The Development of a Soccer-Specific High-Intensity Intermittent Running Protocol

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A thesis submitted partially in fulfilment of the requirements for the Degree of Doctor of Philosophy (Liverpool John Moores University) following work undertaken at the Research Institute for Sport and Exercise Sciences

March 2007

Abstract

Recovery from high-intensity exercise in soccer is very important for players to be able to cope with the physical demands of match-play. Evaluation of soccer players ability to perform repeated high-intensity running should therefore be of particular importance to coaches. The aim of this thesis was to develop and apply a high-intensity intermittent running protocol where sub-maximal and maximal components of soccer-specific endurance could be assessed.

In Study 1 and Study 2, initial pilot work on the 15-50 protocol and then the 15-30 protocol, two high-intensity intermittent running protocols, were examined for reliability and physiological responses. It was reported that a large learning bias was present in both protocols reflected by performance improvements between trials. These improvements were supported by an improved running economy on the test. The physical load was higher in the maximal stage compared to the sub-maximal stage in both protocols with both aerobic and anaerobic energy production highly simulated as a result of a manipulation of the exercise and rest periods from the sub-maximal stage. It was concluded that several familiarisation sessions were needed on both protocols especially for recreational players to remove any learning bias. The structure of the 15-50 protocol may restrict its application to soccer and may be more suitable as an interval conditioning drill than as a test. The structure and the physiological responses in the 15-30 protocol make it a more practical assessment of soccer-specific endurance.

The relationship between the 15-30 protocol and physical performance during match-play, soccer-specific field test performances and aerobic endurance measurements in young professional soccer players was examined in Study 3. There was no relationship between any of the soccer-specific field tests and indices of physical performance during match-play. A significant correlation was reported between maximal oxygen consumption and distance covered in the maximal stage of the 15-30 protocol. No relationship was found between other standardised field tests used in soccer and the 15-30 protocol. It was concluded that physical performance during match-play is highly variable which makes evaluation of the physical capacity of soccer players very difficult. Maximal high-intensity exercise performance was highly influenced by maximal aerobic power. It is plausible that higher aerobic endurance would have facilitated a rapid recovery between high-intensity bouts in the maximal stage.

In Study 4 and Study 5, the sensitivity of the 15-30 protocol to pre-season and in-season training periods was investigated. The in-season training period consisted of weekly additional aerobic interval training. Expected improvements in performance were observed at the end of the six-week pre-season training period in both the 15-30 protocol and the Yo-Yo intermittent recovery test in young professional soccer players. Small increases in maximal oxygen consumption as well as a greater increase in 15-30 protocol performance were also reported after the in-season training. It was concluded that significant physiological adaptations can be obtained as a result of soccer-specific training periods during the season. The physiological adaptations are more likely to be attributed to peripheral factors than central factors.

A new unique high-intensity intermittent running protocol has been developed during these studies. The physiological mechanisms which govern test performance seem to be different from responses to other soccer-specific field tests. Evaluation of soccer-specific endurance performance is complex since physical performance is influenced by numerous variables.

Acknowledgements

I would like to thank my supervisors Professor Thomas Reilly and Dr Barry Drust for their constant support and guidance during the completion of my thesis.

I owe a huge thank you to my research collaborators in Sweden, Dr Paul Balsom at the Swedish Football Association and Helena Andersson at Örebro University for their co-operation especially during Study 1 and Study 2. Our discussions regarding the development of the protocols were always constructive and their input should be acknowledged.

I also express my gratitude to Centrum för Idrottsforskning (Centre for Sport Studies) in Stockholm who provided financial support during Study 1 and Study 2 of this thesis.

The team of laboratory technicians at the Research Institute for Sport and Exercise Sciences at Liverpool John Moores University including Dave Stokes, Robert Kennett, Andrew Hulton, Neil Chester, George Savage and Steve Wilson all provided valuable assistance at various stages during the completion of the thesis.

I am very grateful to Neil Clarke, Gunnar Petterson, Steve Jones, Stephen Gormal and Hugo Relvas for providing technical assistance in the filming of individual players.

I would also like to thank all the recreational players who volunteered as subjects at the Research Institute for Sport and Exercise Sciences at Liverpool John Moores University for their committed participation throughout Study 1 and Study 2.

There are several individuals whom I would like to acknowledge for allowing me to test high-calibre players in Sweden. I thank also Helena Andersson at Karlslund IF for assisting during the testing of elite female players and Kent Niklasson and Mats-Olof Lingersjö at Oskarshamns AIK in allowing me access to the semi-professional soccer players.

This thesis would not have been completed without the helpful assistance of all the coaches at the various clubs which allowed me access to professional soccer players. I wish to especially thank Les Parry and Shaun Garnett at Tranmere Rovers FC, Kevin Thelwell and Glyn Salmon, Derby County FC (previously at Preston North End FC), Paul Simpson, Billy Barr, Dennis Booth, Jamie Hoyland and Dean Ramsdale at Preston North End FC and last by Keith Hill and Paul Conway at Rochdale AFC.

Finally, I would like to thank my family in Sweden and my friends both in Sweden and England for their moral support throughout the completion of this thesis.

Declaration

I declare that the work presented in this thesis is entirely my own, with the exception of:

Some of the work reported in this thesis has already been presented as conference communications or published in international journals (see Appendix A).

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Chapter 1

General Introduction

1.0 General Introduction

1.1 Background

Soccer (association football) consists of an activity pattern where periods of high-intensity exercise are interspersed with periods of lower intensity exercise. This intermittent activity profile leads to a high aerobic and anaerobic energy turnover depending on the ratio of exercise and rest (Bangsbo, 1993a). There are periods during a match where the exercise intensity is either above or below the lactate threshold (Hoff, 2005). In order to sustain work rate during match-play, it is very important for players to be able to recover rapidly between high-intensity exercise bouts and thus delay the onset of fatigue. Mohr *et al.* (2003a) reported that the amount of high-intensity running is reduced towards the last 15 min of the match. This ability to perform repeated high-intensity exercise may also be referred to as soccer-specific endurance.

Soccer is a dynamic activity where the high-intensity exercise bouts occur frequently but randomly. However, the mean duration of a high-intensity bout during match-play bout is 2-4 s (Mayhew and Wenger, 1985; Bangsbo *et al.*, 1991; Mohr *et al.*, 2003a). The definition of high-intensity exercise varies between different studies, which has to be taken into consideration. For example, Bangsbo *et al.* (1991) defined high-intensity exercise as speeds >15 $km.h^{-1}$. The rest period after a bout of high-intensity exercise is variable, highly dependent on the players' positional role, physical capacity and direction of the ball. Due to this inherent unpredictability of soccer match-play, the challenge for players is to be able to recover rapidly from one high-speed bout and perform another bout with minimal rest (Bangsbo, 1993a). As a result, the players can perform more high-intensity bouts with minimal rest during the course of the match. During high-intensity intermittent exercise, there is an accumulation of various metabolites involved in anaerobic glycolysis (Ballor and Volvosek, 1992; Balsom *et al.*, 1992a; Bangsbo and Saltin, 1993). The speed of recovery and removal of these metabolites will depend on several factors including aerobic endurance capacity (Jansson *et al.*, 1990; Hamilton *et al.*, 1991). It is clear that physical performance during soccer, characterised by high-intensity intermittent exercise, is very complex and makes assessment very challenging.

Despite the difficulties in assessing physical performance in soccer, assessment of soccer-specific endurance is important. Data from performance tests can provide objective information on selection criteria, evaluate the effectiveness of training programmes, assess physical performance of new signings and monitor progress during injury rehabilitation (Balsom, 1994). The mode of assessment can take place both in the field or in the laboratory. Field testing may provide a more ecologically valid assessment whereas laboratory tests offer better sophisticated feedback on the players' physical status (Svensson and Drust, 2005). Field tests which evaluate players' physical capacity should where possible reflect the activity pattern observed in match-play. There has been a massive development in the design and implementation of field tests in soccer over the last few decades. Until recently, aerobic endurance performance in elite players was generally evaluated via field tests utilising a continuous activity pattern such as the 12-min Cooper run (Cooper, 1968) and the 20-m shuttle run (Ramsbottom *et al.*, 1988). However, intermittent field tests are more ecologically valid and offer a more specific assessment of endurance. The Yo-Yo tests (Bangsbo, 1993b), which have a progressive intermittent activity profile, have been the most popular field tests to assess elite soccer players in the last decade (Erith, 2004). Physical performance in high-intensity intermittent exercise such as soccer is dictated by a large number of variables. The tests described above may only evaluate some aspects of soccer-specific endurance. Although the Yo-Yo tests have been very popular to use for the evaluation of soccer-specific endurance, there should be further developments of other test protocols with a different structure and activity pattern.

A new prototype for a high-intensity running protocol has been developed based on the above rationale (Svensson and Drust, 2005). The prototype consists of intermittent high-speed runs at a fixed running speed separated into different exercise blocks. The duration of each high-speed run in the protocol is slightly longer than the average time (2 s) spent in high-speed running in match-play (Bangsbo *et al.*, 1991). It was decided that two seconds exercise is too brief for a protocol so the duration of the high-speed runs was longer. The distance of the high-speed runs would be manipulated so that they would resemble a running speed equivalent to high-speed running in match-play. Every other high-speed runs in the new protocol also include a turn at 180°. Furthermore, there is one short and one long rest period in between the high-speed runs to resemble the unpredictable activity pattern in soccer. The new protocol has been adapted from the typical activity pattern observed in match-play.

At the moment, no test protocol which assesses soccer-specific endurance has been developed where sub-maximal and maximal performance can be evaluated from separate components. Such a protocol would be very attractive for coaches as they would have the option of assessing sub-maximal or maximal capabilities. In the new protocol, sub-maximal performance can be evaluated at any time during the season even the day prior to a match since the aim is to limit energy demanding maximal exercise. Maximal performance can then be assessed in the second stage which is performed immediately after the sub-maximal stage. Performance is evaluated through heart rate measurements in Part 1 and distance covered in Part 2.

The aim of the new protocol is to be practical for coaches but in addition go through a rigorous research design. This thesis is based on the development of a new protocol. Initially, two protocols will be developed; the 15-50 protocol and the 15-30 protocol. Extensive pilot work and reliability assessment will aid in refining one protocol that would be suited for the application of assessment of soccer-specific endurance. This protocol has to undergo a carefully controlled scientific procedure which would involve thorough reliability and validity analysis as well as investigating the sensitivity to experimental interventions.

1.2 Aims

This thesis had an overall global aim and this aim was achieved through the completion of five studies. The overall aim of this thesis was to develop a high-intensity intermittent running protocol that can be used in the assessment of soccer-specific endurance.

This overall aim was achieved through the completion of a series of five studies. The first two studies of the thesis were performed to provide background and pilot work for the development of a soccer-specific protocol. The aim of the first two studies was to:

1) examine the reliability of two soccer-specific high-intensity intermittent running protocols- the 15-50 protocol and the 15-30 protocol in both male and female soccer players

The third study of the thesis explored the internal and external validity of the 15-30 protocol in professional youth soccer players. The aims of study 3 were to:

1) explore the relationship between the 15-30 protocol and standard measures of aerobic fitness.
2) examine the relationship between the 15-30 protocol and field tests used to assess soccer-specific endurance and estimated aerobic power.
3) investigate the relationship between the 15-30 protocol and physical performance during competitive soccer match-play.

The fourth and fifth studies of the thesis examined test performance during the 15-30 protocol in response to seasonal training interventions in both professional senior and youth soccer players. This section was split into two parts: pre-season and in-season training interventions. The aim of study 4 was to:

1) examine the sensitivity of the 15-30 protocol to a period of pre-season training in senior professional soccer players
2) examine the sensitivity of the 15-30 protocol and the Yo-Yo Intermittent Recovery test to a period of pre-season training in young professional soccer players.

