield players and full-backs than central defenders. Furthermore, central defenders were characterised in Chapter IV with a lower capacity in most areas of aerobic performance.

The common observation among these findings is that the physiological responses to competitive match-play are dependent upon the position in the team. The greatest work-rate demanded by the game is imposed on midfield players due to the linking role they play between defence and attack, which requires more sustained running. On the other hand, central defenders have more periods of low-intensity work, which may allow for a greater degree of recovery. What is not clear is whether it is the game per se that dictates the work-rate profile or the physiological characteristics of the individual players that determine work-rate. Performance in soccer is the result of a variety of independent factors. Players may or may not be taxed to the limit of their physical capacities during a soccer match due to the tactical responsibilities placed upon them. Given the reduced work-rate over the duration of competition however, it may be that regardless of tactical assignments, all players experience temporary and cumulative fatigue over the duration of a game.

The total distance covered by the players in the second half was significantly lower than in the first half. A reduction in the total distance covered in the second half was also observed by Reilly and Thomas (1976) and Van Gool et al. (1988). This drop in work-rate may be related to a reduction in energy stores (Saltin, 1973) and/or a tactical consideration whereby the players save their efforts for critical situations during the remaining part of the competition (Bangsbo, 1994a). The difference between the two halves in the present study was approximately 4%. This figure is in line with the 5% reported by Bangsbo et al. (1991). These authors reported that the difference between the halves was due to more low-intensity exercise in the first and last 15-min in the first half when compared to the second. No difference was observed in the high-intensity running distance over the duration of a match so it was concluded that the difference in distance covered between the halves was not a reflection of a decreased performance potential. However, the data in the present study demonstrate a significant reduction in sprinting performance over the duration of competition. This significant decline in the exercise intensity manifests the phenomenon of fatigue. Findings from section 5.1 support this decline in work-rate.

Recently, Mohr et al. (2003) reported that the distance covered in high-intensity running by top class players in the last 15-min of a game was 14-45% lower than in the first four 15 min periods (in the present study, sprinting in the last 15-min of a game was 11-36% lower than in the first four 15-min-periods). The reduced amount of high-intensity work late in a game may herald the impending conclusion of the match and a switch to a defensive strategy by the winning team. Such a strategy to protect a lead would reduce the work-rate profiles of players in that a deliberate attempt is made to minimise the playing area. However, when comparing the performance of players who played the entire match with the performance of the substitutes, the amount of high-intensity running in the last 15-min was 25% higher for the substitutes. According to Mohr et al. (2003), this finding supports the notion that fatigue occurs towards the end of the game for the players who play the full 90-min.

In conclusion, significant differences were found in the total distance covered according to playing positions. Midfield players covered the largest distance, supporting previous research findings (Bangsbo et al., 1991). Forward and midfield players also covered greater distances at a higher intensity than central defenders (forwards 1061 ± 85 m; midfield players 1065 ± 237 m; central defenders 651 ± 356 m). Clearly, repeated bursts of high intensity running are important for attacking players to create space for match winning opportunities. It may be that the anaerobic glycolytic system plays a more dominant role during competitive match-play for forwards and midfield players than central defenders. Work-rate profiles provide evidence that the differences observed in the total distance covered are a result of both low and high intensity work. These differences reflect physiological characteristics and/or tactical requirements for play. Midfield players have the highest aerobic fitness (Chapter IV) that may attenuate any reduction in work-rate associated with fatigue (Reilly and Thomas, 1976). The differences in work-rate profiles may also be due to the tactical function of midfield players acting as a link between defence and attack.

The demands of the game may be gauged by monitoring the work-rate of players during matches (Reilly, 2005). In the present study, the work-rate profiles suggest an increased tempo in contemporary professional soccer compared with previous decades (a trend that was replicated in Chapter IV in the fitness levels of players). Evidence for this increased tempo was demonstrated in the total number of activities performed in a contemporary soccer match compared with those of previous decades. In this study, the total number of activities performed during the game was 1606 ± 171. This figure is higher than those of Rienzi et al., (2000) and Reilly and Thomas (1976) who reported 1431 ± 206 and 843 activities respectively.

Match analysis suggests that fatigue occurs towards the later stages of match-play. Indeed, contemporary soccer places high demands on players (as expressed by distances covered, etc). These effects were observed independent of position. The extent that players experience this fatigue may reflect their aerobic fitness (Reilly, 1990). Nutritional status may also play a role in the onset of fatigue as performance decrements are often related to pre-start muscle glycogen stores (Bangsbo, 1994a). These findings have implications for the physiological requirements of play, training regimens and the preparation of elite soccer players. For the purpose of this thesis, the next section (5.3) will explore the training practices of elite players. An understanding of the preparation of elite players will further the picture of the stresses placed on elite soccer players and facilitate a greater understanding of how training factors relate to performance during competition.

Performance in soccer is the result of the interplay of a number of related factors. There are tactical, technical and psychological components of performance as well as physiological factors. Such factors may affect an individual's ability to perform and hence affect the work-rate profile demonstrated. These work-rate profiles have implications for injury rate during the various stages of a game particularly since the incidence of injury can be representative of the stresses associated with the physiological demands of the game. To clarify the link between work-rate profiles, fatigue and the manifestation of these stresses, injury rates will be explored in Chapter VI. In light of the findings of this study the following hypotheses were rejected:

A. H_O: At an elite level of play, work-rate profiles do not vary according to different playing positions.

B. H_O: At an elite level of play, work-rate profiles do not vary between time periods.

5.3 AN ESTIMATION OF PHYSIOLOGICAL STRAIN IMPOSED ON ELITE MALE SOCCER PLAYERS DURING INTENSIVE TRAINING

5.3.1 Introduction

The English Premier League professional soccer season extends for forty-two weeks and is often preceded by a six-week period of physical conditioning. Soccer players are expected to perform at an optimum throughout the entire competitive season. Therefore, it is necessary to manipulate and monitor training not merely during the conventional physical conditioning period, but also during the competitive year. The effectiveness of the conditioning programme will depend on the dosage of the training regimens and how they are organised. Moreover, the dimensions of the training programme – intensity, frequency, duration and mode of exercise, have to be established and detailed planning carried out to maximise the acquisition of subsequent training effects.

Various research groups have examined seasonal variations in the physiological profiles of elite soccer players (Brady et al., 1997; Dunbar, 2002). Although data have been reported on the physiological profiles of elite players, there have been few investigations into the training regimens and patterns of regular competitive match-play, which influence these physiological profiles. Moreover, the physiological assessment of soccer training has been made via references to physiological changes (training outcome) rather than the physiological stress induced by such training (internal load).

Monitoring the physiological strain during training may serve as an appropriate tool for the evaluation of the physiological stress induced by training. Heart rate is linearly related to energy expenditure and the error in estimating energy expended from heart rate in a soccer context is relatively small (Bangsbo, 1994a). Heart rate on its own is a useful indicator of physiological strain and intensity of effort during exercise (Reilly, 1997). Subdivision of heart rate data expressed as a percentage of maximum heart rate can provide important information concerning time spent above, at or below critical exercise intensities. Such data offer valuable information in assessing, monitoring and adjusting training intensities in order to ensure an optimal training stimulus. They will also yield important information concerning the internal training load.

Many studies have stressed the importance of the internal training load in enhancing soccer performance (Helgerud et al., 2001; Hoff et al., 2002). Although such training protocols are in their essence quantitative, there has been limited research into finding a way to quantify soccer training per se using a single method. Endurance athletes have often adopted the training volume (kilometres per week) as an index of training, this index ignores the critical importance of intensity. For soccer players, the use of training volume is an inadequate tool because of the high-intensity bouts of exercise. While many methods have been developed to monitor endurance training (Banister, 1991; Gilman and Wells, 1993; Foster, 1998), there are few published studies on their application to intermittent exercise as reflected in soccer training. One method to quantify internal training load was proposed by Edwards (1990) and entails evaluation of the accumulated time spent in five HR zones. An exercise score is computed by multiplying the accumulated duration in each HR zone by a multiplier for each zone (50-60% of HR_{Max} =1; 60-70% HR_{Max} =2; 70-80% HR_{Max} = 3: 80-90% HR_{Max} =4 and 90-100% HR_{Max} =5). This method has been used as a reference criterion to validate an RPE-based model of training load in basketball players (Foster et al., 2001). It was proposed that the method used by Edwards (1990) could be modified as a valid method to quantify training load in soccer.

The pre-season training period in England traditionally consists of aerobic fitness work, soccer training, and friendly matches. When investigating fitness profiles of English professional soccer players before and after the pre-season period, the training records kept by Mercer et al. (1995) revealed that the conditioning emphasis of sessions in weeks one to three was 85% aerobic/endurance conditioning and 15% game-related activity. The aerobic conditioning was based almost exclusively on variants of distance running such as aerobic interval training, hill running and cross-country running. Time allocated to aerobic conditioning in weeks four to five was 60% of the total training time. While it is suggested that contemporary soccer training should emphasise the use of ball-related activity (Bangsbo, 1994c; Hoff et al., 2002), few studies have determined the integral components of the contemporary soccer-training programme. Moreover, there is a dearth of information relating to the differences in training between pre-season and the competitive season. Clearly, information regarding the content and physiological stresses associated with the annual soccer training programme will further our understanding of the demands of elite soccer participation. Such a proposition has led to the formulation of hypothesis A.

5.3.1.1 Statement of hypotheses

A. H_O: At an elite level of play, the physiological stresses associated with training do not vary throughout the year.

There have been few contemporary investigations into the training regimens of elite Premier League soccer players. The purpose of this study was to identify the physiological strain imposed on elite players during pre-season and in-season intensive training. A further aim was to develop a method to quantify training load in soccer.

5.3.2 Methods

5.3.2.1 Subjects

Subjects were 24 full-time professional male soccer players of a Premier league squad (age 24 ± 5 years). For the purpose of the study, only subjects who had represented the 1st team in the Premier League were included.

5.3.2.2 Procedures

Anthropometric and fitness profiles were obtained on all players throughout the competitive year. Such a protocol allows for fitness changes to be taken into account throughout the study period. All of the tests undertaken were familiar to the subjects as part of their ongoing fitness assessment. The fitness variables included maximal oxygen uptake (Ramsbottom et al., 1988), agility, sprint speed and leg power. Methods for the determination of these variables are described in section 4.2.2.2. Anthropometric variables included muscle mass (Martin et al., 1990), body mass, adiposity (Durnin and Womersley, 1974; Reilly et al., 1996), stature and somatotype (Heath and Carter, 1967). Methods for the determination of anthropometric variables are described in section 4.1.2.2.

A heart rate recording system was developed to monitor physiological strain during training. Each subject's heart rate was monitored during competitive training and match-play via short-range radio telemetry (SportTester^{TM}, PE3000) sampled at 5-s intervals. Heart rate was monitored at three points during the annual year following a period of anthrompometric and fitness testing: Pre-season (July), Mid-season (November/December) and Late-season (March/April). All players were monitored over a duration of five days during each of these periods. For the purpose of this study, no more than eight players were recorded during the same week. Therefore, each selected period lasted three weeks. This strategy allowed for a larger amount of data to be recorded for analyses. For reference data, heart rate was also monitored during competitive match-play.

Following each training session, data for heart rates were downloaded into a computer software package for analysis (Polar Precision Performance SW, 2000). This software computed maximum and mean heart rates for the entire training session. Such software also allowed for calculation of time spent in categories of heart rate responses. The heart rate responses were divided into 4 intensity categories: Maximal (>90 % HR_{max}), High-intensity (80-90% HR_{max}), Moderate Intensity (60-80 % HR_{max}) and other (<60 % HR_{max}). An exercise score for each bout was then computed by multiplying the accumulated duration in each HR zone by a multiplier for each zone (<60% of HR_{Max} =1; 60-80% HR_{Max} =2; 80-90% HR_{Max} =3 and 90-100% HR_{Max} =4) and summing the result.

Pre-season training programme

The pre-season training consisted of a 6-week period of intense physical conditioning. Training sessions were conducted once or twice daily with a squad of 22 players. Only field-related activities were monitored for the purpose of this study. Six competitive games were played during the training period. Heart rate was monitored over three weeks of pre-season training via short-range radio telemetry (SportTester™, PE3000) sampled at 5-s intervals. All players were monitored over a duration of five days during this period. For the purpose of this study, no more than eight players were recorded during the same week.

Competitive season training programme

The competitive season programme consisted of a 42-week period with a total of 44 competitive games. Training sessions were conducted once or twice daily with a squad of 22 players. Only field-related activities were monitored for the purpose of this study. Supplementary strength training sessions completed in the conditioning room at the club's premises were not employed in the analysis (two supplementary strength sessions were conducted per week by all players). The weekly programme consisted primarily of five days training and one competitive game. On occasions during the competitive programme, the training schedule was modified to accommodate mid-week competitive match-play. Heart rate was monitored over a 3-week period at two points during the competitive season: Mid-season (November/December) and Late-season (March/April). All players were monitored over a duration of five days during these periods. For the purpose of this study, no more than eight players were recorded during the same week. Heart rate was monitored via short-range radio telemetry (SportTester™, PE3000) sampled at 5-s intervals.

Competitive match-play

Each subject's heart rate was monitored during competitive match-play via short-range radio telemetry (SportTester™, PE3000) sampled at 5-s intervals. Heart rates were monitored during competitive 1st team fixtures only. All players were monitored during competition. For the purpose of this study, no more than two players were recorded during the same game. Altogether, 18 games were used for data analysis over a period of the competitive season (August to May).

Training components

The training components of a session were classified into seven discrete field categories:

(i) **Flexibility** - training activities designed to increase the range of motion of the main muscle groups.

(ii) **Muscular strength** - training activities designed to increase muscle power output during explosive activities.

(iii) **Speed** - training activities designed to improve high speed muscular contraction and maximum sprinting speed.

(iv) **High-intensity (HI) interval running** - training activities involving running at 90-100% H.R. $_{MAX}$ for a fixed time interval (45-240 s) followed by a fixed period of recovery.

(v) **Varied pace running** - training activities involving running at time intervals that are varied in both duration and intensity and recovery times.

(vi) **Game related** - training activities incorporating the development of technical and tactical skills under conditions corresponding to the stress of match-play.

(vii) **Technique** - training activities involving players working on technical mastery of the ball.

5.3.2.3 Statistical analyses

Differences between mean heart rates during training over time periods (Pre-season, Mid-season and Late-season) throughout the year were determined using one-way analyses of variance with repeated measures. Bonferroni multiple comparisons were carried out to identify where any differences that were found lay. Significance was accepted at $P<0.05$.

5.3.3 Results

The anthropometric and performance characteristics of the subjects are presented in Table 5.3.1. These values were collected at three points over the season. The ranges for stature, body mass, and adiposity are in line with the figures reported in Chapter III for elite soccer players.

Table 5.3.1. Anthropometric and performance characteristics of elite male soccer players (mean ± S.D). (n = 24).

	Pre-season	Mid-season	Late season
Stature (m) (Range)	1.81 ± 0.06 (1.73 – 1.94)	1.82 ± 0.03 (1.73 – 1.94)	1.82 ± 0.04 (1.73 – 1.94)
Body mass (kg) (Range)	80.1 ± 6.9 (67.5 – 90.0)	81.1 ± 5.4 (67.9 – 90.4)	81.2 ± 5.7 (67.7 – 91.2)
Muscle mass (%) (Range)	61.5 ± 2.4 (57.0 – 66.2)	61.6 ± 2.2 (57.3 – 66.6)	61.9 ± 2.6 (57.1 – 66.7)
Adiposity (mm) (Range)	32.6 ± 6.3 (30.9 – 34.7)	32.2 ± 5.7 (30.2 – 34.5)	32.0 ± 6.8 (30.1 – 34.1)
Maximum heart rate (beats·min^{-1}) (Range)	195 ± 7.0 (179 – 208)	196 ± 6.0 (180 – 208)	196 ± 6.0 (180 – 208)
Estimated $\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1}) (Range)	58.8 ± 1.6 (58.2 – 67.5)	59.9 ± 1.5 (58.5 – 67.6)	59.8 ± 1.8 (58.1 – 67.4)

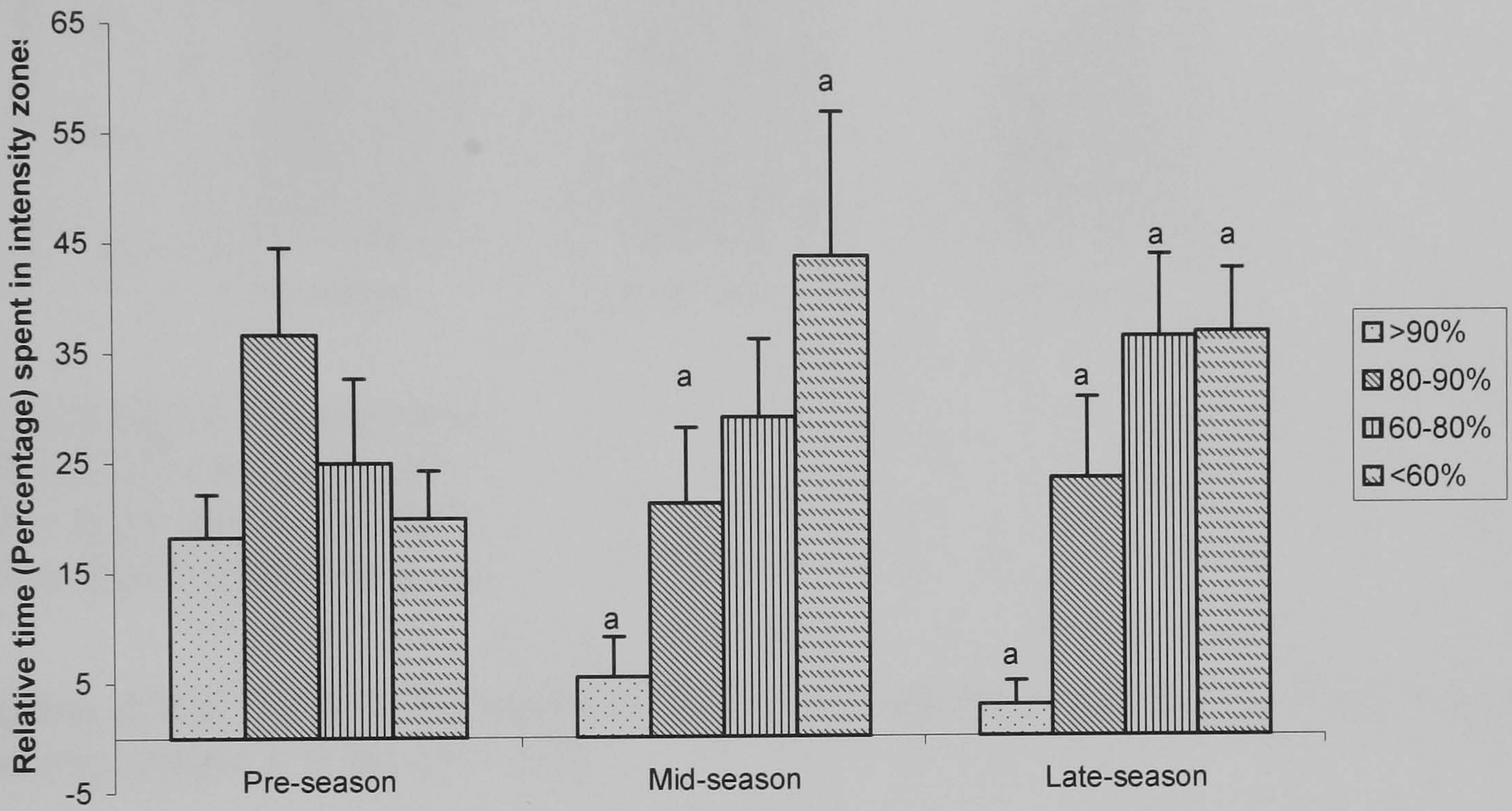
Altogether, 44 1st team and 18 Premier League reserve games were played over the season duration. Characteristics of the training programme are shown in Table 5.3.2. Aerobic conditioning in the form of running related activities accounted for 36%, 3% and 0% of training time during Pre-season, Mid-season and Late-Season respectively. The distribution of time devoted to ball related activities was higher during the Competitive-season than Pre-season. The ratio of ball related to non-ball related activity was 1:3 during intensive pre-season training. In contrast, the ratio of ball related to non-ball related activity was approximately 3:1 during the Competitive-season periods.

Table 5.3.2. Characteristics of the training programme (mean ± S.D., n=24).

	Pre-season	**Mid-Season**	**Late-Season**
Training Sessions per week (n)	9 ± 0.6	5 ± 0.5	4 ± 0.5
Time training per week (h)	12.1± 1.5	8.8 ± 1.4	6.2 ± 0.6
Time training per session (min)	93.8 ± 6	99.6 ± 15	90 ± 11
% Time Flexibility	12	6	5
% Time muscular strength	10	8	9
% Time speed	10	9	10
% Time HI interval running	15	0	0
% Time varied pace running	21	3	0
% Time game related	18	57	62
% Time technique	14	17	14

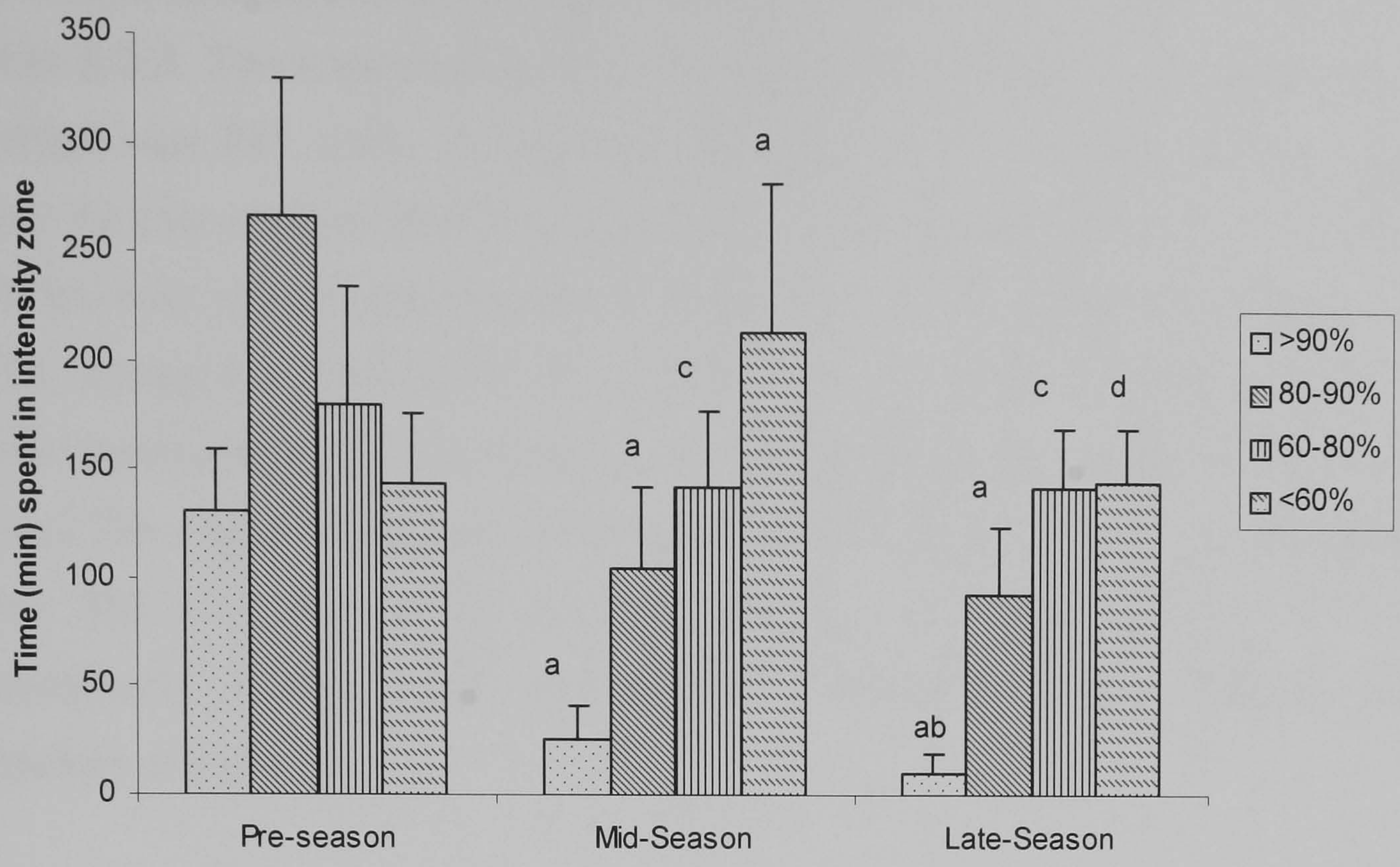
The highest cardiac strain during training occurred pre-season. The mean heart rate response during Pre-season, Mid-Season and Late-Season was 149 ± 7 beats$\cdot$min^{-1}, 148 ± 8 beats$\cdot$min^{-1} and 147 ± 8 beats$\cdot$min^{-1} respectively. The mean percent of time spent at relative exercise intensities during training are shown in Figure 5.3.1. During intensive pre-season training, the percentage of time spent above 90% H.R.$_{Max}$ was significantly greater than at any other period during the season ($F_{2,69}$ =147.7; P<0.001). The mean total time (min. week^{-1}) spent at various exercise intensities during weekly training is shown in Figure 5.3.2. During intensive pre-season training, the total time (min. week^{-1}) spent above 90% $H.R._{Max}$ was significantly greater than at any other period during the season ($F_{2,69}$ =279.1; $P<0.001$).

The relative intensities during competitive match-play according to position are shown in Figure 5.3.3. The relative intensities during competitive match-play indicate a high cardiac strain with heart rate exceeding 80% of the individual maximal value for over 80% of the event.



[a] $P < 0.001$ v Pre-season

Figure 5.3.1. Percent of time spent in various intensity zones during elite training (mean ± S.D). (n = 24).



[a] P < 0.001 v Pre-season
[b] P < 0.05 v Mid-season
[c] P < 0.01 v Pre-season
[d] P < 0.001 v Mid-season

Figure 5.3.2. Total time spent in various intensity zones during elite weekly training (mean ± S.D). (n = 24).

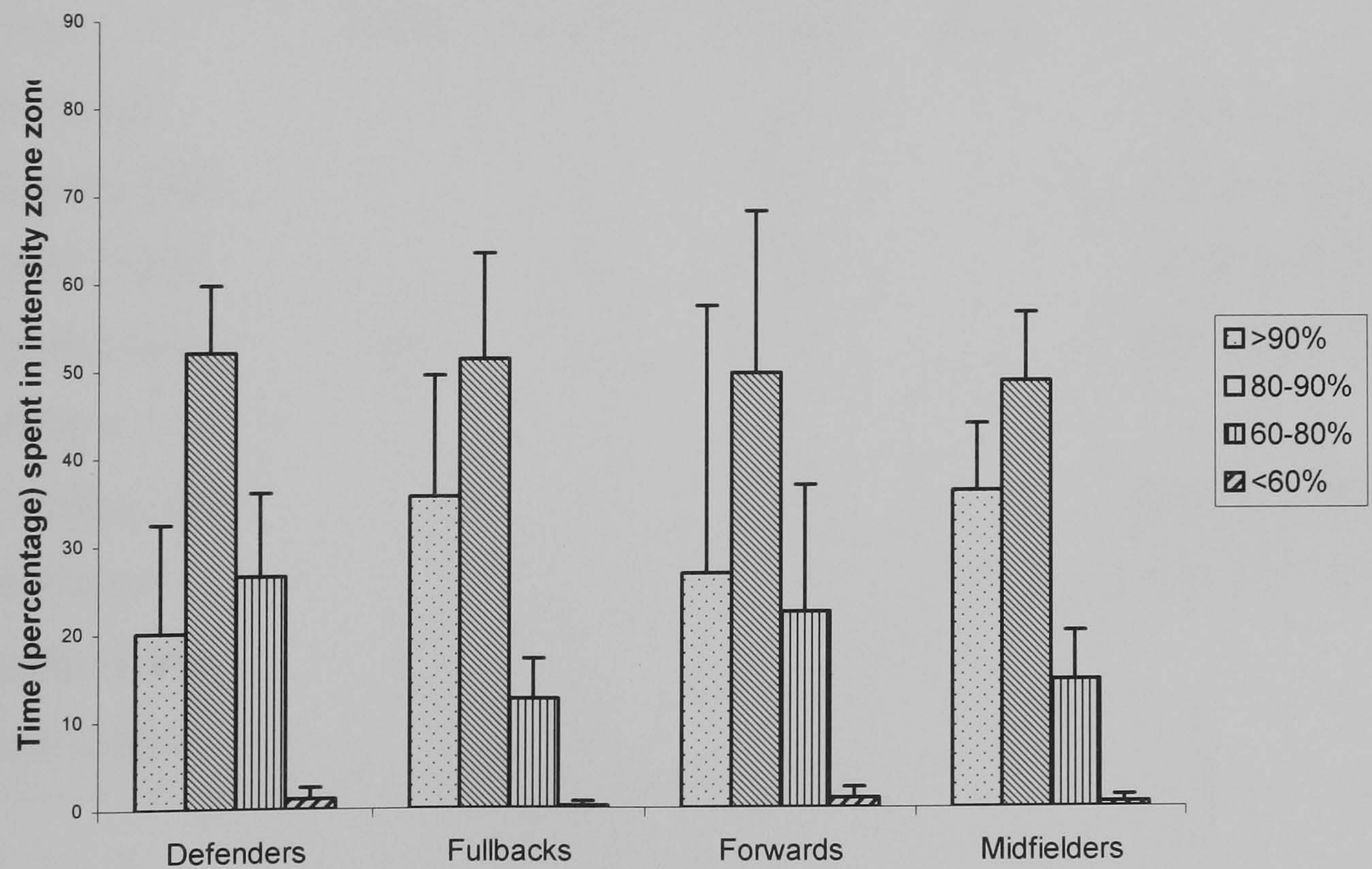


Figure 5.3.3. Percent of time spent in various intensity zones during elite competitive match-play (mean ± S.D). (n = 24).

A practical example of a training session and workload calculation is shown in Table 5.3.3. The total training load for the session using the calculation-based method was 250 units. A practical example of the workload during a typical week for one subject over the study period is shown in Table 5.3.4. The same method was used to assess the workload over the duration of a match. Figure 5.3.4. shows the distribution of workload over a match in 10 min periods. The mean workload for all positions during competitive match-play was 304 ± 32.8 Units. The mean workloads for forwards, defenders, full-backs and midfielders were 293.5 ± 45.7, 282.5 ± 29.9, 322.9 ± 17.7 and 316.3 ± 16.7 Units respectively. Table 5.3.5. shows the workload during different training activities and drills.

Table 5.3.3. Example of a training session and workload calculation

	Time (min) spent in intensity zone				Total Units
Activity	>90%	80-90%	60-80%	<60%	
Warm-up			10	5	(10 x 2) + (5 x 1) = **25**
Passing Drill		5	10		(5 x 3) + (10 x 2) = **35**
Sprint Drills		10	5		(10 x 3) + (5 x 2) = **40**
Small-sided Game 4 v 4	20	5			(20 x 4) + (5 x 3) = **95**
Shooting Drill		5	10		(5 x 3) + (10 x 2) = **35**
Cool down jog/flexibility			5	10	(5 x 2) + (10 x 1) = **20**
Total Units					= **250**

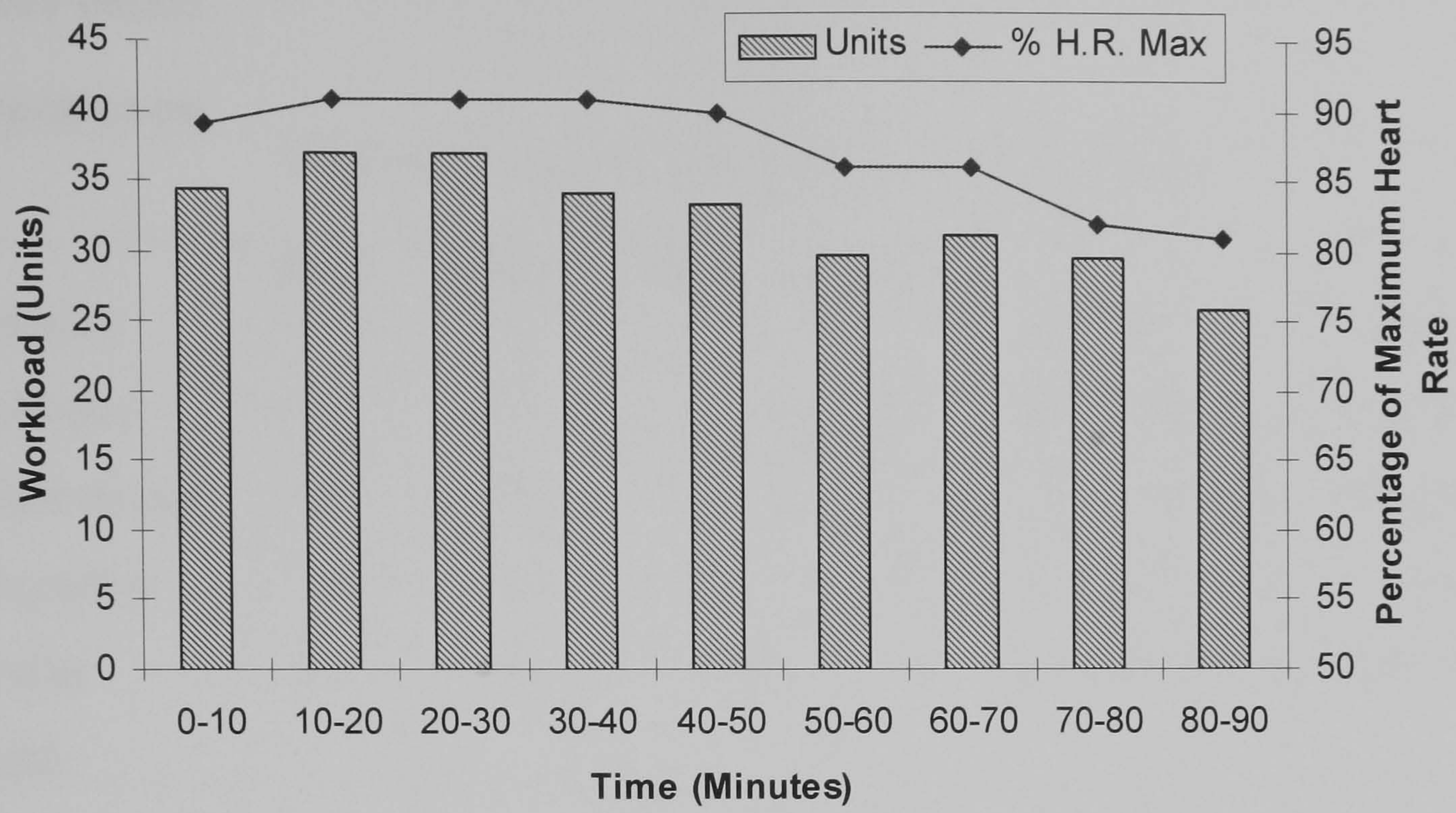


Figure 5.3.4. Workload for an elite male soccer player during match-play.

Table 5.3.4. Weekly workload for an elite male soccer player throughout the study period.

Pre-season

	Time (min) spent in intensity zone				Total Units
	>90%	80-90%	60-80%	<60%	
Monday	23	42	26	51	(23 x 4) + (42 x 3) + (26 x 2) + (51 x 1) **= 321**
Tuesday	35	32	49	48	(35 x 4) + (32 x 3) + (49 x 2) + (48 x 1) **= 382**
Wednesday	26	36	37	49	(26 x 4) + (36 x 3) + (37 x 2) + (49 x 1) **= 335**
Thursday	23	34	38	51	(23 x 4) + (34 x 3) + (38 x 2) + (51 x 1) **= 321**
Friday	22	33	45	54	(22 x 4) + (33 x 3) + (45 x 2) + (54 x 1) **= 331**
Total					**= 1690**

Mid-Season

	Time (min) spent in intensity zone				Total Units
	>90%	80-90%	60-80%	<60%	
Monday	13	16	52	28	(13 x 4) + (16 x 3) + (52 x 2) + (28 x 1) **=232**
Tuesday	2	18	53	31	(2 x 4) + (18 x 3) + (53 x 2) + (31 x 1) **=199**
Wednesday	10	17	40	22	(10 x 4) + (17 x 3) + (40 x 2) + (22 x 1) **=193**
Thursday	1	15	46	28	(1 x 4) + (15 x 3) + (46 x 2) + (28 x 1) **=169**
Friday	2	14	39	16	(2 x 4) + (14 x 3) + (39 x 2) + (16 x 1) **=144**
Total					**= 937**

Late-Season

	Time (min) spent in intensity zone				Total Units
	>90%	80-90%	60-80%	<60%	
Monday	2	18	32	33	(2 x 4) + (18 x 3) + (32 x 2) + (33 x 1) **=159**
Tuesday	2	17	51	72	(2 x 4) + (17 x 3) + (51 x 2) + (72 x 1) **=233**
Wednesday	0	0	0	0	(0 x 4) + (0 x 3) + (0 x 2) + (0 x 1) **=0**
Thursday	6	31	33	34	(6 x 4) + (31 x 3) + (33 x 2) + (34 x 1) **=217**
Friday	0	23	33	55	(0 x 4) + (23 x 3) + (33 x 2) + (55 x 1) **=190**
Total					**=799**

Table 5.3.5. Mean heart rate responses during training activities with assigned workload units.

Activity	Number of players	Pitch Area	Limitations	H.R. (beats min^{-1}) (mean ± S.D)	% H.R. $_{Max}$ (mean ± S.D)	Duration	>90%	80-90%	60-80%	<60%	Total Workload Units
Warm-up Jogging	-	-		130 ± 9	66.8 ± 4.6	10 min	0	0.4	9.6	0	20.4
Dynamic Flexibility	-	-		118 ± 10	60.6 ± 5.2	10 min	0	0	7.25	2.7	17.2
Active stretching	-	-		109 ± 4	56 ± 2.1	10 min	0	0	2.5	7.5	12.5
Juggling	1	-		127 ± 6	65.3 ± 3.2	10 min	0	0	8.5	1.5	18.5
Ball Skills	1	-		133 ± 7	68.2 ± 3.5	10 min	0	0	9.0	1.0	19
Head Tennis	4 v 4	15 x 15 m		129 ± 5	66.2 ± 2.7	10 min	0	0	5.4	4.6	15.4
Set-Plays	11 v 11	½ Pitch		124 ± 9	63.9 ± 4.4	10 min	0	0.5	6.9	2.6	17.9
Passing Drills		10 x 10m		132 ± 9	68.1 ± 4.5	10 min	0	1.8	7.7	0.5	21.3
Team Shape		½ Pitch		142 ± 9	73.2 ± 4.8	10 min		2.9	7.1	0	22.9
Passing Drills		½ Pitch		144 ± 7	74.3 ± 3.7	10 min	0	3.5	6.5	0	23.5
Crossing Drills		-		152 ± 6	78.2 ± 3.2	10 min	0	8.5	1.5	0	28.5
Shooting Drills		-		148 ± 5	76.3 ± 2.7	10 min	0	8.0	2.0	0	28
Dynamic Flexibility		-		118 ± 10	60.6 ± 5.2	10 min	0	0	7.25	2.7	17.2
Head Tennis	2 v 2	15 x 15 m		137 ± 5	70.3 ± 2.4	10 min	0	3.5	6.2	0.3	23.2
Team Shape		Full Pitch		149 ± 8	76.6 ± 3.9	10 min	0	6.5	3.5	0	26.5
Defensive play	6 v 4	½ Pitch	All in	159 ± 9	82 ± 4.7	10 min	1.8	8.2	0	0	31.8
Passing drills		½ Pitch	1 touch	152 ± 7	78.0 ± 3.8	10 min	0	8.8	1.2	0	28.8
Dribbling Drills				145 ± 9	74.4 ± 4.5	10 min	0	6.5	3.5	0	26.5
Shooting drills		-		144 ± 7	74.3 ± 3.7	10 min	0	3.5	6.5	0	23.5
Crossing Drills		-		152 ± 6	78.2 ± 3.2	10 min	0	8.5	1.5	0	28.5

Table 5.3.5. (Cont) Mean heart rate responses during training activities with assigned workload units.

Activity	Number of players	Pitch Area	Limitations	H.R. (beats·min^{-1}) (mean ± S.D)	% H.R. $_{Max}$ (mean ± S.D)	Duration	>90%	80-90%	60-80%	<60%	Total Workload Units
	4 v 2	20 x 30m	All in	162 ± 14	83.5 ± 7.2	10 min	1.4	5.1	3.5	0	27.9
	5 v 2	30 x 40m	All in	164 ± 15	84.2 ± 7.5	10 min	1.5	5.0	3.5	0	28
	10 v 10	½ Pitch	All in	170 ± 13	87.5 ± 6.7	10 min	2.8	7.2	0	0	32.8
	9 v 9	½ Pitch	All in	172 ± 12	88.4 ± 6.2	10 min	3.1	6.9	0	0	33.1
	8 v 8	½ Pitch	2 touch	173 ± 12	89.1 ± 6.0	10 min	4.5	5.5	0	0	34.5
	11 v 11	Full Pitch	2 touch	173 ± 12	89.2 ± 5.9	10 min	4.4	5.6	0	0	34.4
	10 v 10	¾ Pitch	Pressing game	171 ± 8	88 ± 4.2	10 min	3.4	6.6	0	0	33.4
	9 v 9	¾ Pitch	Pressing game	173 ± 8	89 ± 4.0	10 min	3.8	6.2	0	0	33.8
	8 v 8	¾ Pitch	Pressing game	176 ± 10	90.3 ± 5.2	10 min	4.2	5.8	0	0	34.2
	6 v 6	½ Pitch	Pressing game	176 ± 9	90.5 ± 4.5	10 min	5.5	4.5	0	0	35.5
	5 v 5	50 x 40 m	5 v 5 with goals	176 ± 9	90.5 ± 4.5	10 min	6.5	3.5	0	0	36.5
	4 v 4	30 x 40 m	Line ball game	178 ± 6	91.5 ± 3.3	4 min	3.0	1.0	0	0	15
	3 v 3	30 x 30 m	Line ball game	179 ± 5	92 ± 2.4	4 min	3.0	1.0	0	0	15
	2 v 2	20 x 30 m	Line ball game	181 ± 5	93 ± 2.5	3 min	3.5	0.5	0	0	15.5
	1 v 1	20 x 20 m	Line ball game	182 ± 6	93.5 ± 3.0	2 min	2.0	0	0	0	8
800-m Running	-	-	Without ball	167 ± 4	86 ± 2.0	2 min	0.2	1.4	0	0	5
1200-m Running	-	-	Without ball	171 ± 4	88 ± 2.0	4 min	1.5	2.5	0	0	13.5
5 x 2 min Running	-	-	Without ball	172 ± 4	88.5 ± 2.0	10 min	1.2	2.8	0	0	13.2
4 x 4 min Running	-	-	Without ball	174 ± 4	89.5 ± 2.0	16 min	4.4	11.6	0	0	52.4
Dribbling Circuit	-	-	With ball	175 ± 5	90 ± 2.6	4 min	2.0	2.0	0	0	14
Running Circuit	-	-	Without ball	176 ± 5	90.5 ± 2.5	4 min	2.4	1.6	0	0	14.4

5.3.4 Discussion

The highest cardiac strain during training occurred pre-season, when there was an emphasis on physiological preparation for the forthcoming competitive schedule. The pre-season training period in England traditionally consists of aerobic fitness work, soccer training, and friendly matches (Mercer et al., 1995). In the present study, aerobic conditioning in the form of running accounted for 36% of the total time and ball-related activity 32% of the total time. When investigating fitness profiles of English professional soccer players before and after the pre-season period, the training records kept by Mercer et al. (1995) revealed that the conditioning emphasis of sessions in weeks 1 to 3 was 85% aerobic/endurance conditioning and 15% game- related activity. It appears that contemporary methods for the development of soccer-specific endurance emphasise the use of more ball-related activity.

The training activities of the players in this study over the pre-season training period were sufficient in frequency, duration and intensity to increase estimated maximal oxygen uptake ($\dot{V}O_{2max}$) approximately 1 $ml.kg^{-1}.min^{-1}$. Interval training at exercise intensities between 90-95% of maximal heart rate has been shown to increase maximal oxygen uptake ($\dot{V}O_{2max}$) (Helgerud et al., 2001). These authors provided data to suggest that working between 90-95% of maximal heart rate, increased $\dot{V}O_{2max}$ approximately 5 $ml.kg^{-1}.min^{-1}$ in already well-trained elite junior soccer players. Moreover, the training led to several positive on-field adaptations such as increased distance covered, number of sprints performed and involvements with the ball.

Ideally, endurance training for soccer players should be carried out with the ball (Bangsbo, 1994c). The players might then practice technical and tactical skills similar to situations experienced during the game. Whether endurance training should take the form of game-related playing sessions or pure running is a critical decision of the coach. In the present study, the training regimen during pre-season combined high-intensity small-sided play and high-intensity running with satisfactory results in terms of training at an intensity zone between 90 and 95% of maximal heart rate (Helgerud et al., 2001).

Further improvements in aerobic fitness on top of that gained during the pre-season training period are reliant upon the aerobic energy demands of competitive training and match-play. It is reasonable to suggest that the major stimulus for physiological conditioning during the competitive season is via competitive soccer match-play. While such an occurrence may be a reflection of the play-rest-play-rest strategy adopted by contemporary soccer teams, such a phenomenon may explain in part the differences in physiological fitness observed in Chapter IV. Moreover, training regimens that emphasize the playing of matches as the main physiological demand on the body's energy systems are more likely to result in inter-positional physiological differences than regimens that involve general physical training in addition to competitive match-play (Davis et al., 1992).

Brady et al. (1997) demonstrated that the aerobic fitness of elite Scottish soccer players fluctuates over the course of the season following the achievement of peak fitness at the end of pre-season. The deterioration of aerobic fitness levels towards the end of the season was associated with the coaches 'scaling down' training in order to save the players efforts for competition. These observations were supported in the present study, where the lowest exercise intensities were reported towards the later stages of the season. Such a phenomenon may be compounded in some players due to factors such as regularity of competitive match-play, team selection and injury status.

Assuming that heart rate at a fixed exercise intensity decreases as aerobic fitness improves (Wilmore et al., 1996), an elevated heart rate during the pre-season exercise period could indicate a lack of conditioning (Jeukendrup and Van Diemen, 1998). In practical terms this means that when monitoring exercise intensities of soccer players throughout the annual year, the training state of the player must be taken into account. In the present study, there were minor fluctuations in body mass, adiposity and aerobic conditioning. In future, factors such as body mass, dehydration, overtraining, adiposity and $\dot{V}O_{2max}$ need to be controlled or taken into account when heart rate data are analysed. Recently, Lamberts et al. (2004) reported that a change in body mass of 2.4 kg resulted in an increased heart rate recovery of 33 $b.min^{-1}$ following a fixed period of exercise intensity. It is reasonable to assume that these changes in heart rate were caused by a reduced plasma volume as a result of dehydration resulting from training the previous day. Intensive pre-season training can result in accumulative dehydration, which must be accounted for in future research. In addition to the aforementioned concerns, heart rate monitoring is a comparatively poor method of evaluating very high-intensity exercise such as weight training and plyometric training. Therefore, even with the most optimal heart rate monitoring strategy, quantification of training loads does not translate well to very high-intensity exercise training (Foster et al., 2001). Future research may integrate the rating of perceived exertion as well as an attempt to quantify muscular output during very high-intensity exercise training.

In the present study, a high degree in variability of exercise intensity during training was observed. These observations are in line with other studies that have addressed elite contemporary soccer training (Hoff et al., 2002; Sassi et al., 2003). The variability may be linked to a global approach to group exercises. That is, the training stimulus may not simultaneously stress all players to the same relative intensity. This has huge implications for ensuring all players receive an appropriate training stimulus throughout the season, particularly in a rotational squad system. Such an observation may also be linked to a highly individual response (measured as a percent of maximum heart rate) to the use of small-group play.

In line with the findings of this study, Rampinini et al. (2004) reported that the intensity during small-group play was inconsistent and highly variable from day to day, even within the same individual. Fifteen male soccer players performed the same training session twice within one week. The training included a warm-up using the ball, 4 v 4, 4 v 2, 10 v 10 and two circuit tracks

without the ball. The results demonstrated poor reliability of small-group play (intra-class correlation coefficients from 0.381 to 0.624) while running without the ball was found to show good reliability (intra-class correlation coefficients from 0.888 to 0.825). When the training involves the use of small-group play, it is extremely difficult to organise training so that all players receive similar training loads. Such a phenomenon may be addressed in running activities without the ball, where the intensity can be more readily regulated.
The relative intensities during competitive match-play indicate a high cardiac strain with heart rate exceeding 80% of the individual maximal value for over 80% of the event. Similar findings were reported by Rhode and Esperson (1988) who noted that the heart rate response for Danish players participating in 1st division games was below 73% of maximal heart rate for 11% of the total playing time, between 73% and 92% of maximal heart rate for 63% of the playing time, and greater than 92% of maximal heart rate for 26% of the total playing time. According to the present data, the training load (measured by training load units) induced by a match represents a relative high percentage of the weekly training load. For example, in weeks characterised by two official matches, the training stimulus can represent approximately 50% of the total weekly load. When only one match is played, this figure is reduced to approximately 25%.

According to Hoff et al. (2002), playing soccer (11 v 11 match-play) does not put enough pressure on intensity over time to really develop $\dot{V}O_{2max}$ very much. During a game of soccer, concentrating on opponents and the anxiety caused by match situations may lead to heart rates above what reflects the actual metabolic load (Hoff et al., 2002). Moreover, when the playing of games becomes the major stimulus for physiological conditioning, some amount of detraining may occur during the competitive season.

The concept of detraining throughout the season has implications for organising the training regimens of contemporary soccer players as the maintenance programme during the competitive season may not be strenuous enough to retain the physical fitness levels attained by the end of pre-season.

Evidence from the present study suggests that during the competitive season there is a strong bias towards technical and tactical game-related activities. It also appears that the work intensity is reduced when more technical and tactical elements are involved. It may then be beneficial to emphasize high-intensity training to complement technical and tactical work to ensure maintenance of fitness throughout the regular match-play programme.

How such high-intensity training interventions are organised becomes a critical decision for the coach. In the present study, the training load associated with small-group play with the ball can present a training stimulus comparable with and sometimes exceeding that provided by interval training without the ball. These recommendations are in line with the findings of others (Sassi et al., 2003). Hoff et al. (2002) demonstrated how playing in small-sided games induced 91% of HR_{max} in Norwegian 1st Division soccer player (similar to the values reported in this study). They also found that corresponding values for dribbling a soccer ball on a specifically designed track were 93.5% HR_{max}. They concluded that soccer-specific exercise using ball-dribbling or small-group play may be performed as aerobic interval training. This recommendation is in agreement with the findings of Reilly and Ball (1984), and Reilly and Bowen (1984) who observed that unorthodox modes of motion and game-specific activities increase the physiological strain and hence training stimulus. What is clear is that while small-group exercises provide an appropriate stimulus, the individual response must be monitored, particularly during the in-season programme.

In conclusion, identification of the characteristics of training and match-play permits an understanding of the physiological demands placed on elite players. Moreover, such information may also help in the systematic preparation of soccer players. The highest source of cardiac strain during training occurred pre-season. This timing will have implications for injury rates during this period as exercise intensity has been linked to the incidence of injury rate (Woods et al., 2002). It will also have implications for the fitness characteristics and the preparation of players during this phase of the annual calendar. The pre-season training period in England traditionally consists of a high intensity of exercise and it is here that players will maximise the acquisition of fitness states. Therefore, it should be expected that at the end of this period, anaerobic and aerobic characteristics might be at a maximum. Clearly, when assessment strategies are conducted, such factors must be taken into consideration.

One of the prominent findings of this study was that towards the later stages of the season, exercise intensity during training is reduced. This could be attributed to coaches deliberately 'scaling down' training to save the most important efforts for matches. Such a 'scaling down' has implications for the fitness characteristics of players towards the end of the competitive programme. How these factors relate to performance and incidence of injury may require further consideration. What is clear, however, is that following pre-season, there is a mismatch between exercise intensity attained during matches and training. It may be that matches become the major source of physical strain and hence physical fitness. When games become the major source of training, differences may become manifest in the physical capacities of players between positions (Chapter IV). Also given the high degree in variability of work intensity during training, coaches must ensure that all players receive appropriate training throughout the season, particularly in a rotational squad system. Finally, The distribution of time devoted to ball related activities was higher during the in-season than pre-season. While coaches move towards ball-related drills, exercise intensity may be more difficult to control. Given the difficulty in controlling exercise intensity during training, the use of heart rate monitoring systems to ensure appropriate workloads is recommended. Such a protocol may also assist in the reduction of the incidence of injury. The following hypothesis was rejected:

A. H_O: At an elite level of play, the physiological stresses associated with training do not vary significantly throughout the year.

5.4 SUMMARY

The aim in this chapter was to quantify the physiological stresses associated with elite competitive match-play. A further aim was to identify the physiological stresses imposed on elite players during training. Heart rate and work-rate profiles were combined to provide a holistic picture of the stresses associated with professional elite soccer. Elite soccer match-play is characterised by intermittent activity involving the anaerobic and aerobic energy systems. Soccer matches have high-intensity periods where players are exposed to a number of unorthodox modes of action and game-specific activities. Each playing position demands its own set of specific characteristics and these are reflected in the work-rate profiles of players. Evidence from this chapter suggests that contemporary Premier League soccer is characterised by a higher level of physiological stress than in previous decades. Moreover, contemporary soccer is played at a faster tempo and therefore requires individuals to perform at higher exercise intensities in order to compete for possession of the ball. Changes in the rules of the game, such as the rule prohibiting the goalkeeper from picking up a back-pass, the penalizing of time wasting and permission to use three substitutes, have contributed to the rise in tempo (Reilly, 2005). A more systematic approach to training and an increased recruitment of expensive international players further adds to the development of the game at a professional level.

An elite player should ideally be able to maintain a high intensity of exercise throughout the whole game. Evidence from the present chapter suggests a significant reduction in exercise intensity towards the later stages of a game. These effects were observed independent of playing position. Such a reduction may be a manifestation of the phenomenon of fatigue.

Another significant finding was that training intensity was variable throughout the season. The highest source of cardiac strain during training occurred in pre-season. Thereafter, a reduction in exercise intensity during training was observed. During the competitive season there was a strong bias in training towards technical and tactical game-related activities. It also appears that the work intensity is reduced when more technical and tactical elements are involved. It may then be beneficial to emphasize high-intensity training to complement technical and tactical work to ensure maintenance of fitness throughout the regular match-play programme.

In conclusion, the principal findings from this chapter were:

The physiological demands of elite match-play (as measured as a percent of HR_{max}) are high, with heart rates exceeding 80% of the individual maximal value for prolonged periods during competition. A considerable variation in relative exercise response within each positional category was observed. Such a variation could be due to the tactical role assigned to the players and/or their physical capacity. Towards the later stages of a game a significant reduction in heart rate response was observed. Such a reduction reflects the occurrence of fatigue.

Total distance covered during match-play varied according to playing positions. Midfield players and full-backs covered greater distances during competition than central defenders and forwards. Work-rate profiles provide evidence that these differences are the result of both low and high intensity work. Furthermore, differences were observed for the distance covered between halves, for the distance covered in the second half between positions, and for sprint activity over the duration of 90 min. Such data are evidence of cumulative fatigue over the duration of competitive match-play, particularly in high-intensity sprints.