The aims of study 5 were to:

1) examine the sensitivity of the 15-30 protocol to a period of aerobic interval training in-season.
2) investigate the sensitivity of maximal oxygen consumption to a six-week in-season aerobic interval training programme

Chapter 2

Review of the Literature

2.0 Review of the Literature

2.1 Introduction

This review aims to outline the physical demands of soccer by examining multiple factors. Furthermore, high-intensity intermittent exercise models in the laboratory and in the field will be reviewed to show the role of these models in informing the physiological mechanisms that support activity during soccer match-play. Finally, the rationale for physiological assessment of soccer players will be outlined, including a critical evaluation of soccer-specific fitness tests.

2.2 Physical Demands during Soccer Match-Play

2.2.1 Work-Rate

Soccer is an intermittent sport with an acyclic activity pattern. The acyclic activity pattern are characterised by high-intensity exercise periods (e.g. cruising and sprinting) interspersed with lower intensity recovery periods (e.g. jogging and walking). In order to determine the activity pattern and quantify work-rate indirectly through distance covered measurements, it is necessary to film individual players during match-play. Modern technology now allows distance covered to be determined accurately through either complex computerised models (Figueroa *et al.*, 2006) or by global positioning systems (Kirkendall *et al.*, 2003; Carling *et al.*, 2005). An example where activity patterns have been categorised from motion analysis is shown in Figure 2.1.

The total distance covered in a match for both male and female players ranges between 9-14 km (Reilly and Thomas, 1976; Ekblom, 1986a; Gerisch ***et al.***, 1988; Ohasi ***et al.***, 1988; Bangsbo ***et al.***, 1991; Bangsbo, 1994a; Riensi ***et al.***, 2000; Mohr ***et al.***, 2003a; Thatcher and Batterham, 2004; Krustrup ***et al.***, 2005). Distance covered is also reduced by 5-10% from the first to the second half as reported from the aforementioned studies. Such a decrease in distance covered may indicate a reduced exercise intensity and work rate in the second half compared to the first half. Midfield players cover a greater distance than forwards and defenders (Reilly and Thomas, 1976; Ekblom, 1986a; Yamanaka ***et al.***, 1988; Bangsbo ***et al.***, 1991; Rienzi ***et al.***, 2000). The tactical role of the midfielder requires linking defence and attack leading to longer periods of sustained running resulting in a greater distance covered (Bangsbo, 1992). Full-backs and attackers also undertake longer sprints than centre-backs and midfielders (Withers *et al.*, 1982; Barros *et al.*, 1999; Mohr *et al.*, 2003a). The total distance covered can be influenced by the team tactics, fitness levels, the opposition and environmental conditions. Each playing position has therefore a unique characteristic where the physical role is very demanding.

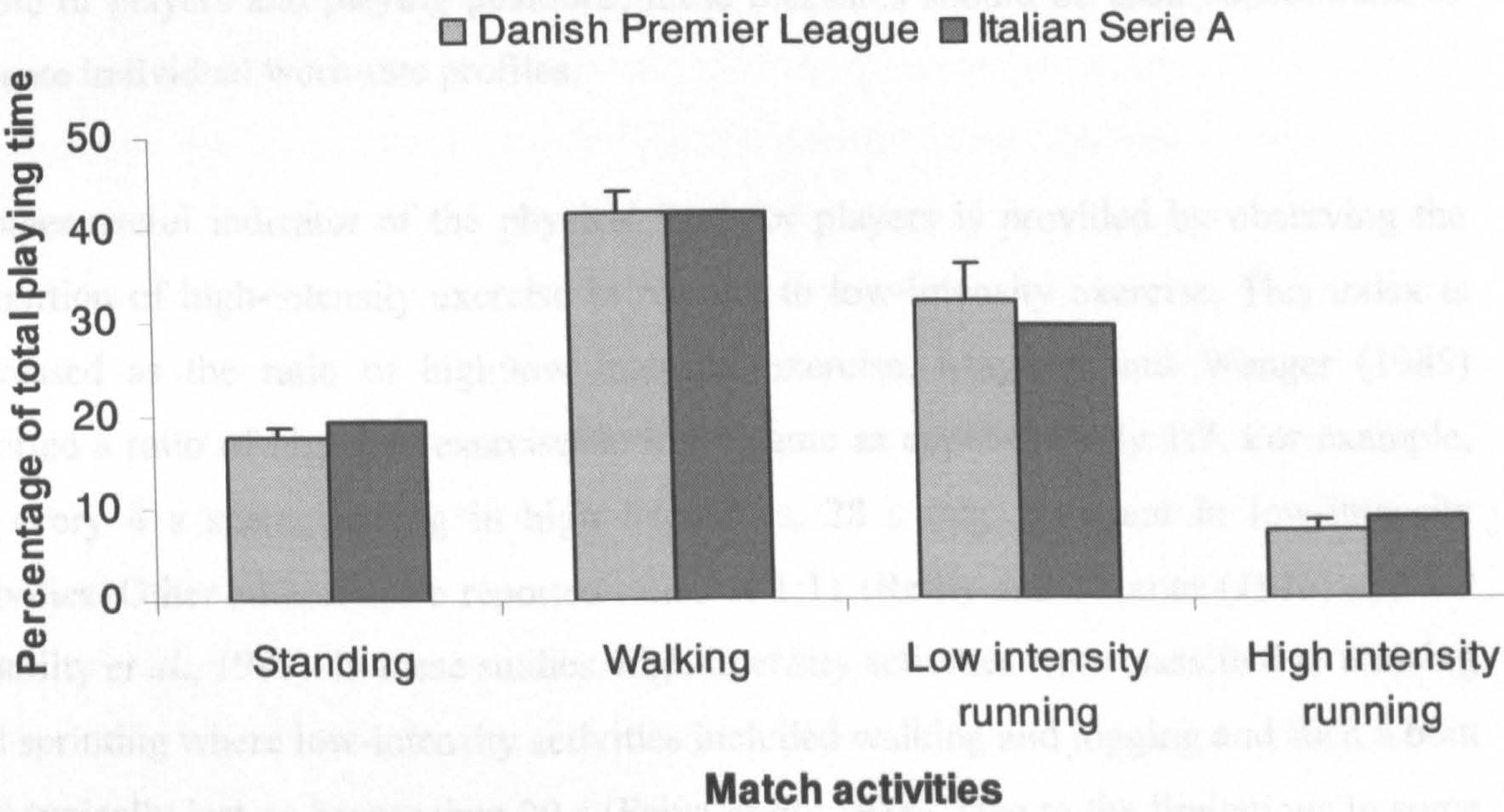


Figure 2.2.1. Example of the activity profile during soccer match-play between two calibre of professional players (data adapted from Bangsbo *et al.*, 1991 and Mohr *et al.*, 2003a with the mean of Danish Premier League players combined from these two studies). Low-intensity running encompassed jogging, low-speed running (12 $km.h^{-1}$) and backward running. High-intensity running consisted of moderate-speed running (15 $km.h^{-1}$), high-speed running (18 $km.h^{-1}$) and sprinting (25 $km.h^{-1}$).

The time spent in high-intensity running (high-speed running, sprinting) is very important as success in these activities often determines the outcome of a match. Typical values for high-intensity exercise in match-play range from 8% (van Gool *et al.*, 1988; Bangsbo *et al.*, 1991) to 11% (Reilly and Thomas, 1976; Mayhew and Wenger, 1985) of the total distance covered. The mean duration of high-intensity efforts is approximately 5-7 s (Bangsbo *et al.*, 1991) with the average duration of a sprint lasing 2-3 s or the equivalent of 10-20 m (Reilly and Thomas, 1976; Mohr *et al.*, 2003a). In Figure 2.2.1, the top-class players (Italian Serie A) spent more time in high-intensity exercise compared to the moderate-class players (Danish Premier League), which demonstrates the importance of such activities. Time spent in high-intensity exercise periods can also discriminate between professional and amateur players (Yamanaka *et al.*, 1988). The ability to perform high-intensity exercise does seem to be highly variable in elite soccer depending on the stage of the season (Krustrup *et al.*, 2003). Mohr *et al.* (2002) reported that aerobic power and exhaustive exercise performance was reduced towards the end of the season in Danish top league players compared to the start of the season. Since distance covered and especially the time spent in high-intensity exercise are sensitive to discriminate between calibre of players and playing positions, these measures should be used concomitant to evaluate individual work-rate profiles.

Another useful indicator of the physical load for players is provided by observing the proportion of high-intensity exercise in relation to low-intensity exercise. This index is expressed as the ratio of high:low intensity exercise. Mayhew and Wenger (1985) reported a ratio of high:low exercise during a game as approximately 1:7. For example, for every 4 s spent running in high intensities, 28 s may be spent in low-intensity activities. Other authors have reported ratios of 1:11 (Reilly and Thomas (1976) and 1:9 (Tumilty *et al.*, 1988). In these studies, high-intensity activities were classified as cruising and sprinting where low-intensity activities included walking and jogging and such a bout will typically last no longer than 20 s (Faina *et al.*, 1988). Due to the limitations in some of the methodologies used to classify specific match actions in these studies, the results may be misrepresentative and restrict comparison between studies.

The high:low intensity exercise ratio will be lower (i.e. recovery between high-intensity efforts is quicker leading to more bouts performed) for higher calibre players. The duration and frequency of high intensity exercise periods in match-play seem to be sensitive to training. Verheijen (2003) reported that there was an increase in the number of high-intensity periods performed during match-play following 3 months of preparation training for the 2002 World Cup in South Korean national team players. For an adequate training adaptation to occur resulting in more high-intensity bouts performed, there needs to be some form of overload stimuli in training. The only study where the number of repeated sprints has been quantified from match-play was performed by Spencer *et al.* (2005) in members of the Australian national field hockey team. They reported that 25% of all recovery periods was less than 21 s. The mean number of sprints within a repeated sprint bout was 4 ± 1 s and the mean recovery time was 14.9 ± 5.5 s from the games analysed. These findings can be related to soccer as field hockey has a similar activity pattern to soccer.

The activity pattern during a match is very unpredictable with players performing about 900-1000 changes in activity, for example jumping to head the ball, competing for possession, tackling and changing direction. This accounts for a change in activity approximately every 6 s (Reilly and Thomas, 1976; Yamanaka *et al.*, 1988). Observations from more recent studies have shown about 1500 changes in movement with a change of activity every 4 s (Rienzi *et al.*, 2000). It is difficult to evaluate the energy cost of such utility movements and activities directly in match situations due to the methodological issues associated with indirect estimations of work-rate discussed previously. Therefore, attempts to quantify the energy cost of activities such as dribbling, sideways and backwards running have been made in standardised conditions in the laboratory. Reilly and Ball (1984) reported that dribbling a soccer ball on the treadmill at different running speeds leads to an 8% higher energy cost compared to normal running at the same speeds. Other unorthodox movements include backward and sideways running (Reilly and Bowen, 1984). Even though a small proportion (~2%) of the total game time is spent in possession of the ball, it is clear dribbling activities are more energy demanding than running without the ball (Reilly, 2003). It is therefore important that players have a high soccer-specific fitness levels that enable them to be 'fresh' for when possession of the ball.

2.2.2 Factors Affecting Work-Rate

A player's work-rate during a match may be affected by factors such as the style of play and the environmental conditions. The style of play is directly influenced by the tactics selected by the coach and indirectly by the playing characteristics of the club and/or country (Reilly, 2000). For example, the characteristics of Latin and South American teams are the emphasis on possession and varied rhythmic changes in pace. In comparison, the British and Norwegian style of play has been characterised by direct play involving long passes, high pressure when retaining possession and pressuring opponents into mistakes often employing a 4-4-2 or a 4-5-1 formation (Bangsbo and Peitersen, 2000). The direct style of play is very physically demanding, which often results in a greater distance covered compared to the more rhythmic and possession style of play seen in South America, as observed by Rienzi *et al.* (2000). These findings seem to support the view that there are differences in work-rate during match-play between cultures.