The highest source of cardiac strain during training occurred pre-season. Thereafter, a significant reduction in training exercise intensity was observed. Towards the later stages of the annual season, the exercise intensity during training did not approximate the exercise intensity of competitive matches. A high degree in variability of work intensity during training was observed.

The assessment of competitive match-play and the exercise intensity in training reveals a general picture of the stresses imposed on elite soccer players. To add to this picture, an assessment of the manifestation of physical stresses is required. This aspect will be explored in the next chapter via an investigation of the prevalence of injuries.

CHAPTER 6

CHAPTER VI

6. INJURIES IN ELITE SOCCER

The contemporary game at the professional level seems to be more demanding than suggested in the early literature (e.g. Reilly and Thomas, 1976). One manifestation of these extra stresses may be the injury rates of elite soccer players. This chapter contains two studies, which combine to provide information relating to the injury rate of elite soccer players and how injuries interfere with professional activity. Such information yields valuable insights into the relationship between injury incidence and participation in elite soccer training and competition. Moreover, data concerning injury incidence during soccer can further contribute to the holistic picture of the demands placed on individual participants. The purpose of the first study was to identify the effects of soccer training and competitive match-play on the injury status of professional soccer players. A prospective analysis of the injuries sustained at a Premier League soccer club over two competitive seasons was undertaken. The purpose of the second study was to conduct a comparable analysis of soccer injuries sustained by elite young players. The outcome of these studies will further our understanding of the physical stresses placed on different sub-groups of the soccer population and complement the studies of physiological load.

6.1 A STUDY OF INJURIES IN ELITE PREMIER LEAGUE SOCCER PLAYERS

6.1.1 Introduction

The physiological loads associated with intensive training and competition may lead to increased stresses in elite soccer players, placing them at increased risk of sustaining injuries. With increased financial incentives, commitment to training and competition is, as a result, often extremely high. In addition, coaches and athletes operating at an elite level are well aware that the small increments in performance standards that are possible at the highest level require training programmes that are extensive in scale and need to be conducted at a high intensity.

The intensive training and frequent competition in elite soccer are invariably accompanied by some manifestation of the stresses associated with the physiological demands of the game. Analysis of these stresses and the injuries that sometimes result is helpful in identifying risk factors associated with specific soccer-related activities. In addition, monitoring injuries during training and competition may serve as an appropriate tool for evaluating the physiological loads associated with elite participation. Such data can offer valuable information to assess, monitor and adjust training and match practices in order to ensure optimal performance and avoidance of injuries.

Professional soccer is known to be associated with a relatively high risk of injury (Hawkins and Fuller, 1999), the features being outlined in several epidemiological studies (Hawkins et al., 2001; Woods et al., 2002). The aetiology of sports injuries has been addressed by several authors (Ekstrand and Nigg, 1989; Taimela et al., 1990; Dvorak and Junge, 2000), with injuries normally found to be the result of a summation of several factors. It is therefore clearly difficult to establish a cause and effect relationship at an elite level of play. Risk factors include the sport itself; the match intensity at an elite level of play that creates occasions for more frequent and powerful player impacts; an extensive number of elite matches; a short off-season leaving little time for recovery and pre-season preparation; excessive pre-match training leading to player fatigue; or musculoskeletal weaknesses.

The Football Association's audit of injuries is one project that has been undertaken in an attempt to identify the aetiological factors associated with injury in elite professional soccer (Hawkins et al., 2001; Woods et al., 2002). Player injuries from 91 professional League clubs were reported from July 1997 until the end of May 1999. The Audit is on-going and is helping to increase the case for quality medical provision in the sport. However, recording the incidence and prevalence of injury is only of real benefit if appropriate consideration is given to the methodology and the means of data analysis and interpretation.

One of the problems associated with the F.A. audit of injuries research project is that exposure time is not accounted for. Collecting data on players' exposure to training and competition, during which there is an opportunity to sustain an injury, is essential to determine the incidence of injury (commonly reported as injuries per 1000 hours exposure). This figure can then be compared with other studies, players, seasons and teams, all of which may have different exposure to training and competition.

A significant finding from the F.A. audit of injuries was the disproportionately high number of training injuries during pre-season training (Woods et al., 2002). As the volume of training is greater during the pre-season period (see previous chapter), the incidence may be no greater, or even less (per 1000 hours) than during training at any other time points during the season. Failure to gather exposure data limits the analysis to reporting proportions of overall injuries and this information cannot be used to assess risk factors. Other methodological concerns include the inconsistencies associated with the large number of individuals involved in data entry, and the large range in level of competition and training methods employed within the 91 League Clubs.

For these reasons, there is a necessity for the injury analysis at one professional soccer club to be researched in depth, to provide a more complete analysis of the incidence and severity of injuries associated with soccer participation. The aim of the present study was to establish, using a prospective epidemiological study, the incidence of injury in a Premier League team over a period of two years. Prospective studies of this type can provide the necessary information for further insight into the physiological demands imposed on elite soccer players.

6.1.1.1 Statement of hypothesis

The following statements are all expressed as null hypotheses:

A. H_O: At an elite level of play, the incidence of injuries does not vary according to different playing positions.

B. H_O: At an elite level of play, the incidence of injuries does not vary throughout the season.

C. At an elite level of play, the incidence of injuries does not vary between competitive match-play and training.

6.1.2 Methods

6.1.2.1 Subjects

Subjects were 42 (3 goalkeepers, 6 central defenders, 5 full-backs, 10 central midfield players, 7 wide-midfield players and 11 forwards) full-time professional male soccer players of a Premier league squad (age 26 ± 3 years). For the purpose of the study, only subjects that had represented the 1st team in the Premier League, or the reserves in the Premier Reserves League were included. All 42 players completed the 2 year observation period.

6.1.2.2 Procedures

The Human Ethics Committee of Liverpool John Moores University approved all procedures. Subjects were fully informed about the aims, procedures and medical confidentiality issues before written consent was obtained. The processes of medical assessment and annotation were familiar to the medical staff and players at the club as part of their daily fitness assessment.

Player injuries were prospectively reported from July 1999 through to the end of May 2001 inclusive. Injuries were recorded by the club's physiotherapist and physician on a specific injury audit questionnaire designed by Hawkins et al. (2001). Prior to the study, the medical staff members attended a briefing meeting and were issued with guidance notes on how to complete the questionnaires. It was therefore assumed that all injuries were reported consistently and objectively. The injury audit questionnaires were analysed by the author weekly to establish which players had been absent and the number of days and competitive matches each had missed that week.

A recordable injury was defined as one sustained during training or competition and which prevented the injured player from participating in normal training or competition for more than 48 hours (not including the day of the injury). Injuries unrelated to soccer were not included, nor was any absence due to illness. Injuries to players on international duty were included since details of such injuries were generally reported back to club medical staff. The severity of each injury was defined as slight, minor, moderate, or major depending on whether the player was absent from training or competition for two to three days, four to seven days, one to four weeks or more than four weeks, respectively. Re-injury was defined as an injury of the same nature and location involving the same player in the same season. The variables identified for each injury are listed in Table 6.1.1.

Table 6.1.1. Injury variables recorded during training and matches.

• The date of the injury	• The injured player
• The playing position at the time of injury	• The number of times the player had been injured during the study
• The time of the injury	• The activity at the time of the injury
• The body side where the injury is located	• The condition of the playing surface
• Whether the injury was a re-injury	• The severity of the injury
• The nature of the injury	• The anatomical location of the injury
• The medical classification of the injury	• The number of training days absent from training and competition

The number of competitive games played by the 1st team over the study period was recorded together with the date of each individual game. Exhibition and testimonial matches were not included as competitive matches and were considered to be part of the training programme. A training log was employed to calculate the total number of hours spent in training throughout the period of the study. Playing hours at risk during training were then calculated on a monthly basis. Similarly, the playing hours at risk during competitive games were calculated assuming that there were eleven players on the field at all times and that each match lasted 100 min. The risk of injury or Injury Frequency Rate (IFR) was calculated as a rate per 1000 playing hours in games and training using the following formula:

$$\mathbf{IFR} = \frac{\textbf{Number of injuries in period}}{\textbf{Total hours worked during period}} \; \mathbf{* \, 1000}$$

6.1.2.3 Statistical analyses

Data were analysed using SPSS (Chicago, Illinois, USA). Descriptive and comparative data are presented. The χ^2 significance test was used to investigate the differences between positions and monthly distributions. Significance was accepted at $P<0.05$.

6.1.3 Results

During the study period there were 184 injuries that prevented a player from either training or competition for at least one day. Sixty-three percent of the injuries occurred during matches, the remainder taking place during regular training and practice.

The nature of injuries sustained during training and matches is shown in Table 6.1.2. Seventy-three percent of all injuries were classified as strains, sprains or contusions. Injuries grouped as others included those that were not accounted for by the audit questionnaire. When examining the injuries during training and competitive matches, the three major types of injuries previously mentioned remained dominant. However, there was a significantly greater percentage of muscular contusions in games compared to training (14.8% v 1.5%, P< 0.01). The occurrence of muscular contusions during matches demonstrates a tendency towards contact injuries during this activity. Similarly the relative proportion of strains was significantly greater during games compared to training (33% v 29.9%, P< 0.05).

The locations of injuries sustained by players are shown in Table 6.1.3. Eighty-five percent of all injuries were sustained in the lower extremities with injuries to the thigh, knee and ankle accounting for approximately two-thirds of those reported. Significant differences were found between the relative proportions of injuries sustained to the knee in matches compared to training (22.4% v 14.7%, P<0.01). The percentage of injuries sustained to the ankle was also greater in matches than in training (21.6% v 17.6%, P<0.05).

Table 6.1.2. Nature of injuries sustained during training and matches

Nature	All injuries		Match injuries		Training injuries	
	No.	%	No.	%	No.	%
Fracture	4	2.2	3	2.6	1	1.5
Capsular Tear	3	1.6	1	0.9	2	3.0
Strain	59	32.2	30	26.1	29	43.3
Muscular Contusion	18	9.8	17*	14.8	1	1.5
Sprain	58	31.4	38†	33	20	29.9
Tendonitis	8	4.4	5	4.3	3	4.5
Tissue Bruising	4	2.2	3	2.6	1	1.5
Hernia	1	0.5	0	0	1	1.5
Avulsion	2	1.1	1	0.9	1	1.5
Inflammation	2	1.1	1	0.9	1	1.5
Muscle Rupture	1	0.5	1	0.9	0	0
Ligament Rupture	2	1.1	2	1.7	0	0
Paratendonitis	3	1.6	3	2.6	0	0
Other	17	8.6	9	7.0	8	10.3
Total	184	100	116	99.1	68	98.5

† $P < 0.05$ Different proportions between match injuries and training injuries
* $P < 0.01$ Different proportions between match injuries and training injuries

Table 6.1.3. Locations of injuries sustained during training and matches

Nature	All injuries		Match injuries		Training injuries	
	No.	%	No.	%	No.	%
Head/face/neck	5	2.7	4	3.4	1	1.5
Upper extremity	7	3.8	4	3.4	3	4.4
Torso	15	8.1	9	7.8	6	8.9
Hip	7	3.8	4	3.4	3	4.4
Groin	11	5.9	7	6.0	4	5.9
Thigh	41	22.2	20	17.2	21	30.9
Knee	36	19.5	26	22.4*	10	14.7
Lower leg	3	1.6	2	1.7	1	1.5
Calf	11	5.9	8	6.9	3	4.4
Ankle	37	20	25	21.6†	12	17.6
Foot	6	3.2	5	4.3	1	1.5
Toe	5	2.7	2	1.7	3	4.4
Total	184	100	116	100	68	100

† $P < 0.05$ Different proportions between match injuries and training injuries
* $P < 0.01$ Different proportions between match injuries and training injuries

The severity of all injuries sustained during the observation period is shown in Table 6.1.4. Injuries classified as slight, minor, moderate and major were 20%, 33%, 30% and 16% of the total injuries, respectively ($P<0.01$). There were further differences in the severity of injuries when match and training injuries were compared. Indeed, greater relative numbers of minor and moderate injuries were sustained as a result of competitive match-play compared to training (minor 36.2% v 26.5%, $P<0.01$; moderate 31.9% v 27.9% $P<0.05$).

Table 6.1.4. Severity of injuries sustained during training and matches

Nature	All injuries		Match injuries		Training injuries	
	No.	%	No.	%	No.	%
Slight (2-3 days)	37	20	18	15.5	19	27.9
Minor (4-7 days)	61	33	42	36.2*	18	26.5
Moderate (8-28 days)	56	30.3	37	31.9†	19	27.9
Major (>28 days)	31	16.8	19	16.4	12	17.6
Total	184	100	116	100	68	100

† $P < 0.05$ Different proportions between match injuries and training injuries
* $P < 0.01$ Different proportions between match injuries and training injuries

During the observation period, the relative proportion of injuries sustained during matches and training by goalkeepers, full-backs, central defenders, central midfield players, wide midfield players and forwards was 7%; 14%; 18%; 18%; 18%; and 24% respectively. The medical classification of injuries was used in an attempt to provide a more in-depth analysis of those injuries sustained. The medical classification of injuries sustained during training and matches according to positional roles are shown in Table 6.1.5.

Table 6.1.5. Medical classification of injuries sustained during training and matches grouped according to position in the team (Goalkeepers = 3, Central defenders = 6, Full-backs = 5, Central midfield players = 10, Wide midfield players = 7, forwards = 11 players)

	Goalkeeper		Full-backs		Central Defenders		Central Midfield		Wide Midfield		Forward	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Face					1	50	1	50				
Tendo-Achilles			4	57			1	14	1	14	1	14
Skull											2	100
Iliopsoas							1	50			1	50
Sartorius	1	16			5	84						
Adductor Longus	1	10	1	10	3	30	4	40			1	10
Gracilis					1	50					1	50
Rectus Femoris			1	20	1	20	1	20	1	20	1	20
Hamstrings†	2	10	1	5	3	14	1	5	7	33	7	33
Calf			2	40					2	40	1	20
Gastrocnemius							1	25	1	25	2	50
Soleus					1	50	1	50				
Ankle†	1	4	3	11	3	11	6	22	7	26	7	26
Knee†	1	3	7	23	2	6	12	39	3	10	6	19
Shoulder	1	50									1	50
Hip							1	50	1	50		
Foot							1	100				
Toe			3	60	2	40						
Back	1	12	1	12			1	12	1	12	4	50
Thigh	1	20	1	20	2	40	1	20				
Other	5	14	2	5	9	25			10	28	10	28
Total•	14	100	26	100	33	100	33	100	34	100	44	100

† $P < 0.05$ Different proportions between positions

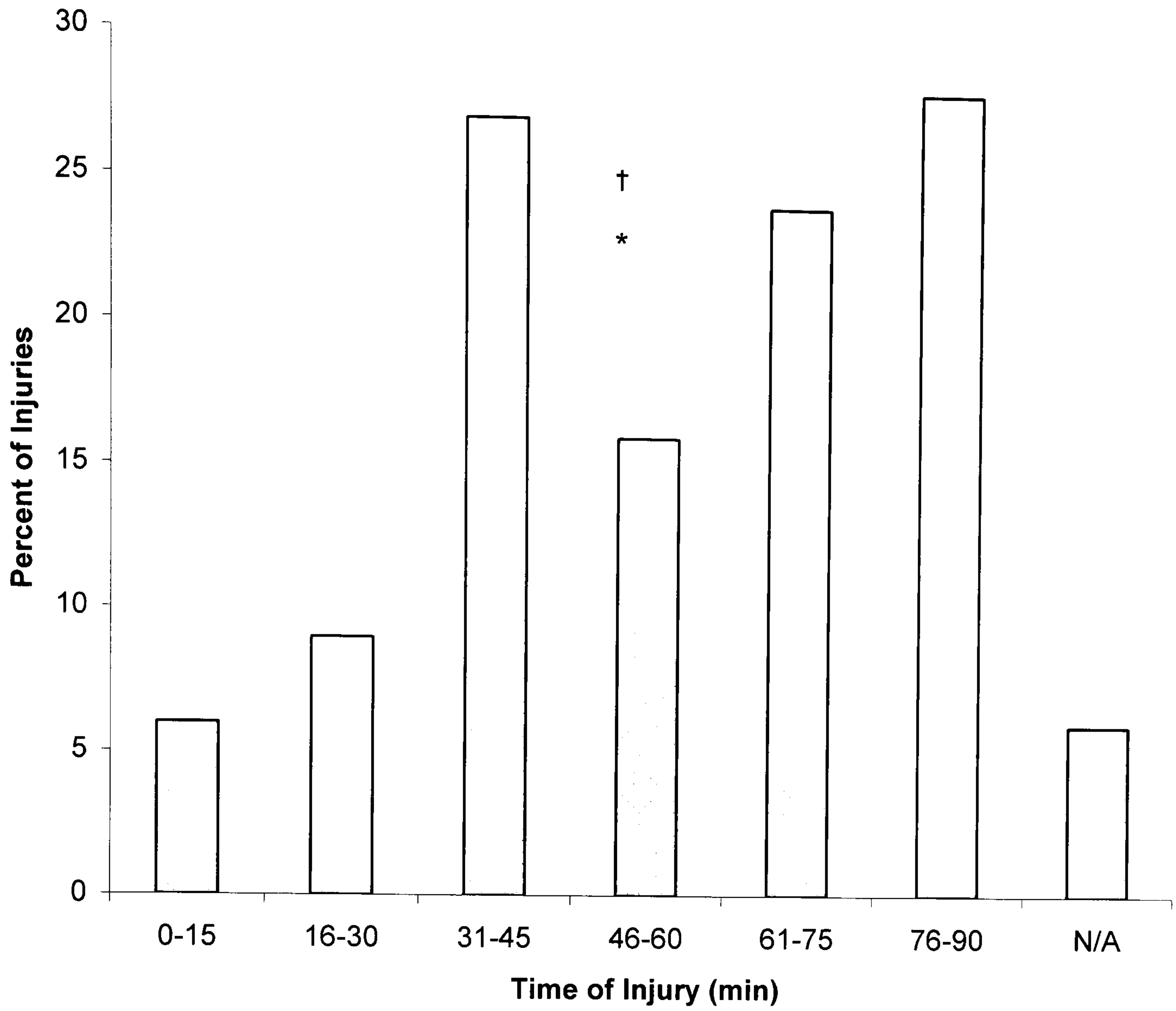
• Percentage totals may be subject to rounding errors associated with individual components

A significant difference was found between positions for injuries sustained to the knee (P<0.04). Central midfield players sustained proportionately more injuries to this site than any other position (P<0.04). Damage to the medial collateral ligament accounted for 68% of injuries sustained to the knee. The lateral collateral ligament was injured in 10% of knee injuries, while damage to the anterior cruciate ligament, posterior cruciate ligament and patellar tendon each accounted for 7% of the knee injuries.

Forwards and wide midfield players sustained significantly more hamstring strains than goalkeepers, full-backs, central defenders, and central midfield players based on observed and expected frequencies (33.3% v 33% v 9.5% v 5% v 14% v 5% respectively, P<0.05). The re-injury rate for hamstring strains was 19%, while the average re-injury rate for all injuries was 9% (P<0.01).

A significant difference was also found between positions for injuries sustained to the ankle. Forwards, wide midfield players and central midfield players sustained a higher percentage of injuries to this location than central defenders, full-backs and goalkeepers (26% v 26% v 22% v 11% v 11% v 4% respectively, P<0.05).

The distribution of injuries in matches according to time elapsed in the game is represented in Figure 6.1.1. Of the 116 injuries sustained during competitive matches, a greater than average frequency of injuries was observed during the final 15-min of the first half and the final 30-min of the second half (P<0.05). Despite the increase in injury incidence towards the later stages of the first half, there remained a greater number of injuries recorded in the second half compared to the first (58.6% v 35.3%, P<0.01).

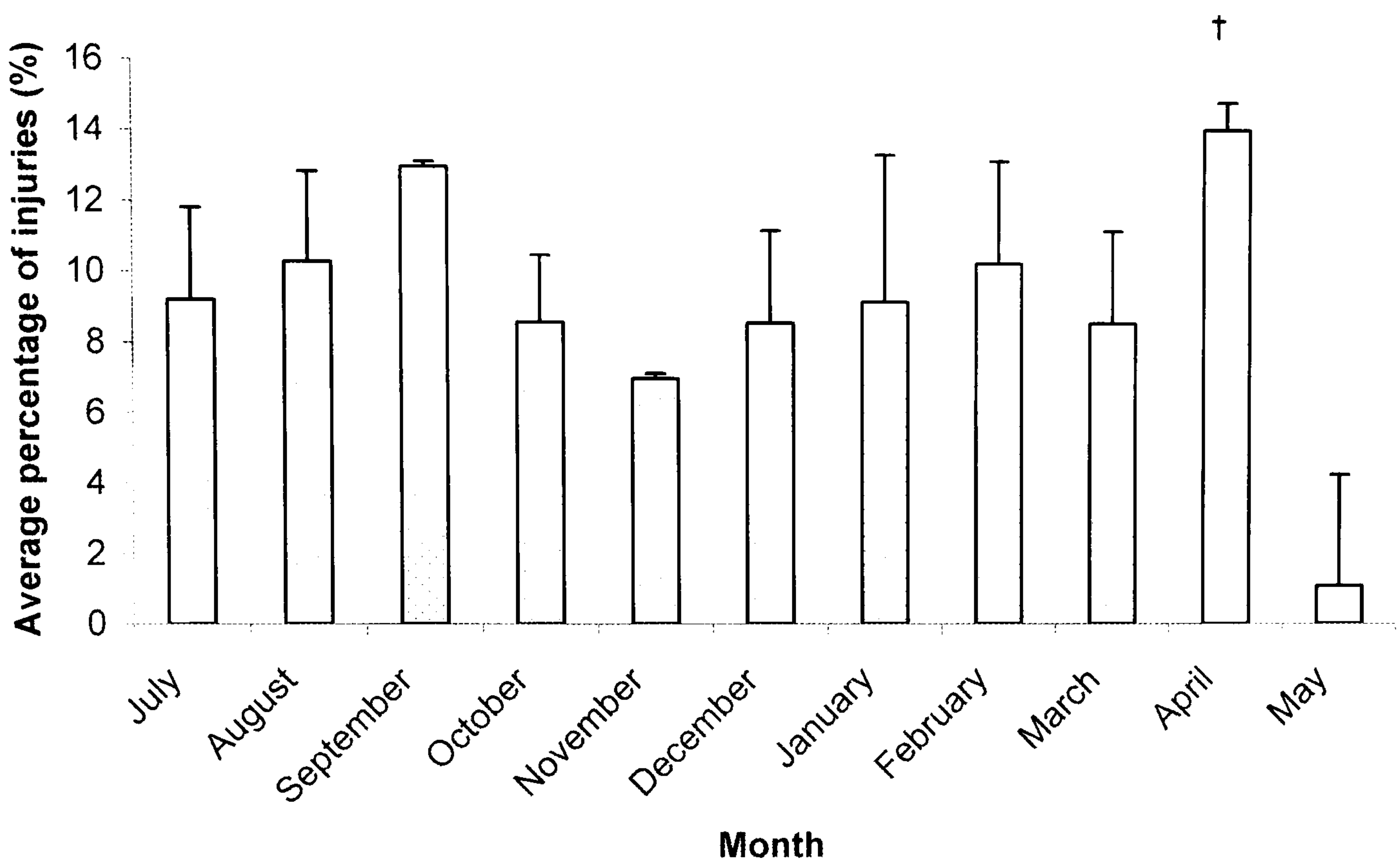


† P < 0.05 Different proportions between match periods
* P < 0.01 Different proportions 0-45 min v 45-90 min

Figure 6.1.1. Distribution of injuries in matches according to time elapsed in the game.

When the distributions of match injuries were compared according to position in the team, significant differences were observed. Central midfield players sustained significantly more injuries in the final 15-min of each half ($P<0.01$), while wide midfield players and forwards sustained a greater percent of injuries in the last 30-min of the match ($P<0.05$).

The average number of injuries sustained per month by players over the study period is shown in Figure 6.1.2. Significant differences were observed between the months in terms of observed and expected frequencies ($P<0.05$). Two peaks in incidence of injury were identified, one in September and the other in April towards the end of the season. This trend was similar when injury incidence was divided into training and matches. With regards to the number of injuries sustained during competitive matches, the greatest incidence of injury was reported during September and April (P<0.05).



† P < 0.05 Different proportions between monthly periods

Figure 6.1.2. Distribution of injuries in competitive match-play according to month.

The observation period involved the players completing 146 competitive games, 97 1st team fixtures and 49 in the Premier Reserve League. On average 42 players were exposed to injury weekly (training and matches), totalling 3990 player weeks. Given that there were eleven players on the pitch for each team throughout all competitive matches, each game lasting 100 min, and that all players took part in regular training, the total number of hours during which players were exposed to injury was 37712; these include 35036 hours and 2676 hours during training and matches, respectively. The risk of injury or Injury Frequency Rate (IFR) was 5.0/1000 hours; 43.0/1000 hours and 2.0/1000 hours during matches and training, respectively. The monthly distribution of IFR during training and matches is shown in Table 6.1.6.

Table 6.1.6. Injury Frequency Rate (IFR) during training and competitive match-play over two consecutive seasons.

	Number of Injuries			IFR per 1000 hours		
	Total	Match	Training	Total	Match	Training
July	17	8	9	3.3	36.4	1.8
August	19	13	6	4.2	54.5	1.4
September	24	16	8	7.4	54.5	2.7
October	15	10	5	4.5	39.0	1.6
November	13	9	4	4.0	35.1	1.3
December	16	11	5	4.9	50.0	1.7
January	17	9	8	5.1	35.1	2.6
February	19	13	6	5.7	59.1	1.9
March	16	7	9	4.8	25.5	3.0
April	26	18	8	8.0	57.8	2.7
May	2	2	0	1.1	15.6	0.0
Total	184	116	68			

6.1.4 Discussion

The aim of the present study was to establish the incidence of injury in a Premier League team over two consecutive seasons. Throughout the observation period, an increased risk of injury was associated with competitive match-play. A greater relative proportion of injuries was sustained at the end of the playing season than at any other phase. Differences were also observed between positions.

An overall Injury Frequency Rate (IFR) of 5.0/1000 hours was observed over the duration of the observation period. The IFR was significantly higher during competitive games than training (43.0/1000 v 2.0/1000, $P<0.01$). Similar observations have been obtained in other studies where IFR has been reported during match-play (Arnason et al., 1996; Hawkins and Fuller, 1999; Hawkins et al., 2001). Greater exercise intensity during competition may explain the high IFR during match-play that creates more frequent contact situations and more powerful player impacts. Evidence for this view was in the higher relative proportion of muscular contusions sustained during match-play ($P<0.01$). Contusions are among the most common injuries in soccer (Hoy et al., 1992), which are usually the result of a blow by an opponent's foot, knee or elbow (Tucker, 1997).

The higher incidence of ligament sprains during competition compared to training also reflects the highly competitive nature of soccer match-play. Arnason et al. (1994) reported contact sprains to be significantly more frequent than non-contact sprains, the major mechanism of ligament sprains being tackling. Therefore, the relatively large percentage of ligament sprains incurred in competition compared to training demonstrates that match-play is characterised by a higher level of player contact in which tackling, collisions and physical contests are all commonplace.

In the present study, the IFR during competitive games was higher in frequency than reported in the literature (Engstrom et al., 1990; Arnason et al., 1996; Luthje et al., 1996). In an analysis of injuries sustained at four English League soccer clubs between the period of 1994 to 1997, Hawkins and Fuller

(1999), reported an IFR of 27.7/1000 hours during competitive match-play. The IFR value in the present study for elite competitive match-play was 43/1000 hours. This difference could be attributed to the increased intensity during contemporary soccer match-play (Williams et al., 1999). Evidence for a high exercise intensity has been provided in sections 5.1 and 5.2 together with improved physical capacities of contemporary players (section 4.2). Various authors have reported a significant association between exercise intensity and greater risk of injury (Jacobs and Berson, 1986; Marti et al., 1988). Moreover, a prospective study of 123 Danish soccer players participating at various levels of competition demonstrated a relationship between injury incidence and level of competition (Nielson and Yde, 1989). It follows that a higher intensity of games may result in increased ball and body momentum, a more intense and competitive style and greater risk-taking behaviour. These demands may lead to increased stresses in elite soccer players, placing them at a greater risk of sustaining injuries.

The incidence of injury has previously been reported to vary over different periods of the playing season with peak rates reported following pre-season training and during congested schedules of competitive matches (Lewin, 1989; Hawkins et al., 2001). These previous reports have not accounted for variations in the monthly distribution of games and the observations may therefore simply be a function of the number of games played at these times. Given that sixty-three percent of injuries occur during matches, and, an increased risk of injury is associated with competitive match-play, match-intensive periods will inevitably yield a greater incidence of injury. In the present study, match-related injuries as reported by injury frequency rate (IFR) peaked during February and in April ($P<0.05$).

In the English Premier League, the season extends for forty-two weeks and is often preceded by a six-week period of physical conditioning. With substantial rewards available to successful teams, and with a variety of other financial incentives including sponsorship, appearance money and win bonuses, the modern game is characterised by a large number of highly competitive games. In addition, elite players have international commitments and will subsequently move from one episodic sequence of games to another. The fundamental concern is that when there is insufficient time between games for rest and recovery, their cumulative effect can lead to a diminution in the adaptive training response and an increased risk of overtraining and injury (Budgett, 1998). Moreover, the increased incidence of injury towards the end of the season may well be a consequence of cumulative fatigue due to the number of games.

In a recent analysis of soccer injuries, it was reported that a greater proportion of training injuries occurred during the pre-season period than at other times of the season (Woods et al., 2002). These observations are in contrast to the findings of the present study, where a greater relative proportion of injuries was reported in the final two months of the season ($P<0.05$). In the study by Woods et al. (2002), the influence of exposure data was not accounted for. It appears that when volume of training is taken into consideration during the pre-season period, the incidence of injuries during this preparation period is less than that observed during the later periods of the playing season. Because training at the elite level of competition by its very nature requires high volumes of training at a high intensity, the fatigue accumulated throughout the competition period may lead to adaptations in the training response that are less than beneficial to the individual players. In the final phases of the season, the use and abuse of the musculoskeletal system may push the athlete further towards overt injury. This pattern is compounded by the reduced ability to recover from the demanding schedule of matches and training.

Repeated high-intensity activity involving large muscle groups greatly exaggerates the strain on the neural, muscular and metabolic systems (Gleeson et al., 1998). The role of muscle fatigue has previously been identified as a factor in injury causation (Lieber and Friden, 1988). It could partly explain the greater risk of injury observed during the second half of matches, especially in the final 30-min ($P<0.01$). Fatigue associated with prolonged intermittent high-intensity exercise results in an inability to maintain the desired power output (Nicholas et al., 1995). Moreover, a decreased ability of a muscle to generate force is thought to reduce its energy absorption capacity, which in turn predisposes the muscle to injury (Garrett, 1996).

Gleeson et al. (1998) compared electromechanical delay following shuttle running, treadmill running at 70% $\dot{V}O_{2max}$ and prolonged intermittent high-intensity running (PHISR). Electromechanical delay is the time taken for detectable electrical activity to be converted into an electrical response. Subjects were recreational soccer players and the PHISR was designed to replicate the physiological demands of soccer match-play. There was a greater increase in electromechanical delay following shuttle running and prolonged intermittent high-intensity running than after continuous treadmill running. These findings suggest that multiple changes in pace and direction place greater stress on the neuromuscular system, resulting in fatigue and prolonged electromechanical delay. According to these authors, the potential threat to knee joint stability is increased by concomitant increases in electromechanical delay and anterior tibio-femoral displacement. Given that the critical phases of match-play place high demands on the musculature of the knee, prolonged intermittent high-intensity exercise resulting in neuromuscular fatigue may compromise knee joint stability. In the present study, midfield players sustained a greater relative proportion of knee injuries during training and match-play ($P<0.05$). From a tactical viewpoint, midfield players serve as a link between defence and attack and cover greater distances during competitive match-play than other players (Reilly and Thomas, 1976; Withers et al., 1982; Ekblom, 1986; Rienzi et al., 2000). Such a work-rate profile requires a greater distance to be covered during match-play, as there is an emphasis on sustained running. This increased work-rate profile may also increase the risk of ligamentous injury to the knee by concomitant impairment to electromechanical delay.

During the acceleration phase of sprinting, stride length and rate are increased. At the beginning of this force production, electrical activity in the biceps femoris peaks, making it a critical component in the early stages of the sprint (Mero et al., 1992). At this point, the centre of gravity falls in front of the contact foot, which evokes a strong reflexive contraction of the biceps femoris. Hip extension and knee flexion increase, which subsequently increase the stretch through the hamstring group. This stretch tension is increased further due to the flexed position of the trunk and the anterior tilt of the pelvis (Mero et al., 1992). According to Whiting and Zernicke (1998), muscle strains occur predominantly in muscles with a bi-articular function due to their propensity to be stretched at both joints simultaneously. The additional stretch created by the tri-articular function of the biceps femoris, may pull the muscle past its optimal length-tension and beyond its elastic limit, resulting in injury. This event is most likely to occur in the acceleration phase of sprinting when the trunk is flexed (Mero et al., 1992). Following the acceleration phase of sprinting, posture becomes more upright, decreasing the contribution of the hamstrings to forward motion (Mero et al., 1992).

In the present study, forwards and wide-midfield players sustained a greater relative proportion of hamstring strains than did players in other positions. These players are often involved in the critical phases of match-play where forceful and explosive actions are important characteristics of match-winning actions. Forward players have a higher dependence on acceleration and force production over short distances (section 5.2). Moreover, the ability to produce as much force as possible in the shortest possible time is one of the characteristics that distinguish forwards from other players (Chapter IV). Since maximal mobilisation of force over short distances is an important determinant of match-winning actions for forwards, the cumulative time spent in the high-risk acceleration phase of sprinting may increase the risk of sustaining hamstring injuries. This increased risk of injury is further compounded by the observation that forward players can have relatively low endurance capacities when compared with other positions (Chapter IV).

In a study of hamstring injuries in sprinters, it was proposed that sprinters with high levels of Type II muscle fibres may have a higher risk of developing injury (Jonhagen et al., 1994). Since acceleration is directly proportional to the force developed, a greater mobilisation of force over short distances equates with greater stress on muscle tissue and thus an increased risk of injury. During the running action the hamstrings are required to absorb large impact forces during the contact phase. It is imperative therefore that the hamstrings are highly activated prior to and at the moment of impact (Mero et al., 1992). If the electromechanical delay is impaired, the foot will impact the ground before the hamstring muscles have been appropriately activated (Gleeson et al., 1998). This mis-match in turn will reduce the resistance to muscle failure and increase the risk of injury. The work-rate profile of the forwards (described in section 5.2) together with the physiological profile of these players (described in section 4.2) combines many of the risk factors associated with injury, perhaps increasing predisposition to hamstring-related injuries.

In summary, differences were observed between playing positions in the incidence of injuries during competitive match-play and training. Forwards and wide midfield players sustained significantly more hamstring strains than goalkeepers, full-backs, central defenders and central midfield players. Injury statistics facilitate an understanding of the demands imposed upon players by their position. Each position demands specific tasks during different phases of the game and players have to meet these demands with a demonstration of appropriate work-rate profiles (Chapter V). Moreover, the incidence of injury can be related to the stresses associated with the physiological and physical demands of the game. What is also clear is that exercise intensity during contemporary match-play and the number of highly competitive games place strain on elite soccer players. The fundamental concern is that when there is insufficient time between games for rest and recovery, the cumulative effect of high-intensity competitive match-play increases the risk of sustaining injuries. Therefore the following hypothesis can be rejected:

A. H_O: At an elite level of play, the incidence of injuries does not vary according to different playing positions.

B. H_O: At an elite level of play, the incidence of injuries does not vary throughout the season.

C. At an elite level of play, the incidence of injuries does not vary between competitive match-play and training.

6.2 A STUDY OF RISK FACTORS FOR INJURIES IN ELITE YOUNG SOCCER PLAYERS

6.2.1 Introduction

Sport by its very nature involves injury risk. Many sports, especially the contact team sports such as soccer are characterised by fast movement, vigorous body contests and maximal bursts of anaerobic power. Soccer players have to adapt to the requirements of the game to compete at an elite level of play. For individuals to succeed in the game, they must possess adequate physical attributes that protect them against the inherent risk factors.

A host of factors may contribute to the incidence of injury during sporting activity and so identifying causal mechanisms poses a great challenge to epidemiologists (Quarrie et al., 2001). Potential risk factors have been classified into those intrinsic and those extrinsic to the individual (Taimela et al., 1990). The intrinsic risk factors are related to the individual biological or psychological characteristics of a person, and include age, sex, anthropometric characteristics, fitness and psychological profiles. Extrinsic risk factors are those external to the individual and include level of competition, exercise intensity, amount of training, environmental conditions and equipment.

Several authors have identified intrinsic factors that influence the risk of injury during intermittent team sports (Ostenberg and Roos, 2000; Watson, 2001; Quarrie et al., 2001). In a study of 180 Nigerian soccer players, Salokun (1994) reported that soccer players whose somatotypes ranged between meso-ectomorphic to the mesomorphic builds were less prone to injuries than their more fragile linear counterparts. Moreover, a 'square' body with prominent musculature is thought to be the best for absorbing the shock of vigorous bodily contacts (Salokun, 1994). Injury risk has also been associated with a number of intrinsic factors such as acceleration (Watson, 2001), muscle imbalance (Knapik et al., 1992) and postural defects (Watson, 1995).

Soccer play demands a variety of fitness attributes and identification of those factors that contribute to successful performance in terms of optimal health status, yields important information on performance requirements of the sport. Moreover, such data can offer valuable information for the treatment and prevention of soccer-related injuries.

For this thesis, the emphasis was switched from studying elite mature players to younger talented groups. While this study employed a similar model to the previous one, a greater depth of information was recorded. This change was in line with the research undertaken by the Football Association's Audit of Injuries research programme. Moreover, such information would complement the findings on adult players and establish how physiological characteristics interact with the stresses and risk factors associated with elite soccer. Given the limited information available on risk factors associated with participation in soccer and the lack of information available on injuries in elite youth soccer, the aim of the present study was to examine intrinsic factors associated with soccer injury. A further aim was to identify the Injury Frequency Rate (IFR) of elite young players.

6.2.1.1 Statement of hypothesis

A. At an elite level of youth play, intrinsic factors are not significant predictors of the incidence and prevalence of injury.

6.2.2 Methods

6.2.2.1 Subjects

Subjects were forty full-time professional male soccer players of a Football Academy squad in the Premier League. Their mean age was 17 ± 0.5 years.

6.2.2.2 Procedures

All procedures were approved by the Human Ethics Committee of Liverpool John Moores University. Subjects were fully informed about the aims, procedures and medical confidentiality issues before written consent was obtained. The processes of medical assessment and annotation were familiar to the medical staff and players at the club as part of their daily fitness assessment.

Player injuries were prospectively reported from July 1998 through to the end of May 2001 inclusive. Three separate yearly cohorts were selected for this study. Injuries were recorded by the club physiotherapist on an 'injury audit questionnaire' designed by Hawkins et al. (2001). All procedures were in line with the study of adult professionals and described in the previous section.

All of the tests undertaken were familiar to the subjects as part of their ongoing fitness assessment. Anthropometric and fitness profiles were obtained on all players during a period of intensive pre-season training (September to November). The test battery included a number a field tests designed to measure anaerobic and aerobic performance. The fitness variables included estimated maximal oxygen uptake (Ramsbottom et al., 1988), sprint speed and leg power. Methods for the determination of these variables are described in section 4.2.2.2. Anthropometric variables included estimated muscle mass (Martin et al., 1990), body mass, adiposity (Reilly et al., 1996, Durnin and Womersley, 1974), stature and somatotype (Heath and Carter, 1976). Methods for the determination of anthropometric variables were as described in section 4.1.2.2.

A recordable injury was defined as one sustained during training or competition and which prevented the injured player from participating in normal training or competition for more than 48 hours (not including the day of the injury). The variables identified for each injury are listed in Table 6.2.1.

Table 6.2.1. Injury variables recorded during training and matches.

• The date of the injury	• The injured player
• The playing position at the time of injury	• The number of times the player had been injured during the study
• The time of the injury	• The activity at the time of the injury
• The body side where the injury is located	• The mechanism of injury
• Whether the injury was a re-injury	• The severity of the injury
• The nature of the injury	• The anatomical location of the injury
• The medical classification of the injury	• The number of training days absent from training and competition

The total numbers of playing hours the elite young players were at risk were calculated using the procedures described in the previous section.

6.2.2.3 Statistical analyses

Data were analysed using SPSS (Chicago, Illinois, USA). Descriptive and comparative data are presented. The χ^2 significance test was used when analysing occurrence of injuries according to time into game or practice, activity at injury, injury mechanism and the nature of the injury. The influence of potential predictor test variables on the risk of days missed through injury was analysed by means of multiple regression. Backward stepwise elimination was employed to obtain the statistically significant predictors. The level of significance was accepted at $P<0.05$.

6.2.4 Results

The anthropometric and performance characteristics of the subjects are presented in Table 6.2.2. The ranges for stature, body mass, and adiposity are in line with the figures reported in Chapter IV for elite young soccer players. The mean ± S.D. somatotype for the subjects was 2.7 ± 0.6 – 4.6 ± 0.9 – 2.7 ± 0.8. The somatotype for these players represents a trend towards mesomorphy or muscularity.

Table 6.2.2. Anthropometric and performance characteristics of elite young male soccer players (mean ± S.D). (n = 40).

Stature (m)	1.78 ± 0.06
(Range)	(1.70 – 1.97)
Body mass (kg)	72.9 ± 7.0
(Range)	(64.0 – 100.0)
Adiposity	35.6 ± 6.3
(Range)	(25.4 – 50.2)
Estimated $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	58.2 ± 2.7
(Range)	(55.9 – 67.5)
Vertical jump (cm)	59.4 ± 4.5
(Range)	(50.0 – 71.0)
0 – 5 m	1.03 ± 0.03
(Range)	(0.95 – 1.09)
0 – 10 m	1.77 ± 0.05
(Range)	(1.68 – 1.86)

During the study period there were 267 injuries that prevented a player from either training or competition for at least one day. This figure did not include players who were unable to play or train due to illness or other non-playing causes of absence. Forty-seven percent of the injuries occurred during competitive matches, the remainder taking place during regular training and practice.

The nature of injuries sustained during training and matches is shown in Table 6.2.3. Sixty-one percent of all injuries were classified as strains, sprains or contusions. Injuries grouped as others included those that were not accounted for by the audit questionnaire. There were a significantly greater percentage of muscular contusions and sprains in games compared to training (15.1% v 4.3%, $P<0.01$; and 27.0% v 17.9%, $P<0.01$ respectively). However, a significantly greater percentage of strains were sustained during training than in games (35.7% v 22.2%, $P<0.01$).

The activities at occurrence of injury are shown in Table 6.2.4. When examining the activity at injury, competitive games, small-sided games and practice games accounted for seventy-five percent of all injuries sustained. This observation demonstrates that activities linked to a competitive game serve as the greatest risk to soccer players for sustaining injuries.

Table 6.2.3. Nature of injuries sustained during matches and training.

Nature	All injuries No.	%	Match injuries No.	%	Training injuries No.	%
Fracture	3	1.1			3	2.1
Periostitis	2	0.7	1	0.8	1	0.7
Meniscal Tear	3	1.1	2	1.6	1	0.7
Inflammatory Synovitis	9	3.4	4	3.2	5	3.6
Capsular Tear	1	0.4			1	0.7
Strain	78	29.2	28	22.2	50	35.7**
Muscle Rupture	1	0.4	1	0.8		
Muscular Contusion	25	9.4	19	15.1*	6	4.3
Sprain	59	22.1	34	27.0*	25	17.9
Ligament Rupture	3	1.1	2	1.6	1	0.7
Tendonitis	19	7.1	6	4.8	13	9.3
Tissue Bruising	18	6.7	12	9.5	6	4.3
Blister	5	1.9	2	1.6	3	2.1
Bursitis	3	1.1	1	0.8	2	1.4
Skin Abrasion	1	0.4	1	0.8		
Osgood Schlatter's Disease	1	0.4			1	0.7
Ilio Tibial Band Syndrome	1	0.4	1	0.8		
Posterior Compartment Syndrome	2	0.7	1	0.8	1	0.7
Spondylolysthesis	1	0.4			1	0.7
Low Back Pain	12	4.5	6	4.8	6	4.3
Groin/Abdominal Hernia	4	1.5	2	1.6	2	1.4
Other Diagnosis	8	3.0	2	1.6	6	4.3
Missing	8	3.0	2	1.6	6	4.3
Total	267	100	127	100.0	140	100.0

* P < 0.01 Different proportions of injuries during matches
** P < 0.01 Different proportions of injuries during training

Table 6.2.4. Activity at injury

Activity	No.	%
Competitive Game*	127	47.6
Small-sided Game*	51	19.1
Practice Drill	20	7.5
Practice Game (11 x 11)	22	8.2
Specific Exercise	15	5.6
Other	6	2.2
Training	25	9.4
Outside Training	1	0.4
Missing	1	0.4
Total	267	100.0

* $P < 0.01$ Different proportions between activities

In an attempt to highlight activities associated with risk of injury during soccer play, the mechanism of injury was recorded. The mechanism of those injuries sustained during training and matches is shown in Table 6.2.5. Of all those injuries sustained during training and matches, 34% were sustained during running. A further 40% of those injuries were sustained during contact situations involving tackling, collisions and body/ball contacts. During training, running accounted for a significantly greater proportion of injuries sustained than other mechanisms (42.1%, $P<0.01$).

Table 6.2.5. Mechanism of Injury for those injuries sustained during matches and training

Nature	All injuries		Match injuries		Training injuries	
	No.	%	No.	%	No.	%
Tackling	15	5.6	9	7.1	6	4.3
Tackled	31	11.6	20	15.9*	11	7.9
Collision	14	5.2	6	4.8	8	5.7
Kicked	40	15.0	31	24.6*	9	6.4
Use of elbow	1	0.4	0	0	1	0.7
Hit by ball	3	1.1	0	0	3	2.1
Other (contact)	2	0.7	0	0	2	1.4
Passing	9	3.4	4	3.2	5	3.6
Shooting	9	3.4	1	0.8	8	5.7
Running	91	34.1	32	25.4*	59	42.1**
Jumping	2	0.7	0	0	2	1.4
Landing	6	2.2	5	4.0	1	0.7
Falling	1	0.4	0	0	1	0.7
Stretching	9	3.4	5	4.0	4	2.9
Twisting/Turning	11	4.1	5	4.0	6	4.3
Diving	2	0.7	0	0	2	1.4
Other (non-contact)	10	3.7	4	3.2	6	4.3
Missing	11	4.1	5	4.0	6	4.3
Total	267	100	127	100.0	140	100.0

* $P < 0.01$ Different injury mechanism proportions during match injuries
** $P < 0.01$ Different injury mechanism proportions during training injuries

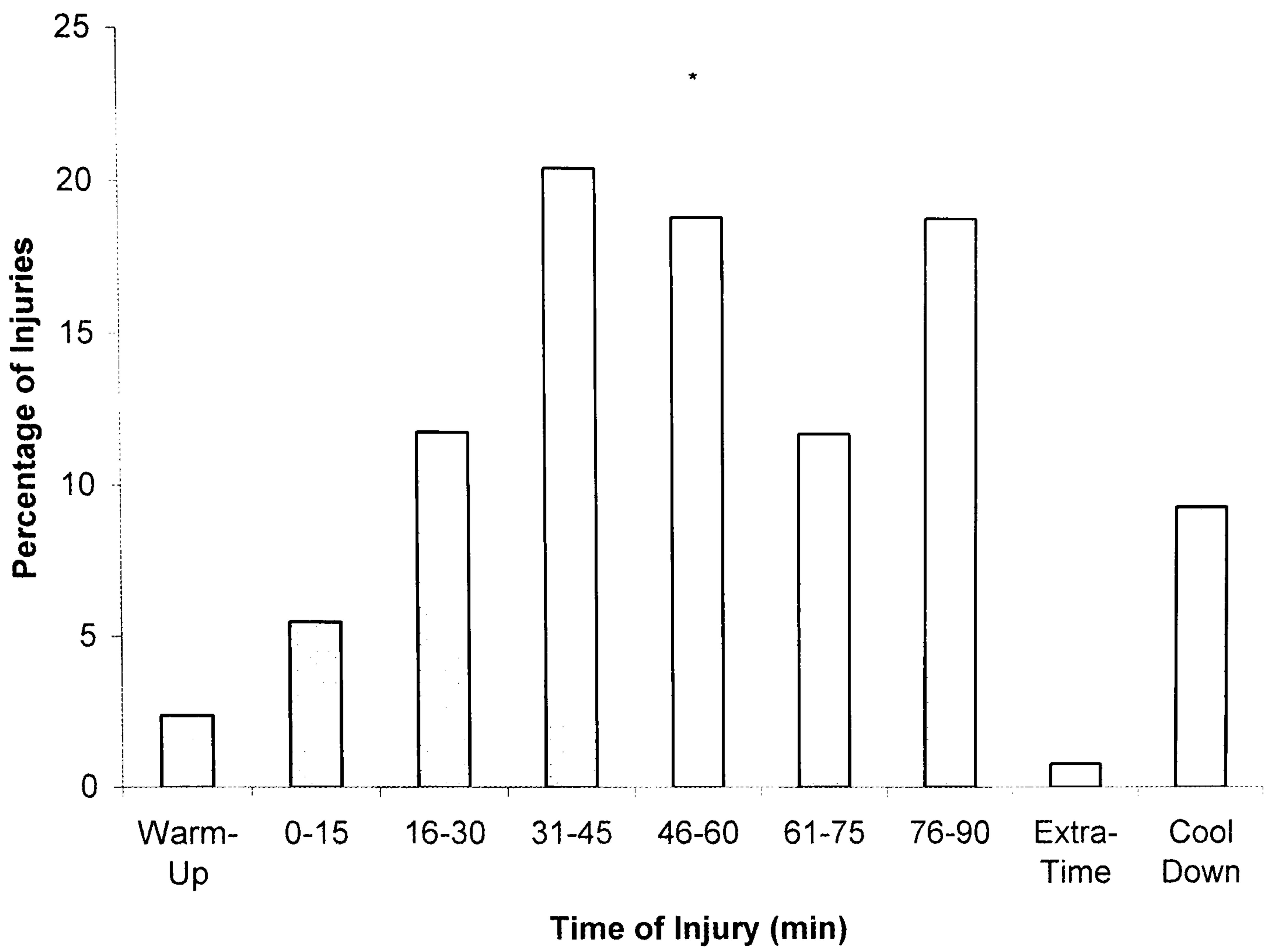
The locations of injuries sustained by players are shown in Table 6.2.6. Ninety percent of all injuries were sustained in the lower extremities. Injuries to the thigh, knee and ankle accounted for a major proportion of those reported (57%).

Table 6.2.6. Location of injuries sustained during matches and training

Nature	All injuries		Match injuries		Training injuries	
	No.	%	No.	%	No.	%
Head/face/neck	6	2.3	2	1.6	4	2.9
Upper extremity	5	1.9	3	2.4	2	1.4
Torso	14	5.0	5	4.0	9	6.4
Hip	9	3.4	5	4.0	4	2.9
Groin	27	10.1	10	8.0	17	12.1
Thigh	59	22.1	29	23.0*	30	21.4**
Knee	44	16.4	22	17.4*	22	15.7
Lower leg	8	3.0	2.0	1.6	6	4.3
Calf	16	6.0	7	5.6	9	6.4
Ankle	50	18.7	30	23.8*	20	14.3
Foot	18	6.7	8	6.4	10	7.1
Toe	11	4.1	4	3.2	7	5.0
Total	267	100	127	100.0	140	100.0

* P < 0.01 Different injury proportions during matches
** P < 0.01 Different injury proportions during training

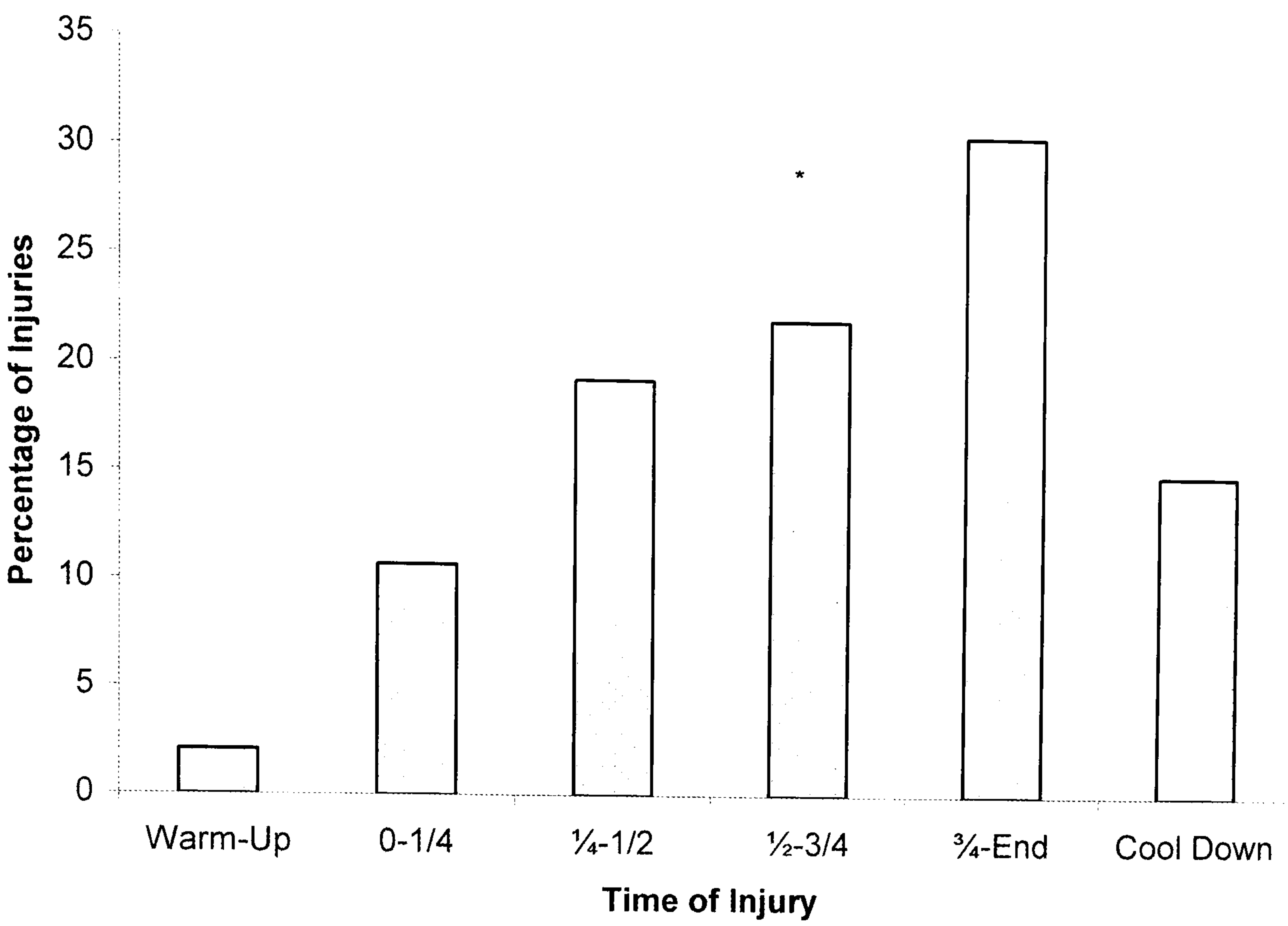
The distribution of competitive match injuries according to time is presented in Figure 6.2.1. Of the 127 injuries sustained during matches, a greater than average frequency of injuries was observed during the final 15 min of each half ($P<0.01$). Despite the increase in injury incidence towards the later stages of the first half, there remained a greater number of injuries recorded in the second half compared to the first (49.6% v 40.2%).