Work-rate may also be restricted due to hot environmental conditions with a high humidity and ambient temperature (Kirkendall, 1993). Such conditions will lead to increases in core temperature, dehydration and an inability to dissipate heat through sweat production (Reilly, 2000). Loss of water from the body leads in turn to a decrease in plasma volume. As a result, physical performance during match-play may be affected as an impaired muscle circulation is associated with more rapid muscle glycogen depletion (Shephard, 1999). As reduced muscle glycogen has been associated with a reduced distance covered (Saltin, 1973) and time spent in high-intensity exercise (Balsom *et al.*, 1999a), it is reasonable to suggest that playing soccer in hot conditions may lead to reductions in work-rate. In order to combat the effects of a hot environmental conditions on physical performance, adequate hydration strategies before, during and after a match are essential (Rico-Sanz *et al.*, 1996).

2.2.3 Summary

Soccer is a complex intermittent activity, which is made up of several utility movements. Data from motion analysis can provide valuable information on distance covered and therefore indirectly quantify work-rate during a match. The time spent in high-intensity exercise during match-play can discriminate between different calibre of players and playing positions. A more useful indicator of soccer-specific fitness is to report the number of high-intensity exercise periods in match-play. However, in order to quantify work-rate directly, physiological responses during match-play have to be monitored.

2.3 Physiology of High-Intensity Intermittent Exercise (Soccer)

The physiology of soccer involving periods of high-intensity intermittent exercise is complex. Both the aerobic and anaerobic energy systems are activated during this type of exercise but the role of these energy systems in the exercise and recovery periods is not clear due to the complex and dynamic acyclic activity pattern of soccer. The lack of clarity in understanding the physiology of soccer may be due to the limited physiological information that can be obtained directly from match-play. Therefore, the aim of this section is to discuss different evaluation techniques (field- and laboratory-based) that are used to examine the physiological responses during soccer and high-intensity intermittent exercise.

2.3.1 Field Methods

As discussed in section 2.2, distance covered is an indirect measure of work-rate during match-play and provides no direct information on the physical demand of the activity. Therefore, coaches and practitioners have to use physiological measurements during the game to be able to quantify work rate directly. However, players are limited to what measurement devices they can wear during the game. Any device worn must be of minimal discomfort and interference to the players when performing complex movements such as tackling, heading and dribbling during the game. Measurements that can be performed continuously during the game are often limited to heart rate via short-range telemetry. Additional measurements can be performed intermittently during half-time or whenever there is a break in play (e.g. blood sampling and temperature measurements). Moreover, measurements are often restricted to lower calibre players (i.e. semi-professional, amateur and recreational). Monitoring of physiological responses of professional players during competitive matches is difficult as coaches are reluctant to allow any measurements to be performed. Some of the most common techniques used to evaluate the physical demand directly during soccer match-play will be discussed below.

2.3.1.1 Heart Rate

The use of heart rate measurements via short-range telemetry is one of the most simplistic methods to measure work-rate directly during a game. Modern short-range telemetry equipment is small and light, where the player wears a transmitter belt strapped around their chest. Wearing the belt causes minimal discomfort and has no interference when running and performing game-related activities. Information on heart rate data during match-play has often been limited to studies using low standard players or elite players during friendly rather than competitive matches. Heart rate values for male players during match-play typically range between 77-85% of HR_{peak} (Rohde and Espersen, 1988; Van Gool *et al.*, 1988; Krustrup *et al.*, 2003; Mohr *et al.*, 2004). Average heart rates in elite female players of 89-91% and 87% of HR_{peak} have been reported in Swedish (Brewer and Davies, 1994) and Danish (Krustrup *et al.*, 2005) players, respectively.

These results show that soccer is a predominantly aerobic sport where the exercise intensity is either above (accumulation of lactate) or below (removal of lactate) the lactate threshold (Hoff, 2005). The relative exercise intensity seems to be similar in professional and non-professional soccer but the absolute intensity is greater in professional soccer (Ekblom, 1986a). In the aforementioned studies, there was a trend for heart rate to be slightly lower in the second half compared to first half. Such observations may indicate a reduced work-rate in the second half compared to the first half, concomitant with earlier discussions on distance covered. It seems that training induced improvements in physical performance can be detected by monitoring heart rate during match play. Helgerud *et al.* (2001) reported that time spent in high-intensity zone (defined as >90% of HR_{peak}) was 19 min longer following 8 weeks of high-intensity training compared to pre-training.

2.3.1.2 Oxygen Uptake

Oxygen uptake in the field has been traditionally measured by using portable Douglas gas bags (~2-3 kg) or more recently by lightweight (~500 g) telemetric devices (i.e. Cosmed K2 and Cortex Metamax 3B). It is obvious that measuring oxygen uptake during match-play using these devices is not practical. In addition to the device's size and weight, the player has to wear a facemask which makes involvement in tackles, headers and other game activities more difficult. A limited number of studies have been conducted where oxygen uptake has been directly measured during match-play. Ogushi *et al.* (1993)

reported that the average oxygen uptake ($\dot{V}O_2$) measured with Douglas bags in 3-minute periods in two players during match-play ranged between 47-61% of maximal oxygen uptake ($\dot{V}O_{2max}$). Distance covered for the two players wearing the Douglas bag was 11% shorter compared to those who did not wear the device. The low oxygen uptake values may indicate that $\dot{V}O_2$ was underestimated and the reduced distance covered that physical performance was inhibited during the game (Stølen *et al.*, 2005). Such limitations may restrict the use of portable gas analysers to non-contact game simulations and other soccer-specific situations- for example fitness tests (Kemi *et al.*, 2003) and dribbling tracks (Kawakami *et al.*, 1992).

An alternative method to estimate the aerobic energy demand during match-play is to estimate oxygen uptake from heart rate measurements. This assumption is based on the linear relationship between heart rate and $\dot{V}O_2$ obtained from sub-maximal steady-state treadmill running in the laboratory (Bangsbo, 1994b). The energy expenditure during match-play has been estimated to be approximately 75% of $\dot{V}O_{2max}$ using this method (Ekblom, 1986a). It is important to consider that this relationship is only an estimation of $\dot{V}O_2$ which has been attained in standardised laboratory conditions. Several factors will also affect heart rate during a match leading to disassociations in the heart rate-oxygen uptake relationship including the discontinuous activity pattern in soccer, ambient temperature, environmental conditions and level of psychological arousal (Herd, 1991) from players (Ogushi *et al.*, 1993). Moreover, heart rate can also be elevated above the heart rate-oxygen uptake relationship during static isometric contractions and exercise with small muscle groups (Åstrand *et al.*, 2003). It is difficult to consider how much influence the latter two factors will have on the heart rate-$\dot{V}O_2$ curve in soccer. Oxygen uptake also remains elevated during recovery from a maximal sprint to restore metabolities ready for the next sprint (Bangsbo and Hellsten, 1998). As a result, heart rate may increase disproportionally to $\dot{V}O_2$ following a maximal sprint (Bangsbo, 1993a). In summary, heart rate measures during a match are practical to use and provide some basic information on the physical demand and work rate of individual players during match play.

2.3.1.3 Blood Lactate

Where heart rate measurements may be used as a broad indicator of aerobic energy production, blood lactate measures provide some information of the anaerobic energy production during match-play. Lactate concentration can be determined either from instant analysis of a blood sample using a portable device such as the Lactate Pro (Pyne *et al.*, 2000; McNaughton *et al.*, 2002; van Someren *et al*, 2005) or where the blood is stored in ice-cold water for analysis in the laboratory. Blood sampling is limited to periods where there is a stop in play or at set pre-determined intervals during the game (pre-game, half-time, post- game). Typical values reported in match-play range from 4-7 $mmol.l^{-1}$ (Ekblom, 1986a; Gerisch *et al.*, 1988; Smith *et al.*, 1993; Bangsbo, 1994a). Lactate concentration also seems to be lower at the end of the match compared to the end of the first half (Rohde and Espersen, 1988; Gerisch *et al.*, 1988; Bangsbo *et al.*, 1991; Bangsbo, 1994a). These results mirror the observations for distance covered and heart rate where work-rate is reduced in the second half as described elsewhere. Higher blood lactate concentrations have also been reported during man-to-man marking compared to zonal marking indicating that lactate measurements may be sensitive to gross tactical dispositions (Gerisch *et al.*, 1988).

It is important to consider that blood lactate concentration will only reflect the activity immediately preceding the measurement (Bangsbo *et al.*, 1991). There are situations where lactate concentration will be high (e.g. after a sprint or high-intensity activity) or low (e.g. during recovery periods of jogging and/or walking). Consequently, there can be large variations when several lactate measurements have been taken during the same match (Ekblom, 1986). From the evidence of these results, a single blood lactate measurement cannot be representative of lactate production for the entire match (Bangsbo, 1994b).

The lactate concentration measured from the blood will underestimate the lactate produced in the muscles. Jacobs and Kaijser (1982) and Tesch *et al.* (1982) reported that lactate concentrations were twice as high in the muscle compared to the blood during incremental cycle ergometer exercise. When analysing any lactate data from match-play the factors discussed above must be taken into consideration. In summary, blood lactate measurements may provide a rough quantification of the anaerobic lactic energy production during soccer if the activity immediately preceding the blood sample is taken into consideration.

2.3.1.4 Blood Metabolites

Aside from blood lactate several other key metabolites can be determined from a blood sample. An indication of the energy provision during match-play as well as information on the level of physical stress during a match can be obtained. Blood glucose increases during the initial parts of a match and remains elevated above resting levels (Ekblom, 1986a; Bangsbo, 1993a). There is an increase in the blood free-fatty acid (FFA) concentration in the second half of matches. This increase in FFA mobilisation may be a result of more low-intensity exercise and rest periods as well as an hormonal increase (Krusrup *et al.*, 2006a). Hormanal responses to soccer matches have been reported by several authors. Carli *et al.* (1986) reported increases in the hormones prolactin and cortisol after the first half in Italian semi-professional players following a friendly match. Malm *et al.* (2004) also reported changes in hormones such as testosterone and cortisol in elite Swedish youth players after a competitive match. These results indicate that there is a high level of physical and psychological stress following a soccer match leading to an increase in the activity of these hormones. High levels of blood ammonia have also been reported in match-play which is evidence that the muscles produce ammonia (Bangsbo, 1994b). The same author also found elevated levels of hypoxanthine during a match. High hypoxanthine levels confirm that adenine nucleotides such as the adenosine monophosphate (AMP) and inosine monophosphate (IMP) reactions to produce adenonise triphosphate (ATP) are activated for energy production during a soccer match.

2.3.1.5 Temperature

Temperature measurements during soccer match-play can provide information about the thermoregulatory responses and energy expenditure during a game (Reilly, 1997). Measurement techniques for the assessment of core body temperature include oesophageal probe, rectal probe or swallowing an intestinal pill. Measurement periods during a game using the former two techniques will be restricted due to the invasive procedure of these techniques. Average rectal temperatures of about 39°C at half-time and at the end of matches have been reported in recreational players using rectal probe measurements (Andersson *et al.*, 1983; Ekblom, 1986a; Mohr *et al.*, 2004). The intestinal pill is a non-invasive technique which enables core temperature to be recorded continuously throughout the game. In the only study where this technique has been used, there was a progressive increase in core temperature during match-play in male university players (Edwards and Clark, 2006). Core temperature was also measured in a cohort of English professional players in the same study but measurements were restricted to before the game, at half-time and after the game. The results showed a similar trend found compared to the university players with the highest core temperature recorded after the match.

In soccer players, muscle temperature is most commonly measured from the *vastus lateralis* muscle with a needle thermistor. In comparison to core temperature, assessment of muscle temperature is more practical where a player only have to be taken out of the game only for a short period (~1 min). Mohr *et al.* (2004) reported that the muscle temperature was 39.5°C and 39.2°C at the end of the first and second half respectively in Danish Fourth Division players. Muscle temperature also decreased by 1.7°C at the end of the first half and after 15 min of half-time. A similar drop (0.9°C) in muscle temperature at half-time has also been reported in elite assistant referees (Krustrup *et al.*, 2002). In addition, Mohr *et al.* (2004) demonstrated that muscle temperature could be better maintained at half-time and sprint performance was improved at the start of the second half following a re-warm-up at half-time.