* P < 0.01 Different proportions between match periods

Figure 6.2.1. Distribution of competitive match Injuries according to time.

The distribution of training injuries according to time is represented in Figure 6.2.2. Of the 140 injuries sustained during training, a greater than average frequency of injuries was observed towards the end of the sessions ($P < 0.01$). Moreover, 30.7% of injuries were sustained during the period ¾ - End of training.



* P < 0.01 Different proportions between training periods
Figure 6.2.2. Distribution of injuries in training according to time of session.

The observation period involved the players completing a total of 185 competitive games, 100 in the Premier Academy U19 League and 85 in the Premier Academy U17 League. On average 28 players were exposed to injury weekly, totalling 3864 player weeks. Given that there were eleven players on the pitch for each team throughout all competitive matches, each game lasting 100 min, and that all players took part in regular training, the total time that players were exposed to injury was 39392 hours; 36000 hours and 3392 hours during training and matches, respectively. The risk of injury or Injury Frequency Rate (IFR) was 4.9/1000 hours; 37.4/1000 hours and 3.9/1000 hours during matches and training, respectively. Monthly distribution of IFR during training and matches is shown in Table 6.2.7.

Table 6.2.7. Injury Frequency Rate (IFR) during training and competitive over three consecutive seasons.

	Number of Injuries			(IFR) per 1000 hours		
	Total	Match	Training	Total	Match	Training
July	30	14	16	5.8	95.5	3.7
August	30	14	16	5.7	63.6	3.9
September	27	12	15	4.3	21.8	4.6
October	18	9	9	3.5	27.3	2.7
November	23	11	12	4.3	28.6	3.7
December	14	7	7	3.1	31.8	2.1
January	37	16	21	6.9	41.6	6.4
February	21	11	10	3.6	22.2	3.1
March	31	15	16	5.9	40.9	4.9
April	27	13	14	6.3	70.9	4.3
May	8	5	3	3.9	45.5	2.1
June	1		1			
Total	267	127	140			

Multiple regression with backwards step-wise entry identified only endomorphy as a significant predictor of injury ($P<0.05$). The beta-coefficient for endomorphy was 0.154. This means that for every unit change in endomorphy there is on average a 0.154 change in the outcome variable.

6.2.4 Discussion

The aim of the present study was to examine the relationship between intrinsic risk factors and the incidence of injury to elite youth soccer players. Results of the analyses indicate that components of somatotype interact in predisposing soccer participants to injury. Similar findings have been obtained in other studies where an association has been found between somatotype and injuries sustained during participation in both soccer (Salokun, 1994) and rugby football (Reilly and Hardiker, 1981; Lee et al., 1997; Quarrie et al., 2001).

The findings of the present study suggest that the greater the amount of soft tissue, the greater is the risk of sustaining an injury. The association between endomorphy and incidence of injury implies that an unfavourable body composition in terms of excess body fat may expose the participant to greater risk by virtue of deficient strength and/or fitness capacity. Given the increase in injury incidence towards the later stages of training and competitive games, deficient strength and fitness associated with an endomorphic physique may predispose participants to increased risk of injury due to their inability to withstand the concomitant effects of fatigue.

Soccer involves vigorous contacts, strength, speed of movement, agility and the use of explosive power. It is essential that an individual who would remain and succeed in the game must possess adequate natural physical protective attributes against the inherent risk factors. Forty percent of all injuries reported in the present study were sustained during contact situations involving tackling, collisions and body/ball contacts. It is therefore plausible that musculo-skeletal robustness is beneficial against injury. Furthermore, as strength is promoted with increased muscle mass, security against injury is provided by a high degree of muscularity. According to Salokun (1994), the player must be one with a predominance of mesomorphy (mesomorph and ecto-mesomorph), which is characterised by a prominent musculature, big and heavy bones and thick muscular limbs. Moreover, this type of musculo-skeletal system is best for absorbing the shock of bodily contacts.

An Injury Frequency Rate (IFR) of 4.9/1000 hours was observed over the duration of the observation period. The IFR was significantly higher during competitive games than in training (37.4/1000 v 4.9/1000 respectively). Similar observations were made in the previous section for elite adult players where a higher IFR was reported during match-play. However, the IFR during competitive games was lower in elite young players compared to those reported in elite adult professional soccer (37.4/1000 v 43/1000 respectively). Greater exercise intensity during competition may explain such differences. On the other hand, IFR during training was higher in elite young players than elite adult players (4.9/1000 v 2.0/1000 respectively). Reasons for such a difference may include an imbalance between physical loading and adaptation of connective tissue (Engstrom et al., 1991), a sudden increase in the intensity and duration of training for young players, more intense training, and depleting glycogen energy stores due to successive days of training. Clearly, there is a need to investigate the training regimen of elite young players so that preventative and management strategies can be implemented.

Of all those injuries sustained during training and matches, 34% were sustained during running. In the present study, this was not subdivided further to take into account the stage of running, speed of running or whether the player was accelerating or decelerating. Nevertheless, a disproportionate number of running injuries were sustained during training compared with competitive games (42.1% v 25.4% respectively). Jones et al. (1994) reviewed the relationship between running parameters and injury. The total amount of running (miles per week) was the most consistently reported risk factor while speed affected injury rates to a lesser extent. This finding demonstrates the importance of carefully monitoring the volume of running within the training programme of elite young soccer players. Moreover, evidence from the present study suggests that elite young players exact and often exceed the training hours per week of their adult counterparts. The incidence of injury in non-competition highlights the need to investigate further the incidence of non-contact injury and overtraining in elite youth soccer.

The incidence of injury has been reported to vary over the course of a season, peak rates following pre-season training and a mid-season break (Anglietti et al., 1994; Hawkins et al., 2001). The findings of the present study are in line with these observations where sudden increases were found in injury rates in August and January. These were consistent when exposure time was taken into account. Furthermore, a greater relative proportion of injuries were reported in matches towards the later stages of the season. Once again, the cumulative effect of fatigue throughout the competition period may lead to the use and abuse of the musculo-skeletal system that pushes the young athletes towards overt injury. Clearly, a tapering of training hours should be applied for young players throughout the season. Coaches must recognise that the developmental process of skill acquisition and learning must be met with adequate rest and recovery, particularly at critical times in the annual calendar.

When examining the activity at the time of injury, competitive games accounted for 75% of all injuries sustained. This finding demonstrates that activities linked to a competitive game serve as the greatest risk to soccer players for sustaining injuries. Moreover, it is likely that despite attempts to reduce the risk factors associated with competitive games, injuries will continue to occur due to the fundamental nature of soccer. That is, injuries occur because of the violent impacts of tackles and the dynamic characteristics of match-play. Reducing the risk of injury may be accomplished through a variety of measures including changes in technique, refereeing, rules, and protective equipment. However, the game itself exerts a fundamental element of risk that physical attributes will not protect its participants against.

In summary, components of somatotype interact in predisposing soccer participants to injury. The multiple regression was an attempt to predict injury based on fitness characteristics. While endomorphy was associated with incidence of injury, the predictive power was low, suggesting that other measures are needed (e.g. peak torque, quad: hamstring ratio, eccentric strength function). The game itself makes different demands during the various phases of the game and players must possess the physical attributes that protect them against these risk factors. Given that the incidence of injury can reflect the stresses associated with soccer, the disproportionate number of running injuries sustained during training highlights the need to investigate further the incidence of non-contact injury and overtraining in elite youth soccer.

Therefore the following hypothesis was rejected:

A. At an elite level of play, intrinsic factors are not significant predictors of the incidence and prevalence of injury.

6.3 SUMMARY

The aim of this chapter was to identify the effects of soccer training and match-play on the injury status of elite professional soccer players. An emphasis was also placed on elite younger players so that a more in-depth analysis could be made and comparisons drawn. The Injury Frequency Rate (IFR) during competitive games was lower in elite young players compared to those reported in elite adult professional soccer. This finding suggests that greater stresses are placed on adult players than their younger counterparts. Contemporary elite adult soccer is played at a high tempo, which in turn increases the risk of sustaining injury. Moreover, the modern game is characterised by a fast pace and high exercise intensity (Chapter V). It follows that improved selection of players with the appropriate physical and fitness requirements (Chapter IV) have collectively increased the risk of sustaining injuries during training and competition.

In both elite adult and talented young soccer players, an increased incidence of injury was observed towards the later stages of competition and training. Fatigue associated with prolonged intermittent high-intensity exercise can result in the inability to maintain the desired power output. This decreased ability to generate force may increase the risk of injury. What is clear is that the game itself exerts demands on its participants that lead to a reduction in work-rate (Chapter V) and the accumulation of fatigue. The increased occurrence of injury towards the later stages of competition in both adult and younger populations provides evidence that injury rate is associated with the development of fatigue.

While the incidence of injury varied over the season for both groups, key considerations must be taken into account. Younger players did have a mid-season break that was reflected by a sudden increase in injury incidence in January. In elite adult players, the incidence of injury was greater towards the later stages of the season and may be a result of a large number of games. Given the fact that adult players are involved in a higher volume of games, and the fact that more injuries are sustained during matches, this difference is to be expected. Of more concern in the younger players was the high incidence of injuries during the pre-season training period. This may be the result of a mismatch between exercise training intensity and the strength of the immature musculo-skeletal system. Such a miss-match can lead to overt injury. Clearly, coaches must be made aware of the inherent risk factors of training younger players.

In conclusion, the principal findings of this chapter were:

The incidence of injuries during competitive match-play and training varied according to playing position. The incidence of injury can be representative of the stresses associated with the work-rate profiles of competitive match-play.

In elite adult players a greater relative proportion of injuries was observed in the final two months of the season. This pattern may be compounded by the reduced ability to recover from the demanding playing and training schedule.

A greater relative proportion of injuries were observed towards the later stages of a match. This observation suggests that incidence of injury is linked with accumulation of fatigue during competition. Such a phenomenon is independent of age and/or level of competition.

Adult and young players both showed an increased risk of injury in competitive match-play compared to training. Furthermore, competitive games, small-sided games and practice games accounted for seventy-five percent of all injuries sustained. This observation demonstrates that activities linked to a competitive game serve as the greatest risk to soccer players for sustaining injuries.

For this thesis, the demands of the game have been explored via work-rate profiles during games, a consideration of the physical characteristics of participants, and an analysis of injuries. Much of the emphasis has been on the monitoring of the demands of soccer in a field-setting. The focus for the remainder of the thesis will now move towards a controlled laboratory setting. The experimental investigation represents an attempt to progress from the classical models of intermittent exercise to a protocol more in line with the findings from this thesis. In order to examine the demands of soccer, a model must be employed that reflects the heart rate responses and work-rate profiles observed during real match-play. These observations were a formal outcome of earlier studies within this thesis. The fitness characteristics of players are likely to place an upper limit to the work-rate capabilities of players, a ceiling that may be raised by nutritional manipulations e.g. carbohydrate or creatine loading. The experimental intervention will test the application of an ergogenic aid to a soccer context in an attempt to establish whether an addition to training might improve performance capability for individual games or short-term training.

CHAPTER 7

CHAPTER VII

7. SOCCER-SPECIFIC INTERMITTENT EXERCISE PROTOCOL

This chapter contains a repeat of a laboratory-based investigation that attempts to fulfil three discrete aims. The first was to finalise a laboratory-based generic intermittent exercise protocol suitable for experimental investigations relevant to football. The second was to determine the physiological responses to this exercise protocol. The major aim was to examine the effect of a nutritional supplement on selected physiological and performance responses to the intermittent exercise protocol. This thesis so far has been concerned with the physical characteristics of players, stresses associated with match-play, work-rate profiles of players, and injury rates of individuals. The question faced in this chapter is whether the physical performance capabilities of players can be improved by means of nutritional support. Given recent interest in creatine supplementation and its use within the sections of the soccer community, this nutritional supplement was investigated using the soccer-specific protocol.

7.1 THE EFFECTS OF SHORT TERM CREATINE SUPPLEMENTATION ON PERFORMANCE DURING A SOCCER-SPECIFIC INTERMITTENT EXERCISE PROTOCOL

7.1.1 Introduction

The occurrence of fatigue during intermittent exercise may be attributed to a host of physiological factors (Reilly, 1997). Several research groups have attempted to replicate the demands of the so-called multiple-sprint sports (Bangsbo et al., 1992; Nevill et al., 1993; Drust et al., 2000a,b; Nicholas et al., 2000). Further, a series of laboratory-based investigations have attempted to identify the intramuscular factors responsible for fatigue during this pattern of activity (Bangsbo, 1994b). While many factors have been associated with fatigue (e.g. energy depletion, potassium imbalance, H^+ ions and blood lactate), it has proved difficult to isolate any single factor or precise combination of factors that explain fatigue definitively (Reilly, 1997).

The capacity to perform repeated bouts of maximal exercise for 6-s is markedly influenced by the preceding number of sprints and the duration of recovery (Wootton and Williams, 1983). Holmyard et al. (1988) examined the effects of recovery duration on performance during multiple treadmill sprints. These authors compared two treadmill tests consisting of ten 6 s sprints either with a 30-s recovery or a 60-s recovery between each sprint. Peak and mean power output decreased by 13.2% and 21.4% respectively, between sprints 1 and 10 with the 30-s recovery protocol. During the 60-s recovery protocol, the decrement in performance was reduced by 3% and 4.2% for peak and mean power outputs respectively. These authors concluded that the larger decrements in sprint performance with a 30-s recovery interval were probably due to an incomplete resynthesis of phosphocreatine (PCr) and increased acidosis.

During a 6-s bout of maximal exercise, PCr contributes to approximately 50% of the total anaerobic ATP production (Gaitanos et al., 1993). Although PCr has a rapid rate of resynthesis (Harris et al., 1976), a recovery interval of short duration will not be sufficient to replenish PCr levels. Resynthesis of ATP will then depend predominantly on the glycolytic rate. It follows that the incomplete recovery of power output during recovery intervals of short duration may be related to decrements in PCr.

The ingestion of Cr for 5 days at a rate of 4 x 5 g per day has been shown to increase resting muscle concentrations of total Cr (Harris et al., 1992) and facilitate PCr resynthesis during recovery (Greenhaff et al., 1994). Given that PCr resynthesis is a major determinant in the recovery of power (Bogdanis et al., 1995), and an increased PCr resynthesis rate would maintain ATP stores (Greenhaff, 1997), the implication is that following Cr supplementation, performance during repeated exercise bouts could be enhanced due to an increased available substrate and the maintenance of the required ATP turnover.

Greenhaff et al. (1993) investigated the influence of oral Cr supplementation on muscle torque production during five bouts of 30 maximal voluntary isokinetic contractions, separated by recovery periods of 1 min. The exercise protocol was repeated after 5 days of Cr supplementation or placebo. Muscle torque was enhanced after Cr supplementation in the later stages of bouts 1 and 5 and throughout bouts 2, 3 and 4. In addition, plasma ammonia concentration was lower post-exercise following Cr ingestion. These authors suggested that these results demonstrated the important link between the extent of fatigue and PCr availability.

Bogdanis et al. (1996) examined the effects of Cr supplementation on sprint running performance. The exercise protocol was completed twice, before and after 5 days of Cr supplementation, and consisted of six 10-s maximal sprints on a non-motorised treadmill, separated by 30 s of passive rest. Following Cr supplementation, power output and distance run were significantly increased in the sixth sprint by 10.8% and 6.9%, respectively. Plasma ammonia during exercise was lower following the period of Cr ingestion, possibly a consequence of a reduction in AMP deaminantion and ammonia production due to the increased availability of PCr and hence the maintenance of a higher ATP turnover.

Previous research on the effects of creatine (Cr) supplementation and performance related parameters have employed a variety of protocols and performance strategies (Birch et al., 1994; Balsom et al., 1995; Cooke et al., 1995; Odland et al., 1997; Snow et al., 1998). While these studies provide useful information, they can only be seen in light of the type of exercise performed, and do not, therefore, seem applicable to the responses of intermittent exercise as commonly associated with soccer match-play.

Mujika et al. (2000) examined the effects of Cr supplementation on intermittent high-intensity exercise activities specific to competitive soccer. Seventeen highly trained male soccer players performed a counter-movement jump test, a repeated sprint test (consisting of six maximal 15-m runs with 30-s recovery), an intermittent endurance test (consisting of forty 15-s bouts of high-intensity running interspersed by 10-s periods of recovery) and a recovery counter-movement jump test consisting of three jumps. The exercise was repeated after 7 days of either Cr supplementation or placebo. The results demonstrated consistently shorter 15-m times during the repeated sprint test following Cr supplementation. However, performance in the intermittent endurance test and the counter-movement jump test remained unchanged. According to the measured blood ammonia and blood lactate values, the observed ergogenic effects occurred concomitantly with reduced adenine nucleotide degradation and without an increased reliance on anaerobic glycolysis. These authors concluded that acute Cr supplementation favourably affected performance of repeated sprints in highly trained soccer players.

Cox et al. (2002) investigated the effects of acute Cr supplementation on the performance of elite female soccer players undertaking an exercise protocol simulating match-play. Twelve players performed 5 x 11 min exercise blocks interspersed with 1 min of rest. Each block consisted of eleven all-out 20-m runs, 2 agility runs, and 1 precision ball kicking drill, separated by recovery 20-m walks, jogs and runs. The exercise was repeated after 7 days of either Cr supplementation or placebo. No overall change in 20-m sprint times and agility run times were observed, although the Cr group achieved faster times post-supplementation in sprints 11, 13, 14, 16, 21, 23, 25, 32 and 39, and agility runs 3, 5, and 8. These authors suggested that Cr supplementation improved performance of some repeated sprint and agility tasks simulating soccer match-play.

More recently, Ostojic (2004) investigated the effects of acute Cr supplementation on soccer-specific performance in young soccer players. Twenty young male soccer players were randomly assigned to Cr supplementation or placebo. Before and after the supplementation protocol, each subject underwent a series of soccer-specific skill tests: dribble test, sprint-power test, endurance test and vertical jump test. Specific dribble test times, sprint-power test times and vertical jump height were all significantly improved following Cr supplementation.

Although research has supported beneficial effects on performance from Cr supplementation, it is not clear whether these benefits apply in exercise protocols that mimic the activity patterns of soccer match-play. These cautionary notes regarding the role of Cr may be well founded. The results from some studies have shown no significant enhancement of performance with dietary supplementation of Cr during single (Rossiter et al., 1996) and repeated bouts of high-intensity exercise (Cooke et al., 1995; Mujika et al., 1996; Barnett et al., 1996; Odland et al., 1997). It would appear that it is the variables associated with the experimental protocol per se that determine whether performance is enhanced following Cr supplementation. Variables include the duration of the exercise efforts, the duration of the recovery periods and the gender and level of the athletes.

Few laboratory studies to date have employed exercise protocols that have attempted to replicate the demands of soccer match-play (Drust et al., 2000a,b). This type of intermittent exercise comprises brief periods of intense muscular activity interspersed with longer periods of lower intensity exercise, or rest. While Cr supplementation has been shown to improve performance during repeated bouts of maximal exercise (Harris et al., 1992; Greenhaff et al., 1993), whether performance can be enhanced during intermittent high-intensity exercise where brief periods of sprinting (< 6 s) are interspersed with longer periods of rest or lower intensity activity (~ 90-180 s) over 90 min in total, has yet to be evaluated.

Therefore, the purpose of this investigation was to examine the effects of acute Cr supplementation on sprint performance and intermittent endurance running during an exercise protocol that simulates the activity patterns of soccer match-play. In order to examine this effect, this investigation will use a model of intermittent exercise that reflects the activity patterns observed in Chapter V.

7.1.1.1 Assumptions

1. There was no significant alteration in the training status or $\dot{V}O_{2max}$ of the subjects between the time of the preliminary measurements up to both trials.
2. The subjects did not engage in any heavy training for the two days prior to the main trials.
3. Each subject consumed an identical diet in the two days prior to the main trials.
4. Environmental conditions were uniform across the main trials for each subject in terms of barometric pressure, temperature and humidity.

7.1.1.2. Statement of Hypotheses

The following statements are expressed as null hypotheses:

A. H_O: Sprinting performance is not improved by the ingestion of 4 x 5 g Cr for 5 days.

B. H_O: There is no difference in the physiological, metabolic and perceptual responses during or immediately after a model of intermittent exercise following the ingestion of 4 x 5 g Cr for 5 days.

7.1.2 Methods

7.1.2.1 Subjects

Eight male soccer players were recruited from the Research Institute for Sports and Exercise Sciences, Liverpool John Moores University to participate in this study. Each subject had at least 10 years playing experience in soccer. Weekly training and playing time ranged from 5 to 8 hours. The Human Ethics Committee of Liverpool John Moores University approved all procedures. Subjects were fully informed about the aims, procedures and the demands that the tests would place upon them, together with any possible risks and discomforts before written consent was obtained (See Appendix).

7.1.2.2 Familiarisation of subjects

In order to minimise the order effect and ensure familiarity with the exercise protocol, all subjects underwent two sessions of familiarisation. Subjects were asked to refrain from intense exercise the day prior to each familiarisation session. Initial familiarisation involved getting accustomed to running on the non-motorised treadmill and having the procedures involved during testing explained. Subjects then performed two 15-min blocks of the soccer-specific intermittent protocol (Drust et al., 2000a).

7.1.2.3 Experimental design

The study consisted of a cross-over design (n=8). Subjects were required to attend the laboratory on 2 occasions and performed a total of 2 trials, under 2 dietary conditions. The trials were performed at least 35 days apart to ensure complete muscle Cr washout following supplementation. The PCr/ATP ratio has been shown to remain elevated in some individuals after a 5-week washout period (Lemon et al., 1995). Two recent studies have demonstrated that the washout time of Cr from human muscle is about 28 days (Febbraio et al., 1995; Hultman et al., 1996), so that the protocol used had a safety margin. Subjects were randomly assigned to creatine supplementation (Cr) or placebo supplementation (Plac). Creatine and Placebo treatments were administered in a double-blind fashion after the initial familiarisation and test sessions. Each subject consumed either 5 g of a placebo in 300 ml of warm water 4 times daily for 5 days or 5 g of creatine monohydrate in 300 ml of warm water 4 times daily for 5 days. Subjects were instructed to avoid consumption of the supplement with caffeinated beverages, as it has been demonstrated that caffeine eliminates the ergogenic effects of creatine (Vandenberghe et al., 1996). On the morning of the sixth day, subjects performed the 'Soccer-Specific Intermittent Exercise Protocol' (SSIEP). The subjects then observed a 28-day period in which no supplement or placebo was ingested. Following this period, the procedure was repeated so that all subjects received both dietary conditions in a cross-over design (Fig 7.1.1.).

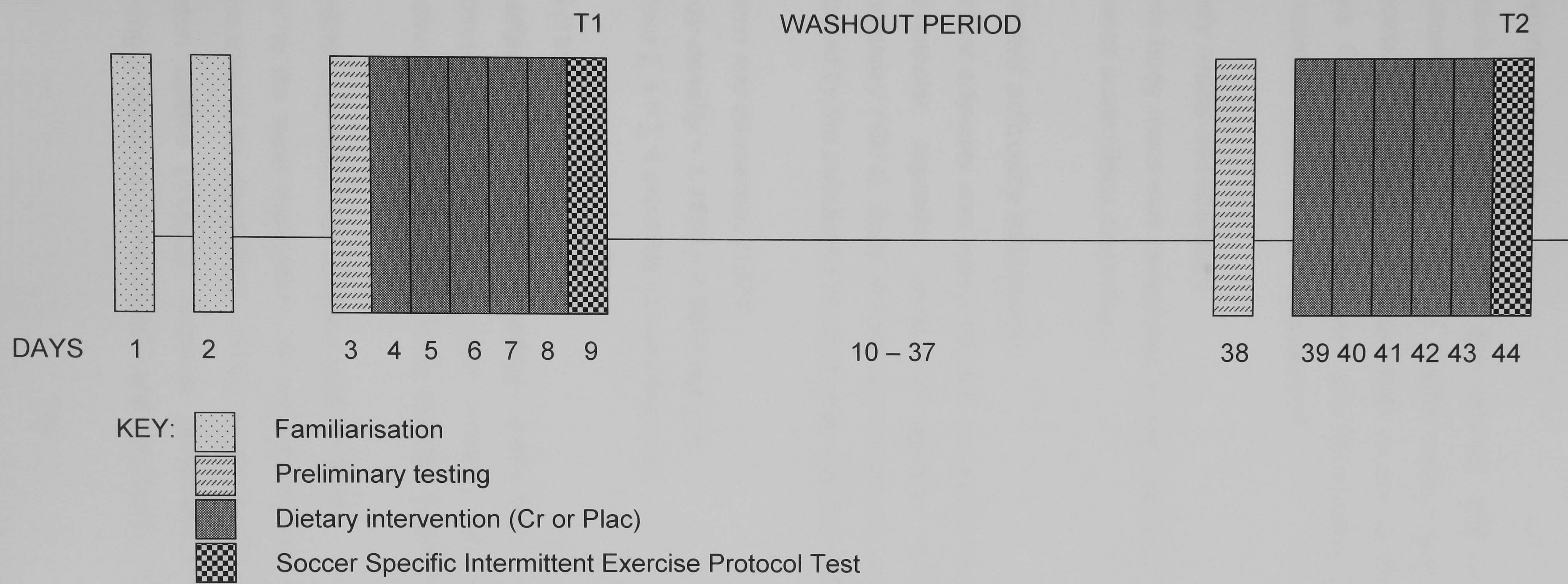


Fig 7.1.1. Schematic representation of the experimental design.

7.1.2.4 Preliminary measurements

Stature

Stature was determined to the nearest 0.05 m using a wall-mounted stadiometer (Seca, Germany). Gentle traction was applied on the mastoid process of the subject to compensate for any shrinkage of the intervertebral discs. Care was taken to ensure that the marked Frankfurt Plane remained horizontal throughout the measurement.

Body mass assessment

Nude body mass was determined to the nearest 0.1 kg using a triple beam balance scale (Seca, Germany).

Percent adiposity estimation

*Percent adiposity was estimated from the sum of four sites – biceps, triceps, subscapular, suprailiac using the equation developed by Durnin and Womersley (1974). Body density was calculated using equation **(1)** and was followed by the calculation of percentage adiposity using equation **(2)**.*

Durnin and Womersley (1974)

Body density = 1.1610 – 0.0632 log ∑ 4 ***(1)***

Where ∑ 4 = ∑ 4 skinfolds as specified (mm)

Siri (1956)

% adiposity = [(4.95/body density) – 4.5] x 100 ***(2)***

Anthropometric procedures and reliability of the technical error of measurement have been previously reported in section 4.1.2.2.

Preliminary maximal oxygen uptake test

Prior to the main experiment, all subjects reported to the laboratory at the same time of the day (09:00 – 10:00 hours), for the determination of maximal oxygen uptake ($\dot{V}O_{2max}$). Subjects performed a continuous incremental running protocol on a motorised treadmill (Quinton instruments, Washington, USA). Following a 5-min warm-up at a speed of 7.5 $km.h^{-1}$, the initial treadmill speed was set at 10 $km.h^{-1}$ for 2 min. Thereafter the treadmill speed was increased by 2 $km.h^{-1}$ every 2 min until a treadmill speed of 16 $km.h^{-1}$ was reached. All additional workloads were introduced through an increase in gradient of the treadmill by 2% every 2 min. The attainment of $\dot{V}O_{2max}$ was assessed using the following criteria: -

1. A plateau in the relationship between oxygen uptake and exercise intensity, as evidenced by an increase in oxygen uptake of less than 2 $ml.kg^{-1}.min^{-1}$ or 3% with an increase in exercise intensity.
2. A final respiratory exchange ratio value of 1.1 or over.
3. A final heart rate within 10 $beats.min^{-1}$ of age predicted maximum.
4. Inability of the subject to maintain the required treadmill speed.