Core and muscle temperature measurements in soccer reveal that the energy expenditure and physical demand are high throughout the game. Moreover, by measuring core and muscle temperature at half-time, marked decreases of both of these parameters have been reported following the half-time interval. The authors recommended that coaches should therefore consider introducing a further warm-up strategy at half-time to prevent any deterioration of physical performance at the start of the second half.

2.3.1.6 Muscle Biopsies

Muscle biopsies provide more detailed and specific information on the metabolic events that occur at muscle level during a soccer match. The obvious limitation with this procedure is the discomfort to the players and the muscle damage caused by the procedure which may restrict running. Therefore, it is very difficult to obtain muscle biopsy samples from professional soccer players during competitive matches or practice games, as coaches are reluctant to allow such invasive measurements to be performed.

Only a limited number of studies have been conducted where muscle biopsies have been taken in real soccer match-play.

In a classic study by Saltin (1973), muscle biopsies were taken from the *vastus lateralis* muscle in Swedish players (calibre of players not known) before and after a simulated friendly match to determine muscle glycogen concentration. One group consumed a normal diet 24 hours prior to the match and the other group performed exhaustive exercise followed by a low carbohydrate diet the day before the match. The players with the reduced carbohydrate intake covered 25% less distance, performed fewer sprints and had almost no glycogen left in their thigh muscles after the match. Krustrup *et al.* (2003) also reported that muscle glycogen decreased by 46% from rest compared to after a friendly match in Danish fourth division players. Muscle lactate levels were 4-fold higher when biopsies where taken after an intense exercise period compared to resting values. Recently, Krustrup *et al.* (2006a) also found significant decreases in muscle glycogen, lactate, PCr at the end of a friendly soccer match in Danish fourth division players. The major disadvantage with these studies is that the calibre of players are of a low standard and the matches were friendlies rather than competitive.

Muscle biopsies were obtained from professional soccer players in-season by Jacobs *et al.* (1982) of a Swedish Premier League team- Malmö FF. Samples were taken from the *vastus lateralis* muscle immediately after a competitive league match and on the next two consecutive days to determine muscle glycogen concentration. Muscle glycogen levels immediately after the match were only 63% of the 'filled' values obtained two days after the match. No biopsies were taken the day before the match. The results from the aforementioned studies have shown that muscle biopsies can provide valuable information on the muscle metabolite changes and energy production during soccer match-play. Such data could also be used to educate coaches and players about the complex physiological demands of soccer and the importance of correct nutrition.

2.3.1.7. Summary

The physiological measurements that could be performed during soccer matches are limited due to restricted access to players and the impracticality of some measurement techniques. Although physiological data from match-play provide gross assumptions of the aerobic and anaerobic energy demand during a match, it is likely to be masked by the physiological mechanisms that regulate this type of work. The quality of data collected may also be influenced by environmental conditions, nature of the game and the coach's permission to perform invasive measurements. The limitations associated with field based physiological measurements during match-play have lead to a rich number of studies investigating the physiological responses to high-intensity intermittent exercise in the laboratory.

2.4 Laboratory-Based Simulations

The problems associated with quantifying the physical demands of soccer in-game have been illustrated in section 2.3. Sport scientists can use intermittent exercise models in the laboratory that mimic the activity profile of soccer. Assessment in a laboratory presents an environment where the exercise intensity can be controlled, environmental conditions are standardised and more physiological measurements can be taken compared to match-play.

2.4.1 Shuttle Tests

Laboratory shuttle tests are a useful non-contact simulation of soccer match-play. One of the most popular simulations is the Loughborough Intermittent Shuttle Test (LIST) developed by Nicholas *et al.* (2000). The test consists of two parts- Part A and Part B. The activity pattern of the test involves intermittent shuttle running between two lines 20-m apart at various pre-determined speeds. The speeds are related to the individuals' $\dot{V}O_{2max}$ values from a 20-m shuttle run (Ramsbottom *et al.*, 1988). In Part A, one exercise block consists of periods of walking, sprinting, standing and running at speeds corresponding to 55% and 95% of individual $\dot{V}O_{2max}$. In total, 5 exercise blocks are performed in Part A interspersed with recovery periods of 3 min between blocks. Part B consists of repeated intermittent shuttle running at speeds corresponding to 55% and 95% of $\dot{V}O_{2max}$ alternating every 20 m. The total duration of the test (Part A + Part B) is about 90 minutes.

The LIST has shown to have acceptable reproducibility (Nicholas *et al.*, 2000) and is sensitive to experimental interventions (Nicholas *et al.*, 1995; Gleeson *et al.*, 1998; Bishop *et al.*, 1999; McGregor *et al.*, 1999; Sunderland and Nevill, 2005) and training

(Siegler *et al.*, 2003). Performance on the LIST also seems to be affected by environmental conditions as total distance covered was reduced by 21% (Morris *et al.*, 1998) in males and 25% (Morris *et al.*, 2000) in females when performing in a hot (30°C) and normal (16°C and 20°C) environmental conditions respectively. During Part A of the LIST the mean heart rate was 167 beats.min^{-1}, $\dot{V}O_2$ was 2.67 l.min^{-1} (70% of $\dot{V}O_{2max}$) and average blood lactate concentration during the test was 5.7 mmol.l^{-1} (Nicholas *et al.*, 2000). It is clear from these results that the LIST is a predominantly aerobic test with situations where the anaerobic contribution is high. These values correspond closely with those reported during soccer match-play. One major limitation with the LIST is that only one player can perform the test at any one time.

A modified LIST protocol was developed by Edwards *et al.* (2003) where the number of blocks was reduced from 5 to 3 and the running speeds was averaged and not individualised. The authors found significant differences in test performance between professional and recreational players. An average running speed used by Edwards *et al.* (2003) instead of an individualised running speed used in the LIST may be more advantageous and practical if several players are to be tested at the same time. Other soccer-specific laboratory shuttle tests include the JRS fatigue test (Rico-Sanz *et al.*, 1999) and the 'field test' (Cox *et al.*, 2002). Neither of these tests has been examined for reliability so it is difficult to evaluate their effectiveness for regular use.

Shuttle tests in general and the LIST in particular are excellent to use for fitness training purposes or to examine the effect of experimental interventions as they closely resemble the activity pattern in soccer. However, such tests do not assess soccer-specific fitness *per se* nor can it be used to predict physical performance during a match.

2.4.2 Soccer-Specific Treadmill Simulations

The activity pattern of soccer can be accurately reproduced using both motorised and non-motorised treadmills. The problems associated with motorised treadmill are the loss of the rapid acceleration and deceleration phases that is typical for soccer match-play. Therefore the non-motorised treadmill offers a more valid and realistic milieu to perform match-specific activities where the running speed is dictated by the subject. Drust *et al.* (2000) created a non-motorised treadmill protocol using five general categories - standing (0 km.h^{-1}) walking (6 km.h^{-1}), jogging (12 km.h^{-1}), cruising (15 km.h^{-1}) and sprinting (21 km.h^{-1}). The pattern and duration of these activities were based on the activity pattern observed during soccer match-play (i.e. a sprint followed by low-intensity running or walking). The activities were then sequenced to resemble the intermittent acyclic nature of soccer (e.g. a high-intensity activity followed by a low-intensity activity) with a total duration of 23 min. The protocol was completed twice to resemble one half (46 min). Mean heart rate during the protocol was 168 ± 10 beats.min^{-1} and the oxygen consumption 2.8 ± 0.3 l.min^{-1}. Similar findings have been reported by Thatcher and Batterham (2004) who designed a similar soccer-specific simulation on a non-motorised treadmill. Physiological responses during the protocol included heart rate equating to 83% of HR_{peak}, $\dot{V}O_2$ corresponding to 70 ± 3% of $\dot{V}O_{2max}$ and a blood lactate concentration of 5.4 ± 1.2 mmol.l^{-1} and 4.7 ± 1.3 mmol.l^{-1} in the first and second half respectively. The physiological responses during these treadmill simulations closely resembled that observed during soccer match-play.

Bangsbo and Lindqvist (1992) developed an interval test on a motorised treadmill where the activity pattern was independent of match observations. The interval test consisted of two parts-Part A and Part B. In Part A, the treadmill speed alternated between 8 different speeds from 0-25 km.h^{-1}. The duration of the test was 35 min after which Part B began where the running speed alternated between 8 km.h^{-1} for 10 s and 15 km.h^{-1} for 15 s until exhaustion. The $\dot{V}O_2$ corresponded to 56% of $\dot{V}O_{2max}$ during Part A and 80% of $\dot{V}O_{2max}$ during Part B respectively. There was a non-significant correlation (0.70) between distance covered in the interval test and the high-intensity distance observed in match-play. Even though the protocol does not exactly resemble the activity pattern during a match, the 8 running speeds encompass the locomotor activities typically observed in soccer.

As with laboratory shuttle tests, treadmill simulations can be used to implement various experimental interventions and examine the physiological responses during intermittent exercise. However, there is a limit to what match activities that can be incorporated on a treadmill simulation with omission of activities such as dribbling, backwards and sideways running which may underestimate the total energy cost of real match-play. There is also no direct indicator of performance or soccer-specific fitness unless repeated trials are performed. The data collection process is also very time-consuming as usually only person can be tested at any one time. Treadmill simulations only offer limited information on the physiological responses during high-intensity intermittent exercise. More specific models that resemble high-intensity exercise activity have to be used to achieve this objective.

2.4.3 One-Legged Models

The advantage of using one-legged models is that these models may provide a more accurate indication of the energy provision during high-intensity exercise. During whole-body exercise, the total energy turnover may be underestimated due to the lag-time in the release of blood metabolites from muscle (Bangsbo, 1996). As a result, the energy contribution of the active muscle may be misrepresented. During one-legged exercise, the exercise can be confined to the quadriceps muscle (Andersen *et al.*, 1985). This allows measurement of blood flow to the exercising muscle and venous blood that is drained from the muscle can also be collected (Bangsbo, 1996). Examples of one-legged exercise models include the knee-extensor exercise (Andersen *et al.*, 1985), one-legged cycle ergometer (Saltin *et al.*, 1976) and the isometric chair (Sahlin and Ren, 1989).

The isometric chair has been the traditional method to use when studying isolated exercising muscle. This procedure involves the subjects seated in an isometric chair and performing repeated contractions starting from 90° to 180°. Isometric contractions provide information on the quadriceps muscle's maximal voluntary contraction (MVC), force-velocity properties (Thorstensson *et al.*, 1976), mechanical efficiency (Edwards *et al.*, 1975), fibre recruitment (Essén and Häggmark, 1975), recovery mechanisms (Sahlin and Ren, 1989) and the physiology of fatigue (Edwards *et al.*, 1972). Synonymous with these studies was that the rate of force development was lower for each bout with repeated contractions.

More recently, the one-legged knee-extensor exercise model was developed as an alternative method to the isometric chair (Andersen *et al.*, 1985). The subjects either sit in a supine or seated position where a rod is attached to the foot. Exercise is performed by executing a knee extension movement moving the knee from a 90° to a 170° angle pulling against a resistance from the cycle ergometer. The advantage of using this model is that the resistance can be manipulated accordingly and the model can also be adjusted to perform isometric exercise. The knee-extensor model has been used in several studies where the subjects have performed repeated intense exercise to investigate the energy demands of this type of exercise. Bangsbo *et al.* (1992a and b) reported that time to exhaustion was reduced when a second exhaustive exercise bout was performed either a short (2.5 min) or long (1 h) time after high-intensity intermittent exercise. Other studies have demonstrated that anaerobic energy production is reduced when intense exercise is repeated leading to an increase in the mechanical efficiency (Bangsbo *et al.*, 1990; Krustrup *et al.*, 2001). Repeated knee-extensor exercise also increases the levels of hypoxanthine in blood (Bangsbo *et al.*, 1992a). The knee-extensor model also seems to be sensitive to investigate the physiological and metabolic effects of high-intensity intermittent training (Nordsberg *et al.*, 2003; Krustrup *et al.*, 2004).