Prior to determination of $\dot{V}O_{2max}$, subjects were fitted with a mouthpiece and nose-clip. Expired gases were measured by means of indirect calorimetry using an open circuit spirometry system (Metamax, Cortex, Frankfurt. Germany). Prior to testing, the system had been calibrated using two calibration gases of known concentrations. Measures of oxygen consumption ($\dot{V}O_2$), minute ventilation (VE) and respiratory exchange ratio (RER) were recorded throughout. Each subject's heart rate was monitored during the test by means of short-range radio telemetry (Polar Accurex Plus, Polar, Kempele, Finland) sampled at 5-s intervals.

Preliminary vertical jump test

Vertical jump was performed prior to the commencement of the Soccer Specific Intermittent Exercise Protocol. Vertical jump was measured as the rise height of the centre of mass using a jump dynamometer (Takei, Japan). Such a method employs a measuring tape around the athlete's waist that unreels with the distance jumped vertically. Subjects were instructed to take off and land within a marked area on a jump mat. Prior to the jump the subjects performed a fast counter-movement. Throughout the jump, the subjects were allowed to swing their arms freely.

7.1.2.5 The Soccer-Specific Intermittent Exercise Protocol

The Soccer Specific Intermittent Exercise Protocol (SSIEP) devised for this study was performed on a modified non-motorised treadmill (Woodway, Vor Dem, Auf Schrauben, Germany). The protocol was a modification of that employed by Drust et al. (2000a) and consisted of the different exercise intensities that were observed during competitive match-play. The protocol was performed on a non-motorised treadmill as the apparatus has the benefits of almost instantaneous acceleration and deceleration. The combination of speeds and activity changes was designed to mimic the activity pattern typically recorded for soccer match-play (Reilly and Thomas, 1976; Withers et al., 1982) and consisted of four movement categories: walking, jogging, cruising and sprinting. Static periods were also included in the protocol in which the subjects were stationary on the treadmill. Due to the technical limitations of the equipment, utility movements (backwards and sideways) were not included.

The protocol was arranged around a 15-min activity cycle (see Figure 7.1.2). This cycle was performed six times in total to make up the 90-min protocol duration. This 15-min cycle was further sub-divided into 3-separate 5-min periods. The order of the presentation of the activities was based on the original protocol devised by Drust et al. (2000a) with minor modifications. Each section of 5-min periods consisted of 3 discrete bouts of walking, 3 bouts of jogging, 3 bouts of cruising, 3 static pauses and one maximal sprint. The duration of each bout of activity was determined by dividing the percentage time of each activity category observed during match-play (Section 5.3) by the time for one 15-min activity cycle in the SSIEP. The percentage of time spent in each movement category expressed relatively to the total time of the SSIEP is shown in Table 7.1.1 The time spent in each category was designed to replicate the physiological stresses of match-play.

The time for each discrete movement bout of activity incorporated into the SSIEP is shown in Table 7.1.2. Treadmill speeds for each activity were prescribed (except for the sprint which was the main outcome variable) according to the data of Van Gool et al. (1988) and Drust et al. (2000a). The respective speeds chosen for each movement category were: walking 4 $km.h^{-1}$, jogging 8 $km.h^{-1}$, and cruising 12 $km.h^{-1}$. No speed restrictions were placed on the sprinting category as subjects were instructed to produce a maximal effort.

Table 7.1.1. Percentage of time spent in each movement category during the SSIEP.

Activity	% Time
Walking	48%
Jogging	32%
Cruising	4%
Static	15%
Sprinting	1%

WALKING 4 0-48	JOGGING 8 48-1.20	STATIC 0 1.20-1.35	CRUISING 12 1.35-1.39	WALKING 4 1.39-2.27	CRUISING 12 2.27-2.31	STATIC 0 2.31-2.46	JOGGING 8 2.46-3.18	SPRINT MAX. 3.18-3.21
JOGGING 8 3.21-3.53	STATIC 0 3.53-4.08	CRUISING 12 4.08-4.12	WALKING 4 4.12-5.00	JOGGING 8 5.00-5.32	WALKING 4 5.32-7.10	STATIC 0 7.10-6.35	CRUISING 12 6.35-6.39	SPRINT MAX. 6.39-6.42
JOGGING 8 6.42-7.14	WALKING 4 7.14-8.02	CRUISING 12 8.02-8.06	STATIC 0 8.06-8.21	JOGGING 8 8.21-8.53	WALKING 4 8.53-9.41	STATIC 0 9.41-9.56	CRUISING 12 9.56-10.00	STATIC 0 10.00-10.15
JOGGING 8 10.15-10.47	STATIC 0 10.47-11.02	CRUISING 12 11.02-11.06	JOGGING 8 11.06-11.38	WALKING 4 11.38-12.26	SPRINT MAX. 12.26-12.29	STATIC 0 12.29-12.44	WALKING 4 12.44-13.32	CRUISING 12 13.32-13.36
JOGGING 8 13.36-14.08	WALKING 4 14.08-14.56	CRUISING 12 14.56-15.00						

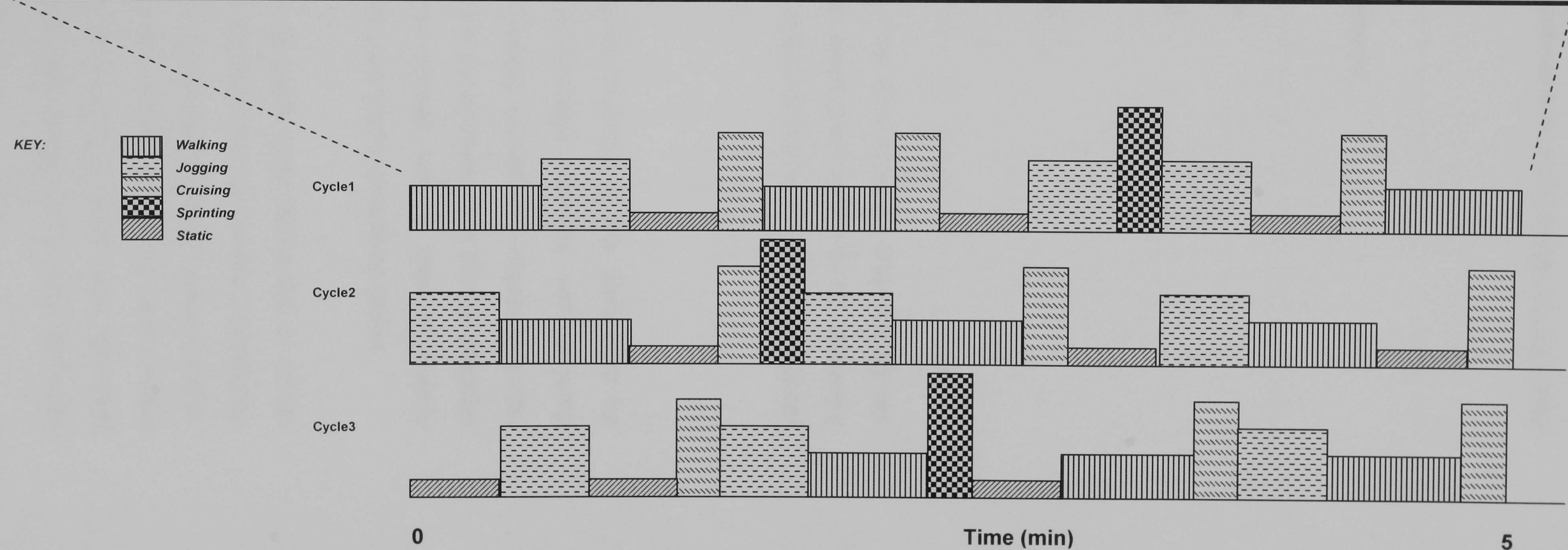


Figure 7.1.2. Diagrammatic representation of the SSIEP

Table 7.1.2. Time (s) for each discrete movement bout of activity incorporated into the SSIEP

Activity	Time (s)
Walking	48
Jogging	32
Cruising	4
Static	15
Sprinting	3

The SSIEP consisted of 90-min of activity. This 90-min period was divided into 2 x 45-min identical periods of exercise separated by a 15-min recovery period. This protocol corresponds to that observed during professional soccer match-play.

7.1.2.6 Experimental procedures

One week prior to the main trials, subjects reported to the laboratory for preliminary measurements. Body mass, percentage adiposity, vertical jump height and $\dot{V}O_{2max}$ were determined. Following preliminary measurements, subjects were randomly assigned to creatine supplementation (Cr) or placebo supplementation (Plac). Subjects were presented with a total of twenty sachets and information outlining how the supplements should be taken.

During the two days preceding each trial, subjects were instructed to refrain from strenuous exercise and consume an identical diet for the two conditions. A diet recording sheet was provided to assist standardisation of dietary intake. Subjects reported to the laboratory at the same time of the day and voided prior to the determination of nude body mass. Body mass was recorded before and after each exercise trial. Subjects also removed all sweat from the skin prior to body mass measurement. This procedure therefore allowed an estimation of total sweat production (assumption mass loss = sweat production rate). Vertical jump height was then determined using a jump dynamometer (Takei, Japan).

Finger-prick blood samples were obtained prior to the warm-up, at half time and immediately following each trial. Blood was collected in a lithium heparinised capillary tube and stored at -70 °C until analysis. The sample was analysed for lactate and glucose by enzymatic methods using the Analox Micro stat GM7 Analyser (Analox Instruments Limited, London, UK). Heart rate was monitored throughout the SSIEP protocol via short-range radio telemetry (Polar Accurex Plus, Polar, Kempele, Finland) sampled at 5-s intervals. Perceived exertion was also rated following each 15-min cycle using the scale devised by Borg (1982). In order to sustain the appropriate running speeds throughout the trials, a display showing speed was placed in front of the non-motorised treadmill. Feedback in terms of time remaining in each movement category was also provided throughout the SSIEP. The test protocol is presented in Figure 7.1.3.

7.1.2.7 Statistical Analyses

The differences between the effects of treatment (Cr v PLA), time (comparing measurements at different time points i.e. Pre v Post SSIEP) and any interaction effect (treatment v time) were determined using a two-way analysis of variance (ANOVA), (SPSS for Windows). When a significant difference was found, Tukey's Honest Significant Difference post-hoc test was performed to elicit where the differences lay. The Tukey test values were calculated from the ANOVA results when sphericity was assumed ($\Sigma \geq 0.75$) in Mauchly's test of sphericity. Values of $\Sigma < 0.75$ resulted in Tukey test values being calculated from the Epsilon[a] (Huynh-Feldt). The Students paired t-test was employed to determine significant differences in data measured at only one time point (Microsoft, Excel). Statistical significance was accepted at $P < 0.05$. Data are presented as Mean $\pm$ Standard error of the mean (SEM).

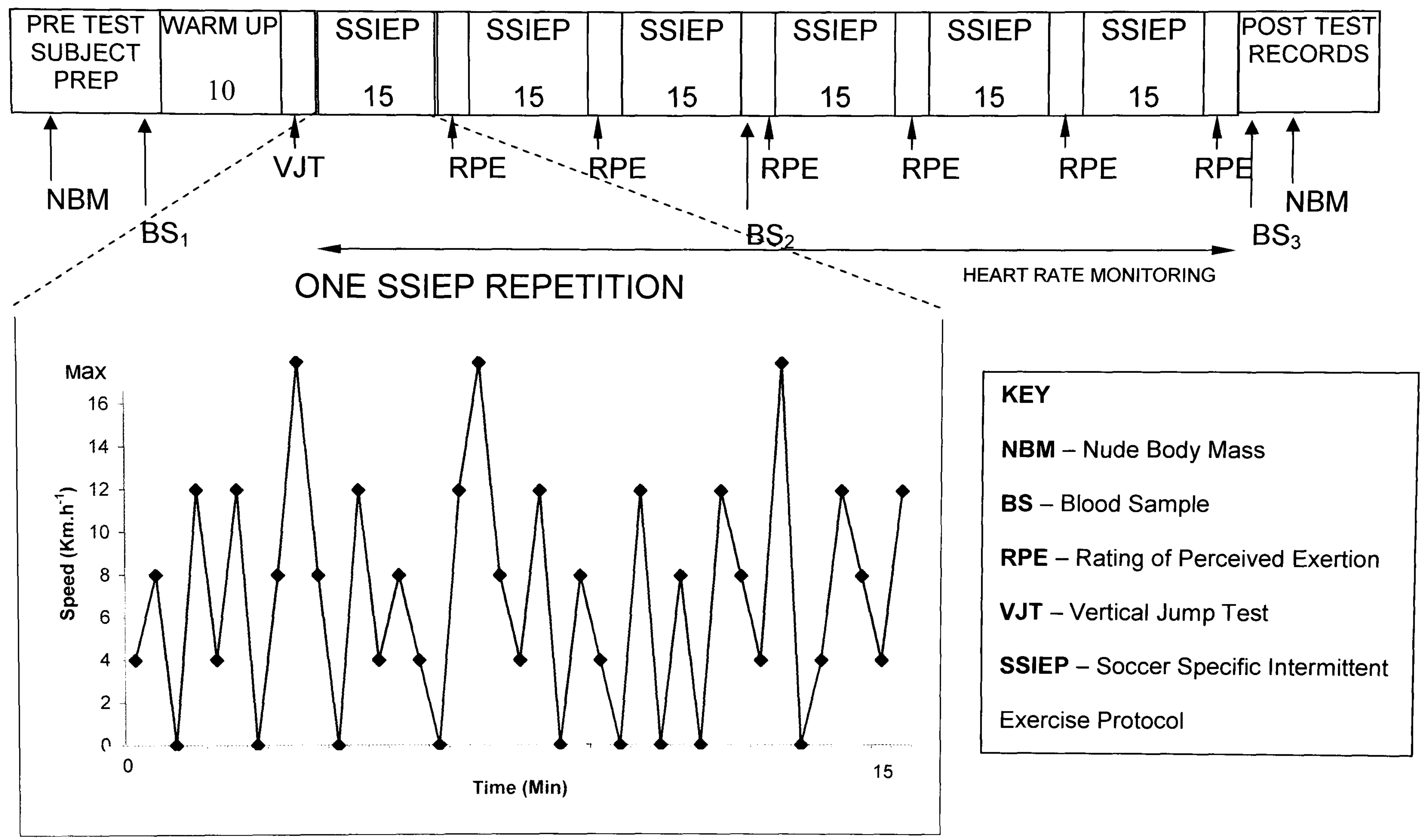


Figure 7.1.3. Schematic illustration of the SSIEP protocol and experimental procedures.

7.1.3 Results

The physiological and performance characteristics of the subjects are presented in Table 7.1.3.

Table 7.1.3. Physiological and performance characteristics of the subjects (mean ± S.D., n=8).

Age (decimal years)	21.1 ± 2.8
Body mass (kg)	77.40 ± 5.8
Stature (m)	1.77 ± 0.06
% Adiposity	15.4 ± 2.0
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	57.2 ± 4.2
HR_{max}	199 ± 5.0
Vertical Jump height (cm)	50.3 ± 3.6
Peak Power Output (W)	1531 ± 235

7.1.3.1 Body mass

In the Cr trial body mass increased from 77.4 ± 4.9 to 78.0 ± 5.2 kg. These values were not significant at the statistical level. Six of the eight subjects increased their body mass between 0.6 and 1.0 kg, one subject maintained pre-supplementation body mass and one subject decreased body mass by 0.5 kg. In the Plac trial body mass remained unchanged throughout the experimental period (77.35 ± 4.8 and 77.4 ± 4.9 kg before and after supplementation respectively).

7.1.3.2 Sprint performance

Mean Power Output during the SSIEP was 1020.1 ± 135.7 W and 1031.1 ± 111.2 W for the Plac and Cr trials, respectively. No differences were observed between trials for mean power output. Mean power output for both trials during each exercise block of the SSIEP are presented in Figure 7.1.4.

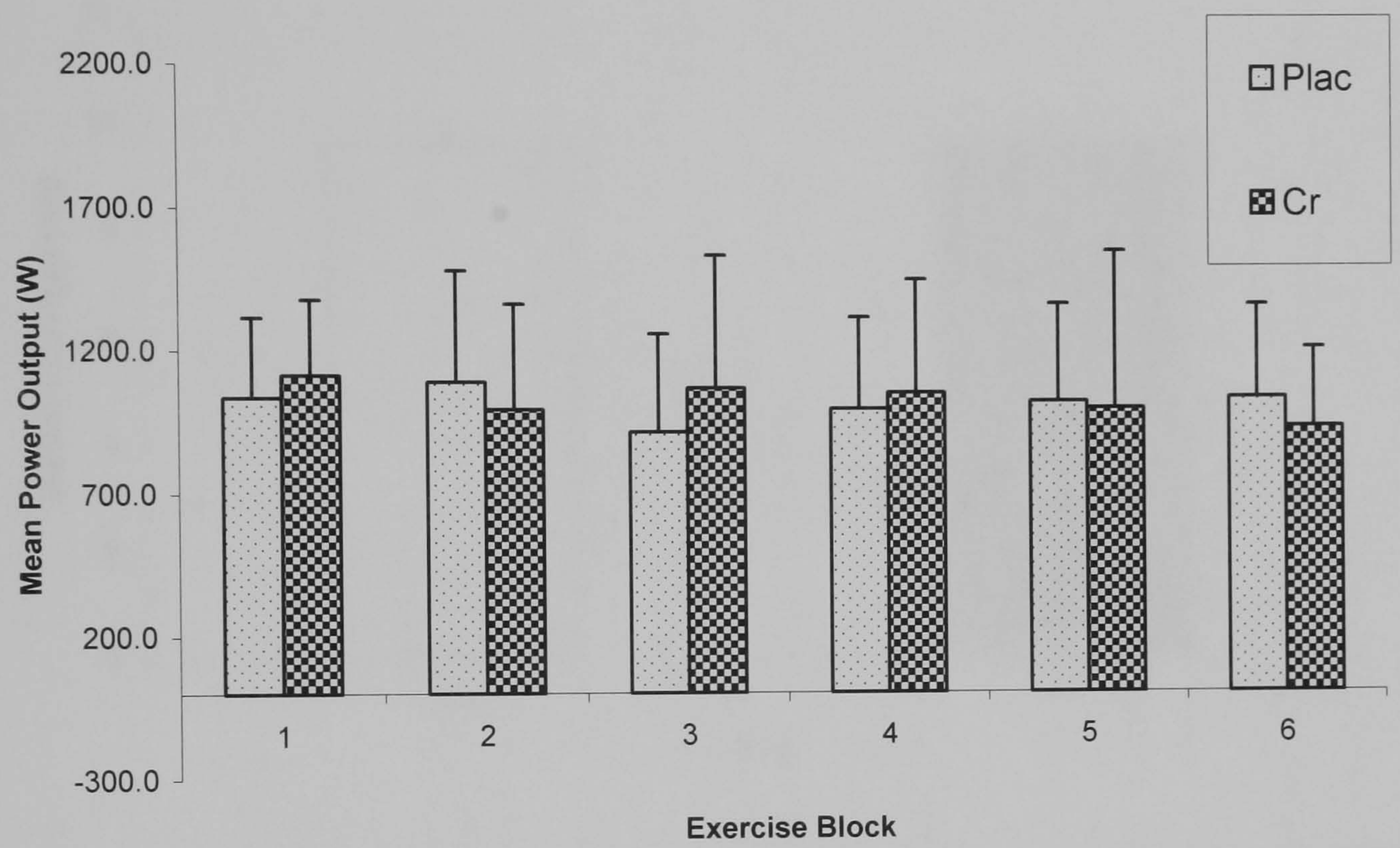


Figure 7.1.4. Mean power output (W) during each block of the SSIEP (mean ± S.D., n=8).

7.1.3.3 Distance covered

Mean distances covered during the SSIEP were 9.55 ± 0.39 km and 9.58 ± 0.54 km for the Plac and Cr trials, respectively. There were no differences in distance covered between trials. Distances covered during the SSIEP are shown in Figure 7.1.5.

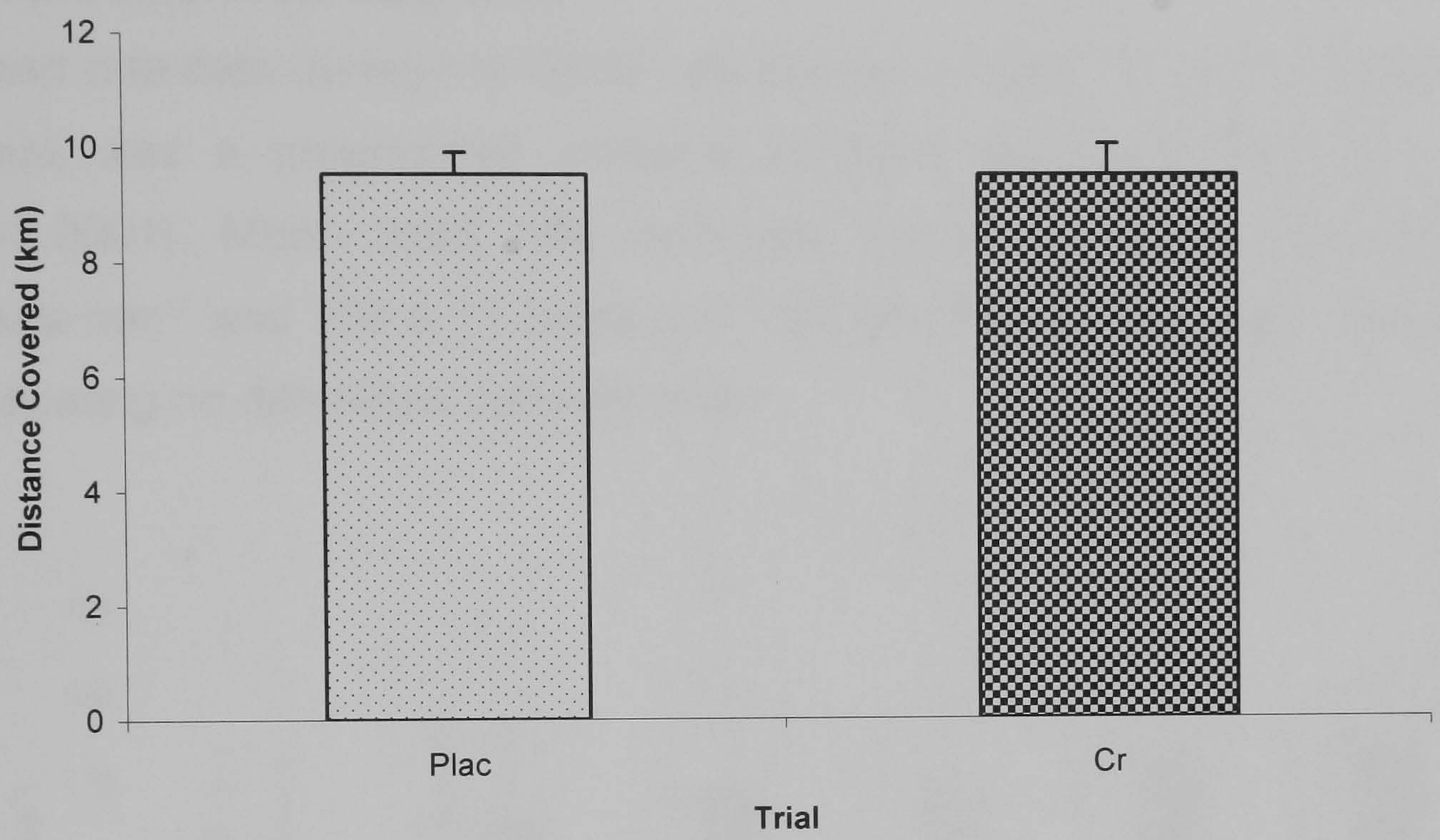


Figure 7.1.5. Distance covered (km) over the 90-min exercise period (mean ± S.D., n=8).

7.1.3.4 Vertical jump

No differences were observed for vertical jump height following supplementation of creatine or placebo. In the Cr trial subjects jumped 50.0 ± 4.9 and 50.2 ± 4.0 before and after supplementation. Values for the Plac trial were 50.3 ± 4.2 and 50.2 ± 3.6, respectively.

7.1.3.5 Heart rate response

Heart rate data during the SSIEP are shown in figure 7.1.6. During both trials, there was a progressive increase in heart rate over time ($F_{5,35}$ =6.35; P<0.0001). Mean heart rate response during the SSIEP was 168 ± 10 beats.min^{-1} and 168 ± 11 beats.min^{-1} for the Plac and Cr trials, respectively, indicating no difference between trials.

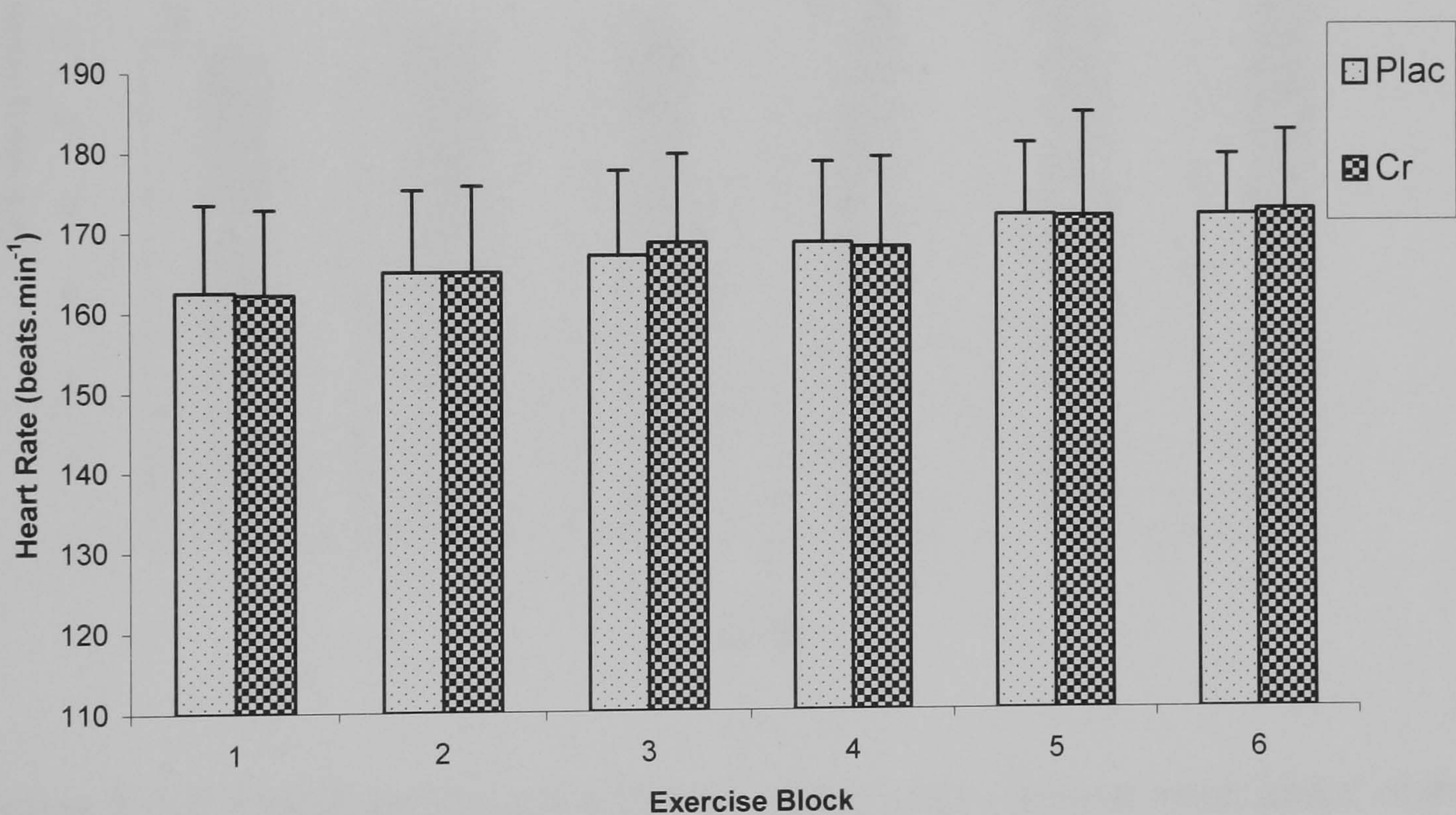


Figure 7.1.6. Mean heart rate response (beats.min^{-1}) during each block of the SSIEP (mean ± S.D., n=8).