The isometric chair and knee-extensor models are excellent for confining the exercise to an isolated muscle and to investigate the physiology of repeated intense exercise. Some of the findings may be applied to soccer especially understanding the physical demands of the exercise and causes of muscle fatigue. However, the model is limited to use in the laboratory and the exercise mode itself has little resemblance to soccer. To increase the application to soccer, laboratory models should incorporate a more specific exercise mode.

2.4.4 Intermittent Exercise Protocols

As stated elsewhere in this section, the ability to perform and recover from high-intensity exercise in soccer is related to the quality of play (Bangsbo, 1992). Therefore, it seems logical to investigate the physiological mechanisms that govern soccer-specific endurance i.e. the ability to recover from high-intensity exercise. This component can be examined in laboratory or field settings from either prolonged high-intensity intermittent exercise protocols or repeated sprint protocols. It is important to distinguish between these two protocols as in prolonged intermittent protocols, typically, the exercise bouts are >10 s, long recovery periods (>30 s), an exercise intensity below $\dot{V}O_{2max}$ and a total duration of >30 min. In repeated sprint protocols, the duration of each exercise bout is normally <10 s, an exercise intensity at or above $\dot{V}O_{2max}$ (i.e. supramaximal) and a total duration <10 min. The intermittent activity pattern in both of these types of protocols is the closest resemblance to multiple sprint sports such as soccer that can be reproduced either in the laboratory or in the field, especially at a high intensity. However, only recently has there been a lot of attention to develop such protocols which are discussed in the next sections.

2.4.4.1 Prolonged Intermittent Exercise Protocols

Prolonged high-intensity intermittent exercise may provide some resemblance to soccer. Christmass *et al.* (1999 and 2001) reported that an exercise protocol consisting of 24-s exercise periods and 36-s rest periods (24:36) produced significantly different physiological responses than a protocol with 6-s exercise periods and 9-s rest periods (6:9). Carbohydrate oxidation was higher and fat oxidation was lower in the 24:36 exercise protocol compared to the 6:9 protocol. The exercise intensity corresponded to 68 ± 2.7% and 73.8 ± 2.8% of $\dot{V}O_{2max}$ in the 24:36 and 6:9 protocols respectively (Christmass *et al.*, 1999; 2001). However, Price and Halabi (2005) showed that the 6:9 protocol elicited a lower lactate and carbohydrate utilisation compared to a medium (12:18) and long (24:36) exercise protocol. Each protocol was 40 min in duration and the exercise intensity corresponded to 120% of $\dot{V}O_{2max}$.

Drust *et al.* (2005) used an exercise protocol consisting of 15-s exercise periods and 15-s rest periods on the cycle ergometer at an intensity corresponding to 60% of $\dot{V}O_{2max}$ lasting 40 min. Glycogen concentration from the *vastus lateralis* muscle decreased by 28% at the end of the intermittent exercise protocol compared to resting values. Bangsbo *et al.* (1992b) also reported that the time to fatigue on an intermittent treadmill test consisting of 15-s exercise bouts with 10-s intervals was greater following a high carbohydrate diet compared to a low carbohydrate diet. Similar findings were reported by Balsom *et al.* (1999a) during a prolonged high-intensity intermittent exercise protocol on a cycle ergometer. It is very important to consider the exercise:rest ratio as well as the exercise intensity for the protocols. The pattern of fuel use is also different where there is an increased fat oxidation in the longer exercise protocols.

Long-term intermittent exercise protocols can produce good information on the physiological and metabolic responses to the activity. However, such protocols do not provide any information on the ability to recover from repeated short high-intensity exercise bouts *per se*. Such information would be more relevant to soccer where the high-intensity bouts during match-play rarely exceeds 10 s. Another limitation is that the intermittent protocols and exercise intensities will vary between studies making comparisons difficult.

2.4.4.2 Repeated Sprint Protocols

There has been a lot of interest in the development of protocols that investigate the physiological responses and performance aspects of repeated sprint exercise (Dawson *et al.*, 1993; Balsom et al., 1994a and b; Aziz *et al.*, 2000; Bishop and Spencer, 2004). One of the most frequently used protocols in the literature consists of ten 6-s supramaximal sprints interspersed with 30-s passive recovery periods (6:30 protocol). The relevance of using 6-s maximal sprints to investigate the physiological demands of soccer may be questioned as sprints in match-play normally last no longer than 4 s as discussed in section 2.1. However, at present these repeated sprint protocols are the most relevant ones used in the literature to describe the physiology of repeated sprints or high-intensity intermittent exercise. All of the studies described below have utilised this protocol on a cycle ergometer unless stated.

Gaitanos *et al.* (1993) reported that 49.6% of the total energy production was derived from phosphocreatine (PCr) and 44.1% was derived from glycolysis taken from the *vastus lateralis* muscle after the first sprint of ten using the 6:30 protocol. After sprint 5, blood lactate concentration had increased from 0.6 ± 0.1 $mmol.l^{-1}$ at rest to 9.2 ± 1.5 $mmol.l^{-1}$. After sprint 10, the PCr contribution to energy production was 80.1% and glycolysis 16.1%. These results shows that 30 s is sufficient to restore muscle PCr concentration as PCr was the largest energy contributor in sprint 10. The 6:30 protocol was also used by Balsom and colleagues in three key studies that examined the physiological mechanisms involved in repeated sprint work. Balsom *et al.* (1994b) reported significant decrements in performance (lower power output, reduced oxygen consumption and increased blood lactate concentration) in a hypoxic condition compared to normoxia. Balsom *et al.* (1993) also showed that creatine supplementation improved performance using the same repeated sprint model compared to a control condition. The creatine supplementation resulted in a higher pedal rate, lower blood lactate and hypoxanthine concentrations compared to the control condition. The former study shows the importance of oxygen availability from aerobic glycolysis during exercise and recovery periods. The latter study shows how creatine supplementation can improve creatine resynthesis and availability during high-intensity intermittent exercise.

Finally, Balsom *et al.* (1999a) investigated the effects of muscle glycogen availability on performance during fifteen 6-s exercise bouts with 30-s recovery periods until exhaustion following a high and low carbohydrate diet. Power output for the final four bouts was lower in the low carbohydrate condition compared to the high carbohydrate condition. The repeated sprint protocol described above has also been used on a non-motorised treadmill (Gaitanos *et al.*, 1991; Hamilton *et al.*, 1991). This information can be related to a soccer context to understand what events occur in the recovery periods during both training and match. Despite all of the useful information that can be obtained from repeated sprint models in the laboratory, protocols in the field provide a more soccer-specific milieu.

Repeated sprint protocols in the field often consist of over-ground sprints performed on a running track. Balsom *et al.* (1992a) reported that performance during fifteen repeated sprints of 15, 30 or 40 m with a 30-s rest period between sprints was significantly influenced by sprint distance. Blood lactate (mean±SEM) was higher after the last sprint in the 30-m (13.9 ± 1.9 $mmol.l^{-1}$) and 40-m (16.8 ± 1.1 $mmol.l^{-1}$) sprints compared to the 15-m sprint (6.8 ± 1.5 $mmol.l^{-1}$). There was also a reduction in the adenine nucleotide pool after the third 40-m sprint resulting in a reduced ATP resynthesis. The same research group also investigated the effect of different recovery durations (120-s, 60-s and 30-s) on performance during repeated overground (15 x 40 m) sprints (Balsom *et al.*, 1992b). A significantly higher blood lactate concentration was found after the 30-s (17.2 ± 7 $mmol.l^{-1}$) recovery period compared to the 60-s (13.9 ± 1.2 $mmol.l^{-1}$) or 120-s recovery periods (12.1 ± 1.3 $mmol.l^{-1}$). Oxygen uptake during the recovery periods was equivalent to 52% (120-s), 57% (60-s) and 66% (30-s) of $\dot{V}O_{2max}$. The shorter recovery period produced a greater physiological stress and an increase in sprinting speed.

These studies demonstrate that sprint distance and the duration of the recovery period will significantly influence the physiological responses and the ability to sustain performance during repeated overground sprints. The concept of understanding the consequences to performance of the length of sprint and recovery periods may be applied to soccer either for programming overload stimulus for training or relating the findings to match-play.

2.4.5 Synopsis of the Physiology of High-Intensity Intermittent Exercise

The previous sections have attempted to present some of the methods used to investigate the physiological responses of soccer-specific high-intensity intermittent exercise. Clearly, this type of activity is very complex. There is no strict definition of the relative contribution of each energy system depending on the intensity of the exercise etc. Therefore, the physiological characteristics of this type of exercise are unique where the anaerobic and aerobic energy contributions are juxtaposed. The complexity of high-intensity intermittent exercise is further enlightened in comparison to continuous sports such as endurance running or cycling where the physiological demands are clearer. To have a good understanding of the energy demands of high-intensity intermittent exercise, it is useful to compare the physiology of single *vs* repeated sprints.

During a single maximal sprint, the majority of the energy is provided via anaerobic sources such as ATP, PCr and anaerobic glycolysis (Gaitanos *et al.*, 1993; Bogdanis *et al.*, 1998). During a short duration sprint (3-6 s) the contribution from the aerobic energy system is about 3-5% (Péronnet and Thibault, 1989; Locatelli and Arsac, 1995). It is clear that the aerobic energy system is activated even before the depletion of PCr stores during a single maximal sprint (Serresse *et al.*, 1988). The contribution of the aerobic energy system will increase as the duration of the sprint is longer (Spencer and Gastin, 2001). Futhermore, Gastin (2001) estimated the relative anaerobic and aerobic energy contribution based on the results from several studies on high-intensity intermittent exercise. For an exhaustive exercise bout lasting 0-10 s the anaerobic and aerobic energy contribution was 94% and 6% respectively. When maximal or near maximal exercise bouts are performed repeatedly, the energy contribution for each bout will change dramatically compared to a single bout.

Repeated short sprints causes a greater disruption to the energy balance compared to a single sprint. Dawson *et al.* (1997) reported that PCr depletion was 45% and 73% after a single 6-s sprint compared to 5 x 6-s sprints departing every 24 s, respectively. During repeated sprints it seems that the contribution of anaerobic glycolysis to energy provision is inhibited by an interaction of various mechanisms such as the inhibition of key regulatory glycolytic enzymes i.e. phosphofructokinase (PFK) (Glaister, 2005). The gradual inhibition of anaerobic glycolysis was supported by the findings of Gaitanos *et* *al.* (1993). They reported that the contribution from anaerobic glycolysis was 44% in the first sprint and 16.1% in the tenth sprint during 10 x 6-s sprints on a cycle ergometer. The reduced contribution of anaerobic glycoloysis leads to an increased taxing of aerobic glycolysis and $\dot{V}O_2$ kinetics during both exercise and recovery periods when sprints are repeated (Tomlin and Wenger, 2001). This increase in $\dot{V}O_2$ kinetics is offset to restore energy substrates such as PCr (Jansson *et al.*, 1990) and remove blood metabolities such as lactate (Balsom *et al.*, 1992b). The aerobic contribution to energy production for each sprint will also increase during repeated sprint (Gastin, 2001).

The relative energy contribution and performance on repeated sprints is influenced by a myriad of factors such as training status (Hamilton *et al.*, 1991; Bishop and Spencer, 2004), recovery duration (Wooton and Williams, 1983; Holmyard *et al.*, 1988; Balsom *et al.*, 1992b), mode of recovery (Dupont *et al.*, 2004) and the number of sprints (Balsom *et al.*, 1992a). In addition, each one of these variables can influence players' physical performance (i.e. time spent in high-intensity exercise, efficiency of recovery) in match-play.