7.1.3.6 Rating of Perceived Exertion

The ratings of perceived exertion (RPE) described by subjects for both trials are presented in Figure 7.1.7. There were no significant differences between trials. There was a progressive increase in RPE over time in both trials ($F_{5,35}$ =33.34; P<0.0001) and a main interaction effect between trials ($F_{5,35}$ =2.87; P<0.028).

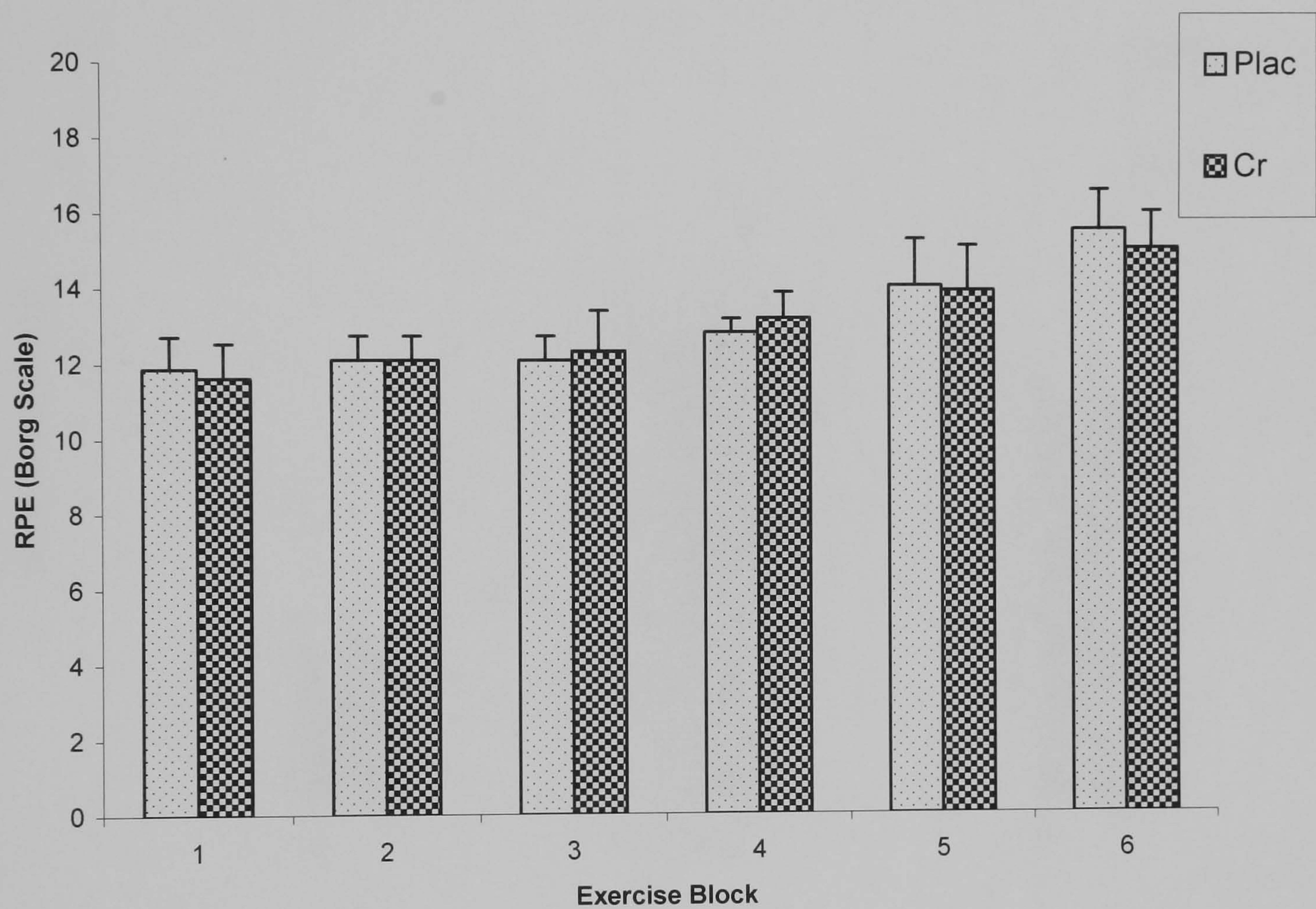


Figure 7.1.7. Perceived Exertion (Borg Scale) values during each block of the SSIEP (mean ± S.D., n=8).

7.1.3.7 Blood lactate

Blood lactate concentrations are presented in Figure 7.1.8. Analysis of the data revealed no differences between trials. In both trials blood lactate increased roughly three-fold over resting values during the first 45-min of exercise ($F_{2,14}$ =48.58; $P<0.0001$). Peak blood lactate concentrations for the Plac and Cr trials were 7.13 $\pm$ 0.8 $mmol.l^{-1}$ and 6.18 $\pm$ 1.8 $mmol.l^{-1}$, respectively.

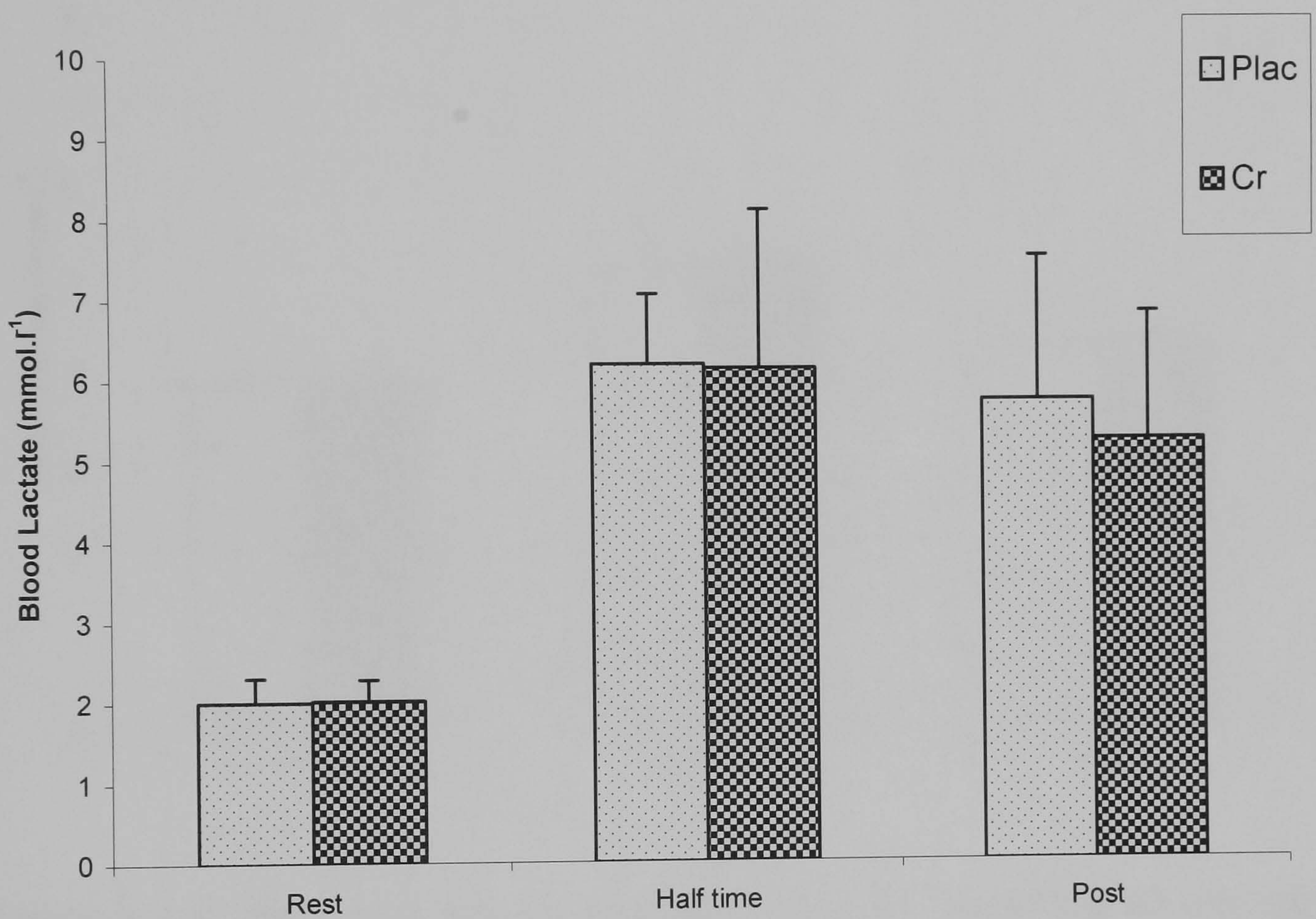


Figure 7.1.8. Blood lactate concentration ($mmol.l^{-1}$) over the 90 min exercise period (mean ± S.D., n=8).

7.1.3.8 Blood glucose

Blood glucose concentrations are presented in Figure 7.1.9. In both trials blood glucose increased from rest to a peak at 45 min (Plac: 5.16 $\pm$ 0.4 mmol.l^{-1}. Cr 5.27 $\pm$ 0.4 mmol.l^{-1} ($F_{2,14}$ =23.46; P<0.0001). No differences were observed between trials.

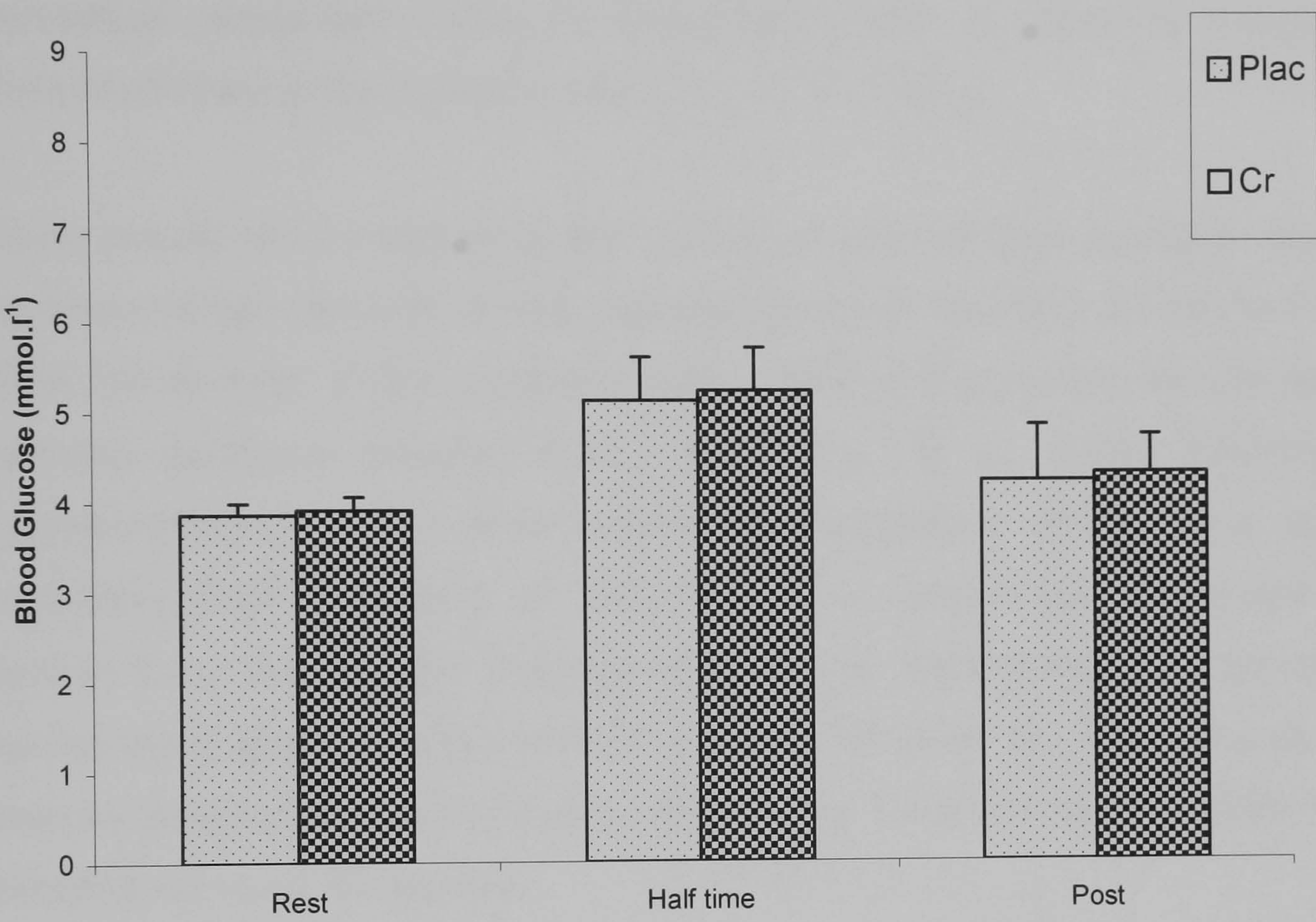


Figure 7.1.9. Blood glucose concentration (mmol.l^{-1}) over the 90 min exercise period (mean ± S.D., n=8).

7.1.4 Discussion

The purpose of this study was to investigate the effect of a Cr supplementation regimen on sprint performance during a Soccer-Specific Intermittent Exercise Protocol. The main finding was that Cr administration had no significant effect on power output during repeated 3-s sprints. There were no further differences observed in the physiological, metabolic and perceptual responses during or immediately after a model of intermittent exercise following the ingestion of 4 x 5 g Cr for 5 days.

These results are in contrast to the findings of other studies that have reported significant improvements during repeated maximal exercise (Greenhaff et al., 1993; Harris et al., 1993; Bogdanis et al., 1996) and purported soccer-specific exercise protocols (Mujika et al., 2000; Cox et al., 2002) following Cr supplementation. The present study used repeated sprints in a context simulating their frequency of occurrence in competitive match-play (see section 5.2). The positive findings following Cr supplementation reported in the literature were in performance of exercise bouts of less frequency and in a manner unrepresentative of soccer match-play. Their ecological validity would therefore be open to question.

During the SSIEP, a high-intensity bout of activity was performed approximately every 90 s and a maximal bout every 5 min. Clearly, the length of recovery interval between repeated bouts of high-intensity exercise will affect performance. Wootton and Williams (1983) reported that although power output decreased during repeated 6-s sprints with either 30-s or 60-s recoveries, the decrement in power output was less when 60-s of recovery was permitted. A longer recovery period ensures more complete recovery of the physiological indices related to performance.

Balsom et al. (1992) observed that maximal bouts of short duration <3 s could be repeated every 30 s without decreases in performance. Creatine phosphate (PCr) and glycogen are the major sources of substrate that generate adenosine triphosphate (ATP) during short duration maximal exercise (Boobis et al., 1987; Hultman et al., 1990). Given that the half life for

PCr resynthesis in human mixed muscle fibres has been reported as 30-40 s (Harris et al., 1976), it follows that there was complete resynthesis of PCr between maximal bouts.

Dietary Cr supplementation has been shown to be a useful ergogenic aid only during exercise where PCr availability limits performance (Birch et al., 1994; Jones et al., 1998; Peyrebrune et al., 1998; Cox et al., 2002). Subjects who performed six 10-s sprints on a non-motorised treadmill following 5 days of Cr supplementation generated a greater power output and ran further than the control group (Bogdanis et al., 1996). Therefore for performance differences in the present study to be observed, maximal bouts of activity should be repeated more frequently or the duration of effort increased to 10 s. The implication here is that maximal bouts of short duration <3 s are not taxing enough on PCr stores and that 5 min between bouts of maximal effort gives sufficient time for complete resynthesis of physiological indices.

Although there are studies in the literature supporting the beneficial performance improvements following Cr supplementation during repeated high-intensity exercise (Mujika et al., 2000; Cox et al., 2002), the extent to which these exercise protocols mimic the activity patterns of soccer match-play remains questionable. During competitive match-play, sprint activities are short both in terms of duration and distance. On average a high-intensity bout occurs every 90 s (Reilly and Thomas, 1976) and is no longer than 2-4 s (Reilly and Thomas, 1976; Bangsbo et al., 1991). Evidence from Chapter V of this thesis is that sprinting constitutes approximately 2% of the total match distance corresponding to 1% of the effective playing time. In terms of distance covered, this figure corresponds to approximately 267 ± 103 m depending on the playing position. On average players may only carry out 20 maximal sprints during a match Therefore, the 55 sprints interspersed with short recovery periods (<10 s) conducted in the experimental protocol of Cox et al. (2002), and the 6 x 15 m runs with 30-s recovery conducted in the protocol of Mujika et al. (2000), do not match the activity pattern in the present study nor that found in competitive match-play (Chapter V).

In both trials, sprint performance was maintained throughout the SSIEP. Subjects in the present study may have been of sufficient training status to maintain performance via an effective oxygen transport system without compromising PCr and ATP stores within the working muscles. Therefore any of the erogenic benefits associated with exogenously administered Cr may have been masked. It has been suggested that PCr resynthesis is a two-component process (Sahlin et al., 1979). The initial fast phase of PCr resynthesis is limited by the availability of O_2, whereas the subsequent slow phase is limited by H^+ ion transport out of the muscle (Harris et al., 1976). Since O_2 supply and H^+ clearance are dependent upon the effectiveness of the oxygen transport system, the maintenance of sprint performance observed in both trials may be related to the training status of the subjects.

Hamilton et al. (1991) compared the aerobic response of endurance-trained athletes and games players during repeated bouts of 6-s sprints on a treadmill (endurance-trained athletes: - $\dot{V}O_{2max}$ 60.8 ± 4.1 ml·kg^{-1}·min^{-1}; games players: - $\dot{V}O_{2max}$ 52.5 ± 4.9 ml·kg^{-1}·min^{-1}). While both groups attained similar peak power values, the endurance trained athletes consumed significantly more oxygen during repeated intervals of maximal sprinting and demonstrated a significantly smaller percentage decrement in power over the 10-sprints compared with the games players. Given that some of the subjects in the present study had $\dot{V}O_{2max}$ values well above 60 ml·kg^{-1}·min^{-1}, the potential benefits of Cr may be negligible in such well-trained individuals.

Blood lactate concentrations were similar during both trials, reaching peak values of 7.13 ± 0.8 mmol.l^{-1} and 6.18 ± 1.8 mmol.l^{-1} for the Plac and Cr trials respectively. These values are similar to those previously observed during repeated bouts of sprinting (Balsom et al., 1992; Nicholas et al., 1995) and illustrate that anaerobic glycolysis plays an important role as an energy source during prolonged intermittent high-intensity exercise. However, the results of the present study are in contrast to the findings of other studies in which the lactate response during repeated sprints is lowered following Cr supplementation (Balsom et al., 1993).

Balsom et al. (1995) investigated the influence of oral Cr supplementation on 5 x 6-s bouts of sprint cycling performed at a constant work-rate of 140 $rev.min^{-1}$. Following the administration of Cr, the total concentration in *m.vastus lateralis* had increased from 128.7 to 151.5 $mmol.kg(dw)^{-1}$. Moreover, muscle lactate concentration measured immediately after the fifth sprint was 70% lower following Cr supplementation (27.1 $mmol.kg(dw)^{-1}$ vs 44.3 $mmol.kg(dw)^{-1}$). This difference was evident despite the fact that the same amount of work had been performed, at the same rate in both conditions. According to Balsom (1995), while the exact mechanism(s) that control flux through the glycolytic pathway during exercise are not fully understood, the glycolytic rate may be controlled by the synergistic effects of a series of positive and negative modulators of PFK. These include PCr, ATP, ADP, AMP and pH.

Williams (1987) observed that during intermittent exercise, the lactate produced within type II fibres during sprinting could be used as substrate by type I fibres during aerobic periods. It follows that much of the qualitative information regarding the anaerobic contribution to ATP production would have been missed in the current study due to the intervals between sampling points. Nevertheless, if there was a reduced reliance on anaerobic glycolysis for ATP resynthesis during the SSIEP, one would expect reduced muscle glycogen degradation and an associated increase in the total distance covered during the bouts of high-intensity work. Given that there were no differences between trials in distance covered, it is unlikely that during prolonged high-intensity intermittent exercise, Cr supplementation exerts any ergogenic effects via a reduced reliance on anaerobic glycolysis for ATP resynthesis. These observations are supported by the findings of others where the lactate response to single or repeated sprints remained unaltered following Cr supplementation (Birch et al., 1994; Greenhaff et al., 1993; Casey et al., 1996; Mujika et al., 2000).

Blood glucose concentrations were similar during both trials, reaching peak values of 5.16 $\pm$ 0.5 $mmol.l^{-1}$ and 5.27 $\pm$ 0.4 $mmol.l^{-1}$ for the Plac and Cr trials respectively. These values correspond to those previously observed for elite Swedish and Danish players during match-play (Ekblom, 1986; Bangsbo, 1994b). At the onset of exercise there is a 2-3 fold increase in the hepatic glucose output (Bergstrom and Hultman, 1967), in part mediated by an increase in plasma glucagon and a concomitant decrease in plasma insulin (Wahren et al., 1971). The increase in glucose output, together with the build up of G-6-P and the subsequent inhibition of hexokinase, accounts for the elevated blood glucose levels during the first 30 min of exercise. Thereafter, hepatic glucose release is closely matched to the rate of glucose uptake and utilisation by muscle during exercise, resulting in a return of blood glucose concentration towards resting levels.

It is unlikely that low blood glucose concentration per se is an exclusive factor in fatigue during prolonged high-intensity intermittent exercise. It seems that despite providing the active muscle tissue with a carbohydrate source, transport into the muscle is too slow for the blood glucose to serve as the major source of carbohydrate for the muscle during exercise >75% $\dot{V}O_{2max}$ (Sahlin, 1986). More recently, subjects receiving carbohydrate supplementation exercised an hour longer than in the control condition, but still fatigued despite a maintained blood glucose and carbohydrate oxidation rate (Coggan and Coyle, 1988). Further, in studies involving prolonged high-intensity intermittent exercise, blood glucose concentrations are well maintained within the normal range (Nicholas et al., 1995).

The similarity of blood glucose concentrations between trials suggests that exogenous Cr has little effect of blood glucose profiles. As with blood lactate, blood glucose concentrations are specific to the individual and influenced by the metabolic activity prior to sampling. Therefore it is difficult to make comparisons with other research reports in the literature due to different protocols and sampling points. Nevertheless, the values reported in the present study are similar to those reported in other studies of intermittent exercise (Nicholas et al., 1995)

The Cr supplementation protocol employed in the present study (4 x 5 g per day for 5 days) has been shown to increase resting muscle concentrations of total Cr (Harris et al., 1992). Several investigations have also shown that this intervention is often accompanied by increases in body mass of 0.4 – 2.1 kg (Balsom et al., 1993; Balsom et al., 1995; Greenhaff et al., 1994; Mujika et al., 2000). The extent of muscle Cr retention during supplementation is variable between subjects. A combination of results from several studies over recent years has revealed that ~20-30% of individuals do not respond to Cr administration, that is, they show less than a 10 mmol.kg $(dw)^{-1}$ (8%) increase in muscle TCr following 5 days of 20 g per day oral Cr supplementation (Greenhaff, 1996). Furthermore, it would appear that the positive effects of Cr supplementation on post-exercise PCr resynthesis are not apparent if the magnitude of muscle Cr accumulation is less than 20 mmol.kg $(dw)^{-1}$. Clearly, these findings have important implications insofar as the subjects in the present study may have been 'non-responders' to Cr supplementation (Greenhaff, 1996). Nevertheless, an average increase of 0.6 kg in body mass was observed in the Cr trial which suggests that Cr loading was attained in the present group of subjects.

Most authors have suggested that increases in body mass following short-term Cr supplementation are the result of the retention of water (Hultman et al., 1996; Ziegenfuss et al., 1997) and the elevation of Cr stores (Volek, 1997). Ziegenfuss et al. (1997) reported a 2% increase in total body water and a 3% increase in intracellular fluid volume in response to a short-term Cr supplementation regimen. Some authors have suggested that the increased body mass following Cr supplementation may be attributed to a positive nitrogen balance that causes an increase in protein synthesis rate (Balsom et al., 1993). It is more likely that long-term Cr supplementation in conjunction with resistance training stimulates an increase in myofibular protein synthesis rate (Earnest et al., 1995; Krieder et al., 1998).

In the present study, Cr supplementation had no effect on vertical jump performance. These findings are in contrast to those reported by Ostojic (2004). However, after a similar Cr loading protocol, Balsom et al. (1995) and

Mujika et al. (2000) found no improvement in vertical jump using physically active males and highly trained male soccer players as subjects. Stout et al. (1999) reported that 8 weeks of Cr supplementation combined with resistance training resulted in an increase of 2.2 ± 1.3 cm in vertical jump height. Furthermore, Volek et al. (1997) have demonstrated that Cr supplementation allowed subjects to perform more work during a weight-training programme. Therefore, increasing the ability to perform work with long-term Cr supplementation may allow athletes to maximise the benefits of resistance training.

In summary, dietary Cr supplementation at a rate of 20 $g.day^{-1}$ for 5 days had no effect on sprint performance, leg power or endurance performance during the SSIEP. Similarly no differences were observed in the physiological, metabolic and perceptual responses during or immediately after a model of intermittent exercise. Further research is required to establish whether a repeated sprint protocol which challenges muscle PCr availability both during exercise and recovery between sprints should be employed. Therefore the following hypotheses were accepted:

A. H_O: Sprinting performance is not improved by the ingestion of 4 x 5 g Cr for 5 days.

B. H_O: There is no difference in the physiological, metabolic and perceptual responses during or immediately after a model of intermittent exercise following the ingestion of 4 x 5 g Cr for 5 days.

7.2 SUMMARY

The aim of this chapter was to examine the effect of a nutritional supplement on selected physiological and performance responses to the intermittent exercise protocol. A pre-requisite was to establish an exercise protocol suitable for experimental investigations. The data provided by the soccer-specific intermittent protocol in the current investigation seem to indicate the protocol replicates the overall energy demands of match-play. Moreover, it was demonstrated that the ingestion of Cr supplementation had no effect on sprint performance, leg power or endurance performance during the soccer-specific intermittent protocol.

The protocol utilised in the present study constituted a simulation of work-rates of soccer players under laboratory conditions. The proportions of activity categories were similar to those found in matches reported in earlier observations within this thesis. Moreover, the exercise model is recommended for laboratory-based studies of interventions relevant to training and match-play.

The mean heart rate response to the intermittent protocol demonstrated rhythmic fluctuations corresponding to changes in activity level. Mean heart response to the intermittent protocol was 168 ± 11 beats.min^{-1} corresponding to 85% of HR_{max}. These figures are similar to those reported in Chapter V for elite soccer players (171 ± 9 beats min^{-1} corresponding to 87.2% of HR_{max}) and indicate that the intermittent protocol provokes a good representation of the cardiovascular demands of match-play. The slightly lower heart rates are probably a reflection of the omission of game skills and other unorthodox changes of direction. Nevertheless, due to the short recovery periods between high-intensity bouts, heart rate remained elevated throughout the protocol simulating that found in match-play.