It is clear that repeated-sprint exercise produces a different physiological challenge to the soccer player compared to a single sprint. It is unlikely that the repeated-sprint pattern during match-play is as demanding as in the aforementioned studies (i.e. 10 x 6 s sprints). Instead, the unpredictable activity pattern of soccer may lead to short episodes of repeated sprints (i.e. 3 x 3 s with ~20-30 s recovery between sprints) with a longer active recovery period spent jogging followed by another episode of repeated sprint (i.e. 2 x 3 s). Multiple-sprint sports such as soccer are unique in that the physiology and energy contribution during match-play is dynamic depending on the activity performed. Such physical demands places great emphasis on players' fitness levels to be able to cope with game intensity.

2.4.6 Summary

Both field and laboratory based prolonged and short-term high-intensity intermittent exercise protocols are good models in studying the physiological responses to soccer-specific intermittent exercise. Prediction of players' physical performance or assessment of physical capacity may be limited unless players' are re-assessed regularly. The time-consuming nature of match simulations and intermittent protocols is also a limitation when assessing a whole squad. It would be beneficial for coaches if assessment of soccer-specific endurance could be done in the field. The design of tests which is based on the specific activity pattern and physical demands of match-play would achieve this aim. The role of laboratory simulations and protocols should not be discarded but to maximise the practically for coaches focus should be on field tests.

2.5 Physiological Testing

Coaches and sports scientists can obtain an indication of fitness levels of individual player's by using a blend of physiological tests. Physiological testing of soccer players is important because information from such tests can be used to determine individual physical strengths and weaknesses for prescription of individual training, study the effectiveness of training programmes, monitor progress during rehabilitation training, evaluate physical capacity of new signings and monitor changes in fitness levels during the season (Hazeldine and Holmyard, 1993; Balsom, 1994). Prior to the use of a test for regular assessment, it's reliability and validity must be established. These two components will be discussed in more detail below.

A fitness test must be able to measure components that are important for successful physical performance during soccer match-play, for example the ability to recover from high-intensity exercise (Green, 1991). Therefore, the primary aim of any fitness test (laboratory or field tests) must be to obtain information that can be used to improve a player's overall performance during match-play (Balsom, 1994). Fitness tests can be conducted both in the laboratory and the field, for measuring different components of aerobic endurance performance and more soccer-specific fitness. Field tests are generally used when cost and utility are important whereas laboratory tests are used when exact precision and control are required (Hrysomallis *et al.*, 1999). Laboratory tests are often more time-consuming and costly than are field tests especially when an entire squad has to be accommodated. However, sub-maximal and maximal laboratory tests such as T_{lac} and $\dot{V}O_{2max}$ provide coaches with valuable information on players aerobic endurance levels. An example of the development of aerobic endurance levels in professional soccer players is shown in Table 2.5.1. Although the activity pattern of soccer can be mimicked in the laboratory via intermittent exercise protocols as described in section 2.3, more ecological valid information would be obtained from field tests.

Field tests are inexpensive, easy to use, short in duration, able to accommodate many players simultaneously, replicate specific fitness components of the game and are sensitive to change (McLean, 1993). Also, any field test should be designed so that the activity profile of the exercise replicates the demand of the specific activity during match-play. For example, measuring 200-m running speed in soccer players may provide no relevant information since the duration of such a sprint would be >21 s and a sprint during match-play rarely exceeds 30 m or 3 s (Bangsbo *et al.*, 1991: Mohr *et al.*, 2003a). Indeed, a 200-m run has been shown to be a poor predictor of physical performance during match-play in elite referees (Castagna *et al.* 2002). Environmental and surface conditions may also significantly affect performance during such field tests. To counteract any change in test performance from these factors, test conditions must be standardised. Standardised test conditions may involve testing indoors on an artificial grass surface. The aim of this section is to discuss the methodological principles that underpins fitness tests as well as critically evaluate some of the most common field tests.

Table 2.5.1. Aerobic endurance values from laboratory tests in soccer players from various standards of play.

Study	*Level/country*	*Position*	*n*	$\dot{V}O_{2max}$ *(ml.kg^{-1}.min^{-1})*	*Lactate threshold (% of $\dot{V}O_{2max}$)*
Reilly (1975)	Division 1/England			66.0 ± 2.7	
Raven *et al.* (1976)	Division 1/USA		18	58.4 ± 0.83	
Åstrand and Rodahl (1977)	National Team/Sweden		11	56.5	
	Division 1/Sweden		50	58.6	
Apor (1988)	Elite/Hungarian[Y]		13	63.2 ± 8.1	
Faina *et al.* (1988)	Amateur/Italy		17	64.1 ± 7.2	
	Professional/Italy		27	58.9 ± 6.1	
Verstappen and Bovens (1989)	Division 1/Holland		15	68.0 ± 5.0	
Tokmakidis *et al.* (1992)	Division 1/Greece		99	56.1 ± 4.7	
Puga *et al.* (1993)	Division 1/ Portugal		19	59.6 ± 7.7	
Bangsbo (1994b)	Division 1/Denmark	G	5	51.0 ± 2.0	
		CB	13	56.0 ± 3.5	
		FB	12	61.5 ± 10.0	
		M	21	62.6 ± 4.0	
		A	14	60.0 ± 3.7	
Raastad *et al.* (1997)	Division 1/Norway		13	62.8 ± 4.1	
Wisløff *et al.* (1998)	Division 1/Norway (first)		14	67.6 ± 5.0	
	Division 1/Norway (last)		15	59.9 ± 4.2	
Aziz *et al.* (2000)	National team/Singapore		23	58.2 ± 3.7	
Al-Hazzaa *et al.* (2001)	National team/Saudi Arabia		23	56.8 ± 4.8	
		FB		57.7 ± 5.1	
		CB		52.3 ± 7.3	
		M		59.9 ± 1.0	
		A		56.9 ± 2.5	
Casajūs (2001)	Division 1/Spain		15	66.4 ± 7.6	79.4
Helgerud *et al.* (2001)	Elite U-19/Norway pre-training		9	58.1 ± 4.5	82.4
	Post-training		9	64.3 ± 3.9	86.3
Hoff and Helgerud (2002)	Division 2/Norway		8	60.3 ± 3.3	85.5

Helgerud and Hoff (2002)	Division 1/Norway pre-training	21	60.5 ± 4.8	
	Post-training	21	65.7 ± 5.2	
Arnason *et al.* (2004)	Division 1/Iceland	8 teams	63.2 ± 0.4 (SEM)	
	Division 2/Iceland	7 teams	61.9 ± 0.7 (SEM)	
Chamari *et al.* (2004)	Elite U-19/Tunisia	34	61.1 ± 4.6	90.1
Dupont *et al.* (2004)	Division 1/France	22	60.1 ± 3.4	
Strøyer *et al.* (2004)	Elite U-14/Danish	7	63.7 ± 8.5	
Vanderford *et al.* (2004)	National U-16/USA	20	56.2 ± 1.5	61.2
	National U-15/USA	19	54.5 ± 1.3	63.5
	National U-14/USA	20	52.9 ± 1.2	65.9
Castagna *et al.* (2005)	Provincial/Italy	11	50.0 ± 6.7	
McMillan *et al.* (2005b)	Elite U-18/Scotland	11	63.4 ± 5.6	
Siegler *et al.* (2006)	Amateur/USA	13	58.3 ± 5.7	
Castagna *et al.* (2006a)	Provincial U-18/Italy	18	52.8 ± 7.4	

G = goalkeeper, CB = centre-back, FB = full-back, M = midfield, A = attacker, SEM = standard error of the mean

2.5.1 Test Reliability and Validity

Any fitness test must be sensitive to ensure that any changes in performance on a test are "real", as a result of an altered physical capability rather than between or within subject variation (Atkinson and Nevill, 1998). Reliability and validity of any new fitness tests must also be determined to ensure that the test is reproducible and mimics physical performance in the real event (Hopkins *et al.*, 1999; Boddington *et al.*, 2001). Reliability of a test procedure can be determined by controlled repeated performances that are analysed using appropriate statistical methods. Such statistical methods should provide a meaningful quantification of both the systematic and random error and relate these values to the requirements of the test for effective practical use (Atkinson and Nevill, 2001). This involves the use of several reliability statistics (i.e. coefficient of variation, correlation coeffcient and analysis of variance), to investigate the repeatability between trials as well as the 95% limits of agreement (Atkinson and Nevill, 1998). These reliability statistics are the more common analytical methods to use for analysis of reliability. Analysis of variance and the 95% limits of agreement have been used as analysing tools when assessing the reliability of several fitness tests for multiple-sprint sports (Wilkinson *et al.*, 1999; Nicholas *et al.*, 2000; Tong *et al.*, 2001; Hood *et al.*, 2002).

It is important that tests used to measure physical fitness are compared to a "gold standard" criterion as well as to performance in the actual event. For example, performance on field tests that estimate aerobic power, such as the 20-m shuttle run, should be compared to performance on incremental treadmill tests in the laboratory where oxygen uptake is measured. If the correlation is high, the usual conclusion is that the test is valid. Tests that evaluate soccer-specific endurance capacity should therefore resemble physical performance during a match. However, physical performance in a soccer match may be highly variable between matches due to the self-paced nature of the sport. Tactics, motivation, increased certainty of the results are factors which may influence the amount of high-intensity running performed in a match (Reilly, 2005).

In addition to being reliable and valid, tests must also be able to measure the minimum percentage increase that is needed to demonstrate an enhancement of performance. These differences may be very small for elite athletes [coefficient of variation of as low as 0.3-

0.4%; Hopkins *et al.* (1999)], which must ensure that test methodologies are very sensitive to change. A large sample size would be necessary for studies of training interventions if such small changes in performance are to be detected. In summary, fitness tests have to be reproducible and measure the specific components of soccer-specific fitness if they are to be used for regular assessment of physical performance in soccer.

2.5.2 Field Tests

Outlined in the next section are some examples of field tests used to evaluate specific fitness components of soccer players. Despite high levels of ecological validity, no field test can predict physical performance in soccer match-play, as it is difficult to isolate the importance of individual physical parameters when the overall demands of the sport are so complex. This review will focus only on fitness tests that assess players' soccer-specific endurance. Examples of such field tests are shown in Table 2.5.2. Many of these tests have, however, not been frequently used in the literature and their reliability and validity has not been thoroughly assessed. As a result, these tests have not been discussed in the following sections. The tests outlined include those tests that are the most commonly represented in the literature base.

Table 2.5.2. Examples of some selected soccer-specific field tests.

Study	*Name of test*	*Description*	*Duration of test*	*Assessment of performance*	*Predominantly on component*
Ekblom (1989)	Interval field test	Four laps of a soccer pitch performing forward, backward, sideways and slalom running including turning and jumping movements	16.5 min	Time to complete course	Aerobic
Balsom (1990)	Repeated sprint test	20 repeated 10 x 10 x 10-m sprints with 42-s active recovery	Self-paced	Time to complete course	Anaerobic
Causarano *et al.* (1992)	Field test	Two 1000 m runs at 85% and 100% maximal velocity with 30 min rest between runs	Self-paced	Time to complete each run	Aerobic
Sarsaniya and Seluyanov (1992)	Running test	7x 50 m runs without any rest periods between runs	Self-paced	Time to complete test	Anaerobic
Baker *et al.* (1993)	40-m maximal intensity shuttle run test	8 repeated 40-m sprints with a 20-s recovery period between sprints	Self-paced sprints	Sprint time/fatigue index	Anaerobic
Malomski (1993)	Two-step interval test	15 x 30-m sprints with 5-s recovery performed in two blocks separated by 30 min	Self-paced sprints		Aneaerobic
Castagna *et al.* (2002a)	Modified Montreal track test	Running at 8 $km.h^{-1}$ for 2 min then speed increased 2 $km.h^{-1}$ every 2 min until exhaustion	~10-12 min	Exercise time to exhaustion	Aerobic
Thomas *et al.* (2002)	Field Anaerobic Shuttle Test	Performing 12 shuttles between two lines 20 m apart	Self-paced/maximal	Time taken to complete run	Anaerobic
Impellizzeri *et al.* (2003)	Sub-maximal running test	Continuous running on the track and/or field at 13.5 $km.h^{-1}$	6 min	Heart rate	Aerobic
Kemi *et al.* (2003)	Hoff test	Dribbling course consisted of dribbling, backwards running, turning and jumping activities	Cover as much distance as possible in 10 min	Number of completed laps/10 min	Aerobic

Lemmink and Visscher (2003)	Interval shuttle run test	Shuttle running test between two markers 21 m apart with speed increments every 90 s	Until voluntary exhaustion	Number of completed shuttles	Aerobic
Ohasi *et al.* (2003)	Field test	1 or 5 min set exercise periods with standing, walking, jogging or sprinting in squares (30 x 20 m)	90 min	Physiological responses	Aerobic
Psotta and Bunc (2003)	Repeated sprint test	10 x 20-m sprints with 20 s recovery period between sprints	Self-paced sprints	Fatigue index	Anaerobic
Cooper *et al.* (2004)	15-m multistage shuttle run test	Repeated shuttle runs between two lines 15-m apart with progressive increase in running speed	Until voluntary exhaustion	Number of completed shuttles	Anaerobic
Gorostiaga *et al.* (2004)	Endurance running test	Sub-maximal run on a soccer pitch in 3 different stages and running speeds (stage 1:12 $km.h^{-1}$, stage 2: 13 $km.h^{-1}$ and stage 3: 14 $km.h^{-1}$) with a 3-min passive rest period between each stage.	10 min (stage 1), 10 min (stage 2) and 5 min (stage 3)	Heart rate	Aerobic

2.5.2.1 Multi-Stage Fitness Test

The multi-stage fitness test (20-m shuttle run) was originally designed by Lèger and Lambert (1982) and modified by Lèger *et al.* (1988) to estimate $\dot{V}O_{2max}$. It has later been validated by Ramsbottom *et al.* (1988). The test is based on the completion of repeated shuttle runs between two lines 20-m apart. The running speed is incremental and dictated by audio signals from a tape recorder. The aim of the test is for the subjects to complete as many shuttles as possible. The 20-m shuttle run has the advantage of evaluating more than one individual at any time, can be performed with relative ease and needs minimal equipment. Performance on the test provides an estimation of $\dot{V}O_{2max}$, as opposed to laboratory tests where a precise measurement of oxygen consumption is recorded, as expired air is not usually collected in the field. Not surprisingly, the 20-m shuttle run has been popular for the assessment of aerobic endurance in soccer as a whole squad can be tested at one time. A revised version of the original 20-m shuttle run protocol has been designed to measure anaerobic capacity where the intensity is based on the individual's final running speed in the 20-m shuttle test (Ramsbottom *et al.*, 1990; 1997; 2001). The running speed during this test is approximately 8% faster than the final speed attained during the 20-m shuttle test designed to exhaust individuals within 1-2 minutes.

The individual's $\dot{V}O_{2max}$ in the 20-m shuttle run is based on the level and shuttle reached by the subjects during the test and predicted from the regression equation $\dot{V}O_{2max}$ = (5.857 x speed on the last stage) – 19.458 (Lèger and Lambert, 1982). This equation is based on the relationship between $\dot{V}O_{2max}$ and the maximal speed achieved during the last stage. Significant correlations between $\dot{V}O_{2max}$ established by direct measurements on the treadmill and performance on the 20-m shuttle test were reported by Ramsbottom *et al.* (1988) (r = 0.92) and Paliczka *et al.* (1987) (r = 0.93). The standard deviation from the regression line was 3.5 $ml.kg^{-1}.min^{-1}$, which indicates that predictions of $\dot{V}O_{2max}$ may be either overestimated or underestimated by up to 3.5 $ml.kg^{-1}.min^{-1}$. Initial inspection of such evidence would appear to indicate a strong relationship between a direct and predicted $\dot{V}O_{2max}$ using the 20-m shuttle test.

There is evidence that indicates a lack of consistency in correlations of test performance with $\dot{V}O_{2max}$ (O'Gorman *et al.*, 2000). Sproule *et al.* (1993) observed that the $\dot{V}O_{2max}$ and heart rate predicted from performance in the 20-m shuttle test was lower in 75% of subjects compared to direct evaluations performed on the treadmill. Similar findings where $\dot{V}O_{2max}$ has been under-predicted have been were reported in squash players, runners (St Clair-Gibson *et al.*, 1998) and adolescent soccer players (Fairbrother *et al.*, 2004). The underestimations may be greater for individuals with a higher $\dot{V}O_{2max}$ and be partly dependent on the specific sport of the subjects. Moreover indirect measurements of $\dot{V}O_{2max}$ have an accuracy of ±15% (Åstrand *et al.*, 2003). The constant deceleration and acceleration actions associated with each turn at 20 m may be more energy demanding and may decrease stride length efficiency (O'Gorman *et al.*, 2000). As a consequence, the anaerobic contribution to the test may be higher compared to continuous running on a treadmill. Therefore, it may be difficult to attain a true $\dot{V}O_{2max}$ during the 20-m shuttle run especially in highly trained athletes. Performance should therefore be expressed as distance covered and not estimated $\dot{V}O_{2max}$.

Table 2.5.3. Performance on the 20-m shuttle run in various standards of play in soccer (mean±SD where appropriate).

Study	*Level/country*	*Position*	*n*	*Distance covered (m)*	*Estimated* $\dot{V}O_{2peak}$ *(ml.kg^{-1}.min^{-1})*
Brewer and Davies (1992)	Professional/England		15	2560	59.8 ± 3.8
	Semi-professional/England		12	2540	59.6 ± 3.4
Davies and Brewer (1992)	Female national team/England		14	1740	48.4 ± 4.7
Tumilty and Darby (1992)	Female national team/Australia		20	1740	48.5 ± 4.8
Tumilty and Smith (1992)	National team U-18/Australia		16	2500	58.9
Davies *et al.* (1992)	Professional/England	GK	13	2320	56.4 ± 3.9
		FB	22	2620	60.7 ± 2.3
		CD	24	2540	59.5 ± 3.2
		M	35	2680	61.4 ± 3.4
		A	41	2580	60.1 ± 4.2
Balsom (1994)	Elite U-16/Sweden		15	2280	56.0
	National team U-16/Sweden		23	2320	56.4
	Elite U-18/Sweden		20	2460	58.5
	First division/Sweden		17	2640	60.9
	Female National team/Sweden		24	2100	53.7
Odetoyinbo and Ramsbottom (1997)	University/England		14	2260 ± 271	55.7
Strudwick *et al.* (2002)	Professional/England		19	2520	59.4 ± 6.2
Aziz *et al.* (2003)	Professional/Singapore		147	2220	55.3 ± 3.8
Edwards *et al.* (2003)	Academy scholars/England		13	2400	57.4 ± 4.7
	Recreational/England		10	2140	54.3 ± 5.1
Fairbrother *et al.* (2004)	Competitive/England[A]		12	2260	56.0 ± 3.8
Lemmink *et al.* (2004)	Amateur/Holland		26	2240	55.7
	Premier league amateur/Holland		31	2360	57.1
	Professional/Holland		24	2400	57.6
Polman *et al.* (2004)	National league females/England		36	1560	45.7 ± 3.0
Aziz *et al.* (2005)	National team U-18/Singapore		21	2041 ± 179	52.8

[A] = adolescent players, GK = goalkeeper, FB = full back, CD = central defender, M = midfielder, A = attacker

Despite the problems associated with predicting $\dot{V}O_{2max}$, the 20-m shuttle run has been used extensively to test soccer players at various playing standards as shown in Table 2.5.3. The majority of evidence indicates that the 20-m shuttle run cannot discriminate between different standards of play and is not sensitive to training status in trained soccer players. Lemmink *et al.* (2004) reported that there was no difference in 20-m shuttle run performance between amateur, top-class amateur or professional Dutch soccer players as shown in Table 2.5.3. They also found that professional players performed significantly better that the top-class amateur and amateur players on an interval shuttle run test. No difference in performance between English academy scholars and recreational players was also shown by Edwards *et al.* (2003). Odetoyinbo and Ramsbottom (1997) found that there was no significant improvement in 20-m shuttle run performance following 8 weeks of high-intensity training in university soccer players (2260 ± 261 m to 2274 ± 256 m). However, performance on the aforementioned high-intensity shuttle run version of the 20-m shuttle run was improved by 12.9%. Similar improvements have also been reported in healthy individuals following 6 weeks of high-intensity interval training (Ramsbottom *et al.*, 2001). The latter finding may suggest that the anaerobic or high-intensity version of the 20-m shuttle test may be more sensitive to training interventions than the aerobic or original version.

Therefore, the 20-m shuttle run may not be suitable for the estimation of changes in $\dot{V}O_{2max}$ in soccer players or for studying effects of soccer-specific training interventions, especially for high-level performers. Performance should be expressed as distance covered rather than estimations of $\dot{V}O_{2max}$. The major limitation of the 20-m shuttle run is the continuous activity pattern, which does not fully represent the intermittent activity profile of soccer or soccer-specific endurance *per se*. Instead, tests that replicate the intermittent activity pattern of soccer should be used to assess soccer-specific fitness.

2.5.2.2 The Yo-Yo Tests

The concept of shuttle running was used by Bangsbo (1993b) to devise a more soccer-specific assessment compared to the 20-m shuttle run. There are two Yo-Yo tests- the Yo-Yo intermittent endurance test (YIET) and the Yo-Yo intermittent recovery test (YIRT). The YIET measures the ability to perform bouts of repeated intense intermittent exercise and YIRT measures the ability to recover from intense exercise (Bangsbo, 1993b). The difference between the 20-m shuttle run and the Yo-Yo tests is that short recovery periods (5 s in the YIET; 10 s in the YIRT) are incorporated after each pair of 20-m shuttles. This intermittent activity profile clearly distinguishes the two Yo-Yo tests from the continuous profile of the 20-m shuttle run making it more specific to soccer. Scoring in the Yo-Yo tests is similar to that for the 20-m shuttle run with the level and number of shuttles completed being recorded. Table 2.5.4 reveal performances on both Yo-Yo tests from different standards of play.

2.5.2.2.1 The Yo-Yo Intermittent Endurance Test

The reliability of the YIET has not yet been established. However, the internal validity of the YIET has been examined in several studies. Oliveira *et al.* (2001a) also showed that distance covered on the YIET (level 1) was higher four (1601 ± 318 m) and seven (1734 ± 476 m) months into the competitive season compared to the beginning of pre-season (1251 ± 280 m) and the end of the transition period (1251 ± 288 m) in elite Portuguese players. The YIET-1 can also detect changes between playing positions (Bangsbo and Michalsik, 2002). These studies show that YIET seems to be sensitive to detect changes in training status throughout the season. In addition, Rainer (2004) showed that performance on the YIET was improved following ingestion of a 6.9% solution carbohydrate drink. Taken together these results would seem to suggest that the YIET can be applicable to soccer for regular testing.

Table 2.5.4. Performance on the Yo-Yo tests (intermittent endurance test and intermittent recovery test) in different standards of play in soccer.