Mean ± S.D. oxygen consumption for a protocol similar to the one employed in this study has been reported to be 2.5 l.min^{-1} (Drust et al., 2002). This value is similar to those reported for match-play when the additional strain associated with performance of game related skills is taken into account

(Seliger, 1968). The $\dot{V}O_2$ associated with the soccer-specific protocol employed by Drust et al. (2000a) was approximately 65-70% $\dot{V}O_{2max}$. This value is similar to the mean relative oxygen consumption associated with soccer match-play (Bangsbo, 1994).

The blood lactate concentration can be used as an indicator of the anaerobic energy provision. During the soccer-specific intermittent exercise protocol plasma concentration increased above pre-exercise values. This suggests that there is an anaerobic component to the energy demands of the intermittent protocol. The peak blood lactate concentrations for the intermittent protocol were 7.13 ± 0.8 $mmol.l^{-1}$ and are in line with values of 4-6 $mmol.l^{-1}$ reported in the literature (Gerish et al., 1988; Rhode and Esperson, 1988). During the intermittent protocol blood glucose levels were elevated above resting values. Mean values of between 3.2 to 4.5 $mmol.l^{-1}$ have been observed for elite Swedish and Danish players during match-play (Ekblom, 1986; Bangsbo, 1994). These figures are similar to those reported in the present study and give further credence to the ecological value of the intermittent protocol.

The mean total distance covered during the soccer-specific intermittent protocol was 9.58 ± 0.54 km. While these values are lower than those reported in Chapter V for elite soccer players, they are similar to the values reported for elite South American players (Rienzi et al., 2000). Clearly, some differences with respect to the activity profile still exist between match-play and the soccer-specific protocol. Moreover, the replication of utility movements (backing and sideways) is not possible as the non-motorised treadmill permits only forward motion. Furthermore, the total number of activity changes in match-play cannot be fully modelled in a laboratory situation due to their frequency and irregular pattern of reacting to opponents. The omission of other game-related skills with and without the ball will further result in the energy demands being lowered during the intermittent protocol. Nevertheless, the locomotive pattern employed in the intermittent protocol was modelled on results of motion analyses of elite match-play and given the physiological and metabolic responses by the individual participants, it can be deemed appropriate for investigation. Moreover, it can be used to investigate the benefits of nutritional supplementation for soccer players. The current data indicate that creatine is not a substance that improves performance on the protocol simulating work-rate in soccer.

In conclusion, the principal finding in this chapter was that an attempt to enhance performance capability by nutritional supplementation with creatine was unsuccessful. Moreover, creatine did not alter the physiological, metabolic or performance responses during intermittent exercise modelled on soccer match-play.

CHAPTER 8

CHAPTER VIII

8. SYNTHESIS OF FINDINGS

The purpose of this chapter is to integrate the results obtained within this thesis. In doing so, the realisation of the aims of the thesis will be confirmed. Within the general discussion and conclusions that follow, the results of the chapters will be interpreted with respect to the physiological demands of elite soccer-play.

8.1 REALISATION OF AIMS

The integration of field-based and laboratory-based investigations has fulfilled all of the aims stated in Chapter II. The anthropometric characteristics of elite soccer players were determined (Aim 1). Elite soccer players can be described as lean and muscular. In terms of body size, the players in this thesis constitute a relatively heterogeneous group. The goalkeepers and the central defenders were the tallest while the mean height for full-backs, midfield players and forwards was equivalent. While mean values of height and body mass may mask the heterogeneity of elite soccer players, they nonetheless demonstrate that contemporary soccer players are taller and heavier than players in previous decades. It is evident that particular positions have their own unique physical demands and that body size allows players to best meet the demands imposed on them by their positional role.

Assessment of fitness profiles of players forms part of a field-based approach to sports science support systems (Aim 2). Field-based research provides critical information about the demands of the sport and the relative importance of the different components of fitness to soccer performance. The players in this thesis were characterised by a high level in all areas of physical performance. Estimated $\dot{V}O_{2max}$ values of midfield players and full-backs were higher than all other positions. In addition, anaerobic profiles of speed and power were higher in forwards than in midfield players and central defenders. These results suggest that the fitness tests utilised were sensitive enough to differentiate between players based on playing position. When compared with games players from another football code, the anaerobic qualities of the soccer players were superior. Such an observation reflects a greater requirement for speed and explosive power at an elite level of contemporary soccer.

Anthropometric and physiological characteristics of elite young players were investigated for fulfilment of Aim 3. The goal of this investigation was to identify potential discriminators of successful performance. Components related to body mass, endomorphy and estimated $\dot{V}O_{2max}$ were critical in determining eventual success in soccer.

The effects of soccer training and match-play on the injury status of elite adult and young professional players were investigated (Aim 4). The high occurrence of muscular contusions (14.8 %), sprains (33%) and strains (26%) demonstrates that competitive match-play is characterised by physical contact in which tackling, collisions and contests are all commonplace. An overall Injury Frequency Rate (IFR) of 5.0/1000 hours was observed over the duration of the observation period for adult players. The IFR was significantly higher during competitive games than training (43.0/1000 v 2.0/1000). The IFR during competitive games in the present study was also higher in frequency than has previously been reported. Match-related injuries as indicated by the IFR peaked during February and in April. The increased incidence of injury towards the end of the season may be a consequence of cumulative fatigue due to a high number of games. Forwards and wide-midfield players sustained a greater proportion of hamstring strains than did players in other positions. Central midfield players also sustained proportionately more injuries to the knee than any other position. When elite young players were investigated, components of somatotype were found to interact in predisposing participants to injury.

The demands of match-play were established by techniques of motion analysis and heart rate monitoring (Aims 5 and 6). The total distance covered in a game was 11065 ± 920 m. The mean heart rate response during competitive match-play was 171 ± 9 beats$\cdot$min^{-1} corresponding to 87.2% of HR_{max}. These data suggest that the physiological demands of match-play were high with heart rate exceeding 80% of the individual maximal value for over 78% of the event. Taken as a whole, these observations point to a greater level of physiological stress associated with contemporary soccer compared to the game in previous generations (see Reilly, 1990).

When the training regimens of the players were investigated for fulfilment of Aim 6, a mismatch between playing intensities and training intensities was observed. The mean heart rate response during Pre-season, Mid-season and Late-season was 149 ± 7 beats$\cdot$min^{-1}, 148 ± 8 beats$\cdot$min^{-1} and 147 ± 8 beats$\cdot$min^{-1} respectively. Aerobic conditioning in the form of running-related activities accounted for 36%, 3% and 0% of training time during Pre-season, Mid-season and Late-Season respectively. During intensive pre-season training, the total time (min. week^{-1}) spent above 90% $H.R._{Max}$ was significantly greater than at any other period during the season.

An intermittent exercise protocol based on elite work-rate profiles was established by modifying an existing protocol to evaluate the physiological and metabolic responses to soccer-specific exercise (Aims 7 and 8). The protocol incorporates a simulation of the work-rate of matches and periodically includes a short all-out effort during which power output is recorded. This protocol was employed to investigate the effects of creatine supplementation on selected physiological and performance responses (Aim 9). Creatine supplementation had no effect on the physiological, metabolic and subjective responses or on performance during a model of intermittent exercise.

8.2 GENERAL DISCUSSION

The lines established within this thesis follow a logical path in their investigation of the demands of elite soccer. Firstly, an assessment of the playing requirements was made. This task involved analysis of the anthropometric and fitness characteristics of elite Premier League soccer players. Secondly, an investigation of the physiological strain imposed on players during match-play and training was undertaken. This involved analysis of work-rate profiles, heart rate responses and injury rates. Finally, an emphasis was placed on a laboratory simulation to supplement the data provided during match-play. Both the requirements of play and the physiological demands associated with match-play will be discussed. The issues arising from this overview will be considered in light of training regimens, injury rates, fitness profiles and laboratory simulations of match-play. This overview will provide a holistic picture of the demands of elite soccer per se.

Chapter 4 of the thesis aimed to elicit the physical characteristics of elite male soccer players. Limited current data were available regarding the anthropometric characteristics of elite Premier League soccer players. The data collected helped to clarify the inter-positional variation of characteristics related to body size and physical performance.

Individuals with a particular stature are oriented towards specific positions in the team. Goalkeepers and central defenders are the tallest, while the mean height for full-backs, midfield players and forwards are similar. It appears that players who occupy the central defensive areas of the game need to be tall in order to contest aerial possession of the ball whilst stature is not emphasised in other positions. A similar pattern of positional variation was observed for body mass. Goalkeepers and central defenders were the heaviest suggesting that a large body mass is beneficial to those players whose role is to prevent opponents from scoring. These results support the view that at an elite level, a relationship is observed between body size and tactical function. Moreover, the tactical role given to a player is related to individual anthropometric characteristics.

Body composition is an important aspect of suitability for soccer. Low adiposity and high muscularity are key characteristics of elite level soccer players. The mean values of elite soccer players (Chapter IV) for percent adiposity were relatively low (11.0 ± 1.8%). The systematic preparation of players as well as their dietary practices will have important implications for body composition. Furthermore, players with low adiposity are likely to be more mobile around the pitch. Estimation of muscle mass was obtained by using the equation of Martin et al. (1990). When muscle mass is expressed as a percent of body mass, the values are high (61.4 ± 2.4%) reflecting the tendency of elite players towards a high muscular make-up.

The muscular make-up of elite soccer players is evidenced in their somatotype. The physiques of the players represent a trend towards mesomorphy. Such a physique would be of benefit to a player in the performance of match activities. Tackling, jumping, kicking, turning and changing pace require forceful and explosive bursts of energy and are among the actions that can be related to the level of muscular development in the lower limbs. In addition, the musculature of the upper body could be employed in holding off opponents and shoulder-to-shoulder charging. Moreover, muscularity has been related to maintenance of a high overall work-rate throughout match-play, leading to a reduction in low-intensity recovery periods and a concomitant increase in the total distance covered. The implication of these observations is that in order to cope with the physical requirements for elite soccer match-play, it is important that players have a high level of muscularity.

Contemporary soccer players are characterised as lean and muscular. Body Mass Index (BMI) and body mass values are also rising amongst participants when compared with previous decades. This probably reflects the systematic preparation of contemporary soccer players with an increased emphasis on conditioning. A key consideration however, is where the selection process for the 'ideal' soccer athlete (tall, lean and muscular) will end, particularly given that professional clubs have started to place emphasis on the long-term development of its young players. While increased muscularity and body mass are beneficial in bodily contact situations, perhaps the shift in emphasis may be towards the training and selection of those players with superior aerobic power.

Analysis of fitness profiles demonstrates that soccer players constitute a relatively heterogeneous group. While elite players do not have an extraordinary capacity within any of the areas of physical performance, they nonetheless have a reasonably high level within all areas with marked individual differences. The mean values of $\dot{V}O_{2max}$ estimated for elite players are high, supporting the view that there is a large contribution from aerobic power when playing at the highest level. Midfield players have the highest $\dot{V}O_{2max}$ values, and goalkeepers and central defenders the lowest. In elite soccer, a high $\dot{V}O_{2max}$ does seem to be a hallmark of well-trained midfield players. The consistent observations of $\dot{V}O_{2max}$ values above 60 $ml.kg^{-1}$ min^{-1} implies a threshold below which a midfield player is unlikely to possess the physiological attributes for success in elite contemporary soccer. Central defenders, forwards and to a lesser extent full-backs may not need an extraordinary endurance capacity but must possess a moderately high $\dot{V}O_{2max}$ that will influence work-rate and critical involvement during match-play.

When compared with players from another football code, soccer players are broadly similar in fitness levels, except for sprint times over short distances. It seems that quickness over short distances and agility are the elements that characterise a uniqueness of soccer players and distinguish them from players in other codes. There is evidence of more passes, runs with the ball, dribbles and crosses in contemporary soccer compared with previous decades. An increase in these match-specific actions suggests a significant increase in the 'tempo' of games (Williams et al., 1999). In order to cope with these increased demands, it is important that the participants have high levels of speed, agility and muscular power. Two factors that interact to produce players capable of demonstrating the required physical attributes include recruitment and preparation.

There is now an increasing interest in identifying talented players with exceptional athletic abilities. The growing number of international players represented in the Premier League also exemplifies an emphasis on international recruitment. For participants to succeed in the game, they must possess adequate physical attributes that allow them to react quickly to continually changing game situations. With the 'tempo' of games increasing the search for appropriate players will become more systematic and may employ more readily the use of fitness profiles and sports science strategies. Where this search will end is uncertain, but what is clear, is that the game will continually evolve as a fast paced, fast moving spectacle.

Within the past two decades there has been a growth in research that is directly related to soccer. There is also a wider array of training manuals with emphasis on speed training, strength and power training and 'complex training' (Bangsbo, 1994c; Pearson 2001; Hoff and Helgerud, 2002). The net effect of this growth of literature is that the preparation for professional soccer players more readily involves the development of speed and explosive leg strength. Whilst the main uses of 'plyometric' and 'complex' training have been prompted by the growth of sport science support systems, power training has potential to optimise fitness levels and shift the boundaries of athletic performance.

Variations in speed performance were not only found between the football codes, but also within each code as inter-positional differences. Forwards were significantly faster over 0-5 m than central defenders and midfield players, reflecting a high reliance on force production over short distances to beat their markers. On this basis, quickness is an important determinant of match winning actions for forward players. In soccer, a self-selection of individuals into specific positional roles is apparent where individuals possess the appropriate fitness characteristics. A coach may also modify team formation and style of play to accommodate individuals according to physical attributes. Nevertheless, physical characteristics and work-rate profiles are inextricably linked. The forward's work-rate profile is characterised by sudden bursts of high-intensity activity in order to facilitate the creation of space or receive a pass from a team mate or to move on to a goal-scoring opportunity (Rienzi et al., 2000). Clearly, quickness when changing direction over a relatively short distance is a critical component necessary for successful performance.

Elite level soccer players may develop successful soccer strategies on the basis of their physical attributes. It may be that players who are not endowed with a large body size develop alternative skills on the basis of their physiological characteristics. Evidence for such a phenomenon was demonstrated in the intra-positional differences in anthropometric profiles and performance in field-based physiological tests. Within each group a large variation was observed for body size and performance on field-related tests. Whereas taller players demonstrate an advantage in jumping, shorter players may develop an advantage when the body must be rotated around an axis, such as turning away from opponents. That is, shorter players compete more readily with their taller counterparts by relying on their quickness and agility. Future research may focus on the relationship between stature and quickness over short distances. Moreover, practitioners involved in talent identification and youth development may focus on searching for tall, quick players and/or developing the movement characteristics of their tall players.

The relationship between physiological profiles and success in elite soccer has not yet been extensively investigated. Successful soccer performance is the result of a variety of independent factors. There is a need for individuals to possess a high degree of both anaerobic and aerobic fitness qualities. The failure to observe significant correlations between elite youth performance in field-tests and eventual success in soccer, may be due to the difficulty in examining such a relationship when there are so many other factors that may mask the relationship. Players may also develop technical, psychological and tactical coping strategies to counteract physical deficiencies. The relationship between physical characteristics and success in soccer is complex. However, it is possible that factors such as body size may prove to be an overriding indicator for those players already exposed to systematic training. Clearly, more research is required.

Chapter 5 of the thesis aimed to quantify the demands of soccer match-play and training. Motion analysis techniques were employed as the physiological demands of soccer are a function of the work-rate displayed during match-play. A primary finding of the investigation was that the total distance covered during match-play was dependent upon the position in the team. Whilst this specificity of positional role was outlined some years ago (Reilly and Thomas, 1976), it is equally as evident in the game played now. This specificity indicates that the individual contribution towards the total team effort is different amongst the different positions. Such differences are probably due to the tactical role assigned to individual players according to the team's playing formation. The physical characteristics of the individual players must also vary if they are to meet the demands placed upon them.

The greatest work-rate is imposed on midfield players due to the linking role they play between defence and attack, which requires more sustained running. On the other hand, the work-rate profile of central defenders demonstrates that these players are placed under less stress than other positions. The total distance covered for central defenders is lower and the relative amount of high-intensity running lower than players in other positions. The forward player's work-rate profile is associated with a larger contribution of anaerobic work than other positions. The forward player's profile is characterised by a greater percentage of the total distance covered sprinting and cruising than players in other positions. These high-intensity bouts are interspersed with low-intensity recovery that indicates a lack of direct involvement in the play.

A practical method to equalise inter-positional differences in work-rate profiles is to adopt the concept of 'Total football' into match tactics and training regimens. During the 1970's a version of 4-4-2 was developed in Holland. 'Total football', as it is known relies on the versatility of the players who play the system (Gray, 1999). First developed at Ajax under Rinus Michels, the system encourages players to switch positions constantly. Where once the player was strictly a forward, midfielder or a defender, in this system every player becomes an interchangeable part of a machine. If central defenders go forward with the ball, midfield players drop into their position. If a forward comes into defence to collect the ball a central defender advances into the forward role. Such a system has a fluid quality. 'Total football' is a redefinition of an individual player's work-rate profile. Such a system may also negate any of the observed differences between positions in fitness profiles.

The total distance covered during the first and second half of match-play was approximately 11 km. The activity during match-play consisted of 40% jogging, 36% walking, 9% cruising, 2% sprinting and 13% utility movements. High-intensity activities were the least frequently performed actions with sprinting and cruising accounting for 20 $\pm$ 10 and 74 $\pm$ 28 discrete bouts respectively. This figure represents a high-intensity bout of activity approximately every 60 s and a maximal effort every 4 min. These findings confirm that the energy demands of elite soccer match-play are predominantly aerobic in nature with only a small contribution coming from anaerobic sources. Such a profile underlines the requirement for players to develop a high degree of aerobic fitness.

The activity in games is executed more or less continuously as the rest pauses are infrequent and short in duration. Players perform about 1600 activities during the game, reflecting the highly intermittent nature of soccer. These results suggest that contemporary elite soccer players need to have a well-developed capacity to perform high-intensity actions repeatedly throughout the duration of 90 min. High levels of aerobic fitness are required to facilitate substrate replenishment between sprints and reduce the fatigue caused by regular changes in inertia due to the frequent calls for utility and other movements. In addition, training the ability to sustain repeated sprint activity should form an important part of any training programme and should be undertaken once a sound aerobic endurance level has been achieved.

It seems that work-rate in soccer increased with the establishment of the Premier League (Williams et al., 1999). It was relevant therefore to obtain current data on the circulatory strain during Premier League match-play. During competition, approximately 80% of the time was spent with a heart rate response greater than 85% of the individual maximal value. These figures reflect a high physiological demand during contemporary soccer. The high heart rate responses appear to conflict with the observation that only 5% of the time during match-play is spent in high-intensity activity. A similar response has been related to the increased physiological requirements associated with acceleration, deceleration and changing direction. In addition, the metabolic requirements associated with high-intensity activity cause oxygen uptake to be elevated during subsequent recovery periods and heart rates may remain high for prolonged periods of time. The high heart rate responses during soccer may also reflect the contact situations where players are required to maintain position against physical resistance from an opposition player. Such events were not included in the movement analysis but are likely to contribute to the demands of elite soccer.

There was considerable variation in the heart rate responses between the subjects. This difference may be related to the fitness levels of the subjects, variations in the intensity of games or the different positions of individual players. In general, the results suggest a higher overall intensity for midfield players and full-backs compared to central defenders and forwards. Central defenders and forwards work for short periods at high intensities, with prolonged periods of rest. As a consequence of their high-intensity work-rates, midfield players and full-backs maintained higher work-to-rest ratios than central defenders and forwards. Heart rate data for the moderate and low-intensity zones further indicate an overall lower degree of exertion for central defenders and forwards. This lower exertion reflects the more intermittent nature of central defensive and attacking play.

Developing a soccer-specific conditioning programme requires an understanding of the demands experienced by players during competition. Maximum benefits are obtained when the training stimulus mimics or overloads the physiological systems challenged in performance conditions. The observation of high aerobic demands during competition supports the adoption of training regimens that raise the aerobic fitness of soccer players to high levels. A high aerobic fitness will facilitate recovery from periods of high-intensity exercise during a game and allow players to undertake sprints more frequently. Soccer players with a high aerobic fitness can also be expected to spare glycogen during moderate intensity exercise due to an increased ability to utilise of free fatty acids. This glycogen sparing effect may help to reduce the decrement in work-rate during the later stages of competition, as fatigue associated with soccer-related exercise has been linked with glycogen depletion (Jacobs et al., 1982).

Results from chapter 5.3 demonstrate that the heart rate responses of players when training towards the end of the season were significantly lower than those during match-play. The intensity of training should be increased if it is to reflect more accurately that which occurs during competition. Drills likely to mimic the match-performance conditions include those that emphasise the ability to change direction quickly and repeatedly and those that demand the ability to maintain high-intensity movements for a sustained period. The kind of training must be allied to aerobic exercise. Small-sided games offer such an occasion.

During elite soccer-play a reduction in work-rate was observed towards the end of a match. This reduction in work-rate suggests that players tax their physiological capacities close to their limit during a soccer match. This phenomenon was reflected in a reduction in sprint activity, distance covered and heart rate responses towards the later stages of competition. An increased risk of injury was also noted towards the later stages of match-play. These observations indicate that at an elite level, the players' physical performance is reduced towards the end of a match. These effects were observed independent of position in the team. Cumulative fatigue, therefore, did not simply depend on distance covered as this measure varied according to positional role.

As soccer entails physical contact in combination with vigorous efforts, the risk of injury during competition is high. Strains, sprains and muscular contusions are an inherent component of participation due to their common occurrence. The incidence of injury can be representative of the stresses associated with the physiological and physical demands of the game. The higher injury frequency rate (IFR) during games compared to training reflects the greater exercise intensity during games. Injuries incurred were also specific to playing position. Forwards and wide midfield players sustained a greater relative proportion of hamstring strains than did players in other positions. These players are often involved in the critical phases of match-play where forceful and explosive actions are important characteristics of match winning actions. It is likely that many of the soft tissue injuries sustained by soccer players are attributable to the nature of the intermittent exercise with its frequent sudden decelerations, changes in direction and body contact situations. In this regard many types of injury will be common across the football codes. It follows that when there is a competitive search for elite players with greater body size, muscularity and anaerobic power, a higher intensity of exercise will prevail. This will inevitably result in increased ball and body momentum, a more intense and competitive style and greater-risk taking behaviour. These demands may lead to increased stresses in elite soccer players, placing them at greater risk of sustaining injuries.

The overall physiological strain for the soccer-specific exercise protocol was similar to that of match-play. The total distance covered during the intermittent protocol was in the order of 9-10 km. While these values are lower than those reported in Chapter V for elite soccer players, they are similar to the values reported for elite South American players (Rienzi et al., 2000). Moreover, the subjects who participated in the laboratory study were not elite soccer players. The mean heart rate response to the intermittent protocol demonstrated rhythmic fluctuations corresponding to changes in activity level. Mean heart responses to the intermittent protocol were similar to those reported for elite match-play and indicate that the intermittent protocol provokes a good representation of the cardiovascular demands of match-play. The slightly lower heart rates are probably a reflection of the omission of game skills and other unorthodox changes of direction. During the intermittent protocol, plasma lactate concentrations increased above pre-exercise values, consistent with values reported for soccer play (Gerish et al., 1988; Rhode and Esperson, 1988). These data underline that there is an anaerobic component to the energy demands of the intermittent protocol. Plasma glucose levels were maintained above resting concentrations throughout the intermittent protocol, as is the case during match-play. It therefore seems that the soccer-specific intermittent exercise protocol modelled on match-play can be used to investigate the physiological responses observed during a competitive game.

Dietary Cr supplementation at a rate of 20 $g.day^{-1}$ for 5 days had no effect on sprint performance or leg power during a laboratory-based protocol that reflects the heart rate responses and work-rate profiles observed during real match-play. Similarly no differences were observed in the physiological, metabolic and perceptual responses during or immediately after a model of intermittent exercise. These findings demonstrate that Cr supplementation does not assist players to cope better with the demands of soccer-specific intermittent exercise. For further improvement of performance capability, players may have to rely on optimising their training programme.

8.3 RECOMMENDATIONS FOR FUTURE RESEARCH

The lines established within this thesis provide an overview of the physiological requirements and demands of contemporary elite soccer. In achieving these aims, some issues have arisen and certain findings prompted the formulation of recommendations for further research.

Research proposals in response to the findings in Chapter 4:

(1) Physiological measures other than estimated oxygen uptake employed in Chapter 4.3 were not sensitive enough to distinguish between elite young players on the basis of eventual success. Further research employing a more extensive battery of tests and a greater sample population would be useful in attempting to identify physiological characteristics of successful players. The sample population could be further divided to elicit those characteristics associated with success in each of the discrete playing positions.

(2) The mean anthropometric data of elite English soccer teams have changed over the past three decades. Mean stature values for British soccer players (Williams et al., 1973) three decades ago were 1.74 ± 0.09 m compared to 1.81 ± 0.07 m in the subjects of the present thesis. Mean body mass values of British soccer players have also risen 10.3 kg over the past three decades, a change that equates to approximately 3.0 kg per decade. This trend probably reflects the systematic preparation of contemporary players as well as the effect of recruitment from overseas. Further research would be useful in determining the influence of international recruitment on reported mean values. Anthropometric data on international players could be compared with those born in the United Kingdom. Such data may provide information of use in recruitment from specific regions of the world based on anthropometric and physical characteristics.

Research proposals in response to the findings in Chapter 5:

(3) Significant differences were observed between positions in the total distance covered during match-play. Further research would be useful in determining if such discrepancies are the result of tactical roles assigned to individual players or a result of their physical capacities. Techniques of motion analysis could be used along with field-based physiological performance tests to establish in more detail the relationship between fitness characteristics, work-rate profiles and tactical roles.

(4) During elite soccer-play a reduction in work-rate was observed towards the end of a match. Further research would be useful in determining the effect of aerobic high-intensity training in delaying fatigue. Techniques of motion-analysis and heart rate responses could be used to determine the effect on soccer performance following a training intervention. Motion analysis may prove valuable in evaluating training interventions for improving soccer performance and have implications for prescription of training in elite players.

(5) Given that fatigue was observed towards the later stages of a competitive match and that recovery is essential when the next game is so soon, there is a need for more sophisticated analytical tools (e.g. functional magnetic resonance spectroscopy) to examine the time-course of recovery of energy substrate in muscle. Identifying optimal recovery may assist in reducing fatigue related injuries during heavy fixture periods.

(6) Heart rate response during training fluctuates over the course of the season with the lowest exercise intensities reported towards the later stages of the season. Further research into the seasonal variation of fitness levels would be useful in determining the effect of coaches 'scaling down' training. Such data would also provide important information on whether competitive match-play is sufficient stimulus to maintain fitness levels towards the later stages of the season.

Research proposals in response to the findings in Chapter 6:

(7) Components of somatotype interact in predisposing soccer participants to injury. While endomorphy was associated with injury, the predictive power was low, suggesting that other measures are needed. Further research employing a more extensive battery of tests would be useful in identifying intrinsic risk factors (e.g. peak torque, quadriceps: hamstring ratio, eccentric strength function and so on).

(8) The disproportionate number of running injuries sustained during training highlights the need to investigate further the incidence of non-contact injury and overtraining in elite youth soccer. Clearly, there is a need to investigate the training regimen of elite young players so that preventative and management strategies can be implemented.

Research proposals in response to the findings in Chapter 7:

(8) The inclusion of some of the specific match actions in the intermittent protocol, may lead to the laboratory based protocol possessing an even greater validity to soccer match-play. Moreover, there is a need for exercise models to replicate the physiological and cognitive stresses associated with match-play. The effects of match-play on cognitive performance could be presented via a soccer-specific virtual reality system.

(9) There was no difference in the physiological, metabolic or performance responses during a model of intermittent exercise following the ingestion of Cr. It would be of interest to determine the effects of other potential ergogenic aids i.e. caffeine, water and carbohydrate on performance during the intermittent exercise protocol.

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