Study	*Test/level*	*Level/country*	*Position*	*n*	*Distance covered (m)*
Oliveria *et al.* (2001b)	Intermittent endurance/level 2	Professional/Portugal		62	1361 ± 352
Castagna *et al.* (2003)	Intermittent endurance/level 1	Provincial/Italy		18	2914 ± 448
Krustrup *et al.* (2003)	Intermittent recovery/level 1	Professional/Denmark	FB	7	2241 ± 25
			CD	9	1919 ± 47
			M	13	2173 ± 23
			A	8	1966 ± 30
Mohr *et al.* (2003a)	Intermittent recovery/level 1	Professional/Denmark		24	2040 ± 60
		Professional/Italy		18	2260 ± 80
			FB	9	2210 ± 40
			CD	11	1910 ± 120
			M	13	2230 ± 100
			A	9	1990 ± 110
Malina *et al.* (2004)	Intermittent recovery/level 1	Elite U-18/Portugal		69	2469 ± 673
			D	29	2469 ± 627
			M	30	2529 ± 736
			A	10	2288 ± 639
Wells *et al.* (2004)	Intermittent recovery/level 2	Professional/England		18	840 ± 153
		Amateur/England		18	716 ± 123
Aziz *et al.* (2005)	Intermittent endurance/level 2	National Team U-18/Singapore		21	1676 ± 314
Krustrup *et al.* (2005)	Intermittent recovery/level 1	Female Premier league/Denmark		14	1379 ± (600-1960)
Castagna *et al.* (2006a)	Intermittent recovery/level 1	Amateur/Italy		24	2138 ± 364
Castagna *et al.* (2006b)	Intermittent endurance/level 1	Provincial/Italy		18	3025 ± 432
Krustrup *et al.* (2006b)	Intermittent endurance/level 2	Professional/Denmark		35	1059 ± 35
		Second Division/Denmark		15	771 ± 25
			GK	6	602 ± 27
			CD	21	985 ± 43
			FB	20	978 ± 40

			WM	26	984 ± 41
			CM	22	968 ± 48
			A	24	894 ± 47
Majgaard Jensen *et al.* (2007)	Intermittent endurance/level 2	Professional/Denmark		16	851 ± 35

FB = full back, D = defender, CD = central defender, M = midfielder, WM = wide midfielder, CM = central midfielder, A = attacker

When examining the internal validity of the YIET, there seems to be no association between $\dot{V}O_{2max}$ determined from treadmill running in the laboratory and YIET performance. Aziz *et al.* (2005) reported a poor association between $\dot{V}O_{2max}$ and performance on the YIET (level 2) in elite junior players from the Singapore National Team. This lack of association between YIET-2 performance and $\dot{V}O_{2max}$ has also been reported by Oliveira *et al.* (2001b) in elite Portuguese players, Castagna *et al.* (2003) in provincial Italian players (YIET level 1) and Metaxas *et al.* (2005) in elite Greek players. These results would suggest that performance on the YIET is affected by other variables other than $\dot{V}O_{2max}$ alone.

The only study which has compared performance on the YIET and the 20-m shuttle run was conducted by Aziz *et al.* (2005). They found a low association between the total distance covered in the YIET (1676 ± 314 m) and in the 20-m shuttle run (2041 ± 179 m) in Singapore U-18 national team players. Both post-test blood lactate and peak heart rate was similar between the two tests (192 ± 8 beats.min^{-1} *vs* 192 ± 8 beats.min^{-1} and 13 ± 1.6 mmol.l^{-1} *vs* 13.1 ± 2.7 mmol.l^{-1} for the 20-m shuttle run and the YIET respectively). The YIET also yielded a lower $\dot{V}O_{2max}$ (56.1 ± 4.5 ml.kg^{-1}.min^{-1}) compared to the 20-m shuttle run (59.1 ± 4.8 ml^{-1}.kg^{-1}.min) and an incremental treadmill test in the laboratory (57.8 ± 5 ml.kg^{-1}.min^{-1}). Despite the different activity pattern of the YIET to the 20-m shuttle run, blood lactate and peak heart rate was similar at the end of each test. However, the start-stop nature of the YIET may have contributed to the players not reaching $\dot{V}O_{2max}$. The poor association between the YIET, $\dot{V}O_{2max}$ and the 20-m shuttle run may be explained by the fact that the YIET was not designed to estimate $\dot{V}O_{2max}$ from performance but is only concerned with performance in distance covered *per se*.

2.5.2.2.2 The Yo-Yo Intermittent Recovery Test

The external and internal validity and reliability of the YIRT (level 1) were established by Krustrup *et al.* (2003). No significant difference was reported in the distance covered (1867 ± 72 m and 1880 ± 89 m) between a first and second test performed within one week of each other in 17 healthy individuals (non-soccer players). A significant correlation (r = 0.71) was also observed between performance on the YIRT and the amount of high-intensity exercise performed during match-play in 12 Danish professional soccer players. Interestingly, the correlation between total distance covered in match-play and YIRT performance was lower (r = 0.53) than the correlation for high-intensity running. Average (after 1080 m and 1720 m in YIRT) and peak heart rate during the test corresponded to 92 ± 1%, 96 ± 1% and 99 ± 1% of HR_{peak}, respectively which showed that the aerobic loading was high in the latter stages of the test. In addition, blood lactate concentration was 10.1 ± 0.6 $mmol.l^{-1}$ and the PCr concentration had fallen by 51% at the end of the test compared to rest. This also suggests that anaerobic energy production was highly taxed especially towards the end of the test. These energy loads are similar to those, which support soccer-match play. An alternative sub-maximal version of the Yo-Yo intermittent endurance test has recently been described by Mohr *et al.* (2003b). This version utilizes heart rate measurements to predict maximal performance on the basis of a 6-min test. The sub-maximal test was also sensitive to track changes in fitness in Danish national team players leading up to the 2002 World Cup. Such test procedures may enhance the effectiveness of the Yo-Yo test within the competitive season as energy demanding maximal efforts are not requested.

The YIRT-2 (2-10 min) is of a shorter duration than the YIRT-1 (10-20 min) and evaluates a different component of soccer-specific endurance. Whereas the YIRT-1 assesses the ability to perform repeated aerobic high-intensity work, the YIRT-2 focuses on the ability to perform intense intermittent exercise with a larger anaerobic component (Krustrup *et al.*, 2006b). The reliability and internal validity of the YIRT-2 was established by Krustrup *et al.* (2006b). They reported no significant difference between test-retest scores (688 ± 46 m *vs.* 677 ± 47 m) of a YIRT-2 performed twice within a week in active non-soccer players. The same authors also reported that distance covered on the YIRT-2 was improved by 42% following 8 weeks of pre-season training in elite male Danish players. The YIRT-2 can also distinguish between successful and unsuccessful teams in the Danish premier league (Bredsgaard Randers *et al.*, 2007) and between playing positions (Bangsbo and Michalsik, 2002). Performance on the YIRT-2 was also improved by 15% following a 12 week in-season high-intensity training period performed once a week in elite male Danish players (Majgaard Jensen *et al.*, 2007).

Table 2.3.3 shows that both the YIRT-1 and YIRT-2 has been used extensively in the assessment of soccer-specific endurance capacity in players and can discriminate between playing positions and different levels of play. In addition, the YIRT (level 1) has also been used to assess the physical capacity of elite soccer referees (Krustrup and Bangsbo, 2001; Weston *et al.*, 2004) and assistant referees (Krustrup *et al.*, 2002). The YIRT was also used by Krustrup *et al.* (2003) to monitor changes in fitness during the season in professional Danish players. Following pre-season, distance covered in the YIRT-1, $\dot{V}O_{2max}$ and time to exhaustion on an incremental treadmill test increased by 25% (from 1760 m to 2211 m), 7% (from 55 to 59 mmol.l^{-1}) and 14% (from 293 s to 331 s) respectively. Furthermore, YIRT-1 performance at the end of season (2103 ± 68 m) was not significantly different to the end of pre-season (2211 ± 70 m). It may be argued that the large improvements in test performance (25%) may have been associated with the acute responses to the training stimulus following a period of inactivity. In addition, Majgaard Jensen *et al.* (2007) reported that distance covered on the YIRT-2 increased by 15% following aerobic high-intensity interval training in-season. These results demonstrate that the YIRT may be more sensitive to changes in training status and is a better predictor of physical performance during a match than $\dot{V}O_{2max}$. It seems that the YIRT is sensitive to detect improvements in soccer-specific endurance in referees. Performance on the YIRT was improved by 31% and 46.5% in elite Danish (Krustrup and Bangsbo, 2001) and Belgian referees (Weston *et al.*, 2004) following a 12-week and 16 month high-intensity training programme respectively. The YIRT-1 has also been used to test professional rugby league players (Atkins, 2006).

2.5.2.2.3. Summary

Both the YIET and the YIRT can discriminate between playing positions and is sensitive to monitor changes in fitness during the season. These tests may be more appropriate to use for assessment of soccer-specific endurance rather than $\dot{V}O_{2max}$ measurements or the 20-m shuttle run. The major disadvantage of the YIET and YIRT is that players have to perform repeated turns at 180°, which can place strain on the joints of the lower limbs but considerably fewer turns are performed in comparison to the 20-m shuttle run. The exercise intensity in both of the Yo-Yo tests is progressive starting at a low intensity and gradually increasing with a test duration of ~10-15 min. Some coaches may be reluctant to allocate time for fitness testing, both at a professional and lower league level. Therefore, it would be advantageous to have a test which not only would be of considerable duration to be used as a conditioning drill but also could be used as a performance test to evaluate soccer-specific endurance. The prime aim of the two Yo-Yo tests was for performance assessment only making dual use of the tests (conditioning drill and performance test) of the tests difficult.

2.5.2.5 Multiple Sprint Tests

There is an increased physiological demand during multiple sprints as opposed to single sprints, as muscle pH, PCr and subsequently ATP must be resynthesised between sprints (Balsom *et al.*, 1992b). Assessment requires test protocols that include a repeated sprint component interspersed with rest periods. Examples of how laboratory repeated sprint protocols and the duration of the sprint and/or recovery period can influence performance have been discussed in section 2.4. Assessment of this repeated-sprint ability in the field is practical and can be easily conducted using electronic timing gates. Recently, there has been development of several multiple-sprint tests with varying sprint distance, recovery time and number of sprints (Dawson *et al.*, 1991; Fitzsimmons *et al.*, 1993; Aziz *et al.*, 2000; Mujika *et al.*, 2000; Boddington *et al.*, 2001).

One of the most widely used test protocols to assess repeated speed endurance is Bangsbo's multiple-sprint test (BMST) (Bangsbo, 1994a). The BMST consists of 7 x 35-m sprints separated by 25-s recovery periods. The test results include best sprint time, mean sprint time and a fatigue index. The best sprint time is defined as the fastest of the seven sprints and the mean sprint time is the average time taken to complete the seven sprints. Both of these indices should be low: the latter expresses the player's ability to perform several sprints and the former the ability to perform "explosive" actions within a short period of time during match-play. A high fatigue index suggests that the player shows inconsistency in sprint performance and has a poor ability to recover between sprints, which may be due to the inability to replenish PCr stores and remove blood lactate between sprints (Tomlin and Wenger, 2001).

The reliability of the BMST was established by Wragg *et al.* (2000) where seven male soccer players performed the multiple sprint test over six trials with a coefficient of variation in sprint times of 1.82 % between trials. Significant differences occurred between trials 1 and 2, indicating that a learning effect was present. Based on these results, it is advisable for players to perform several familiarisation sessions prior to the proper assessment trial(s) to ensure accurate results.

It seems that the BMST is sufficiently sensitive to discriminate between different standards of players and be used as an indicator of changes in physical performance during match-play in soccer. Reilly *et al.* (2000) reported that performance on the BMST was significantly better for elite compared to sub-elite youth soccer players with elite players recording lower mean velocities and higher fatigue indices compared to the sub-elite players. Similar findings were reported by Sampaio and Macas (2003) in elite and amateur Portuguese players. Rebelo *et al.* (1998) also observed that BMST performance in 14 elite Portuguese youth players was significantly better in the first half compared to during the second half in a friendly match. If the BMST can discriminate between different standards of players and detect changes in physical performance during match-play, the test has potential for inclusion in soccer-specific assessments.

A major disadvantage of multiple-sprint tests in general may be that individuals develop "pacing" strategies throughout the test and therefore not exert maximal effort in the sprints due to the self-paced nature of the test. Furthermore, the uses of fatigue index may over- or underestimate a player's speed-endurance capacity. Slight variations in performance on any one sprint can have a large impact on the overall fatigue index score (Fitzsimmons *et al.*, 1993). As a result, the data may be skewed and misleading leading to incorrect assumptions of a player's true speed-endurance capability. Moreover, multiple sprint tests of 7 x 35 m may be more appropriate for amateur-level players as a more demanding protocol (i.e. either through an increase in sprint distance, number of sprints or a reduction in the recovery time between sprints) may have to be introduced for elite-level players. It may be more difficult to detect inter-group differences in fitness levels between elite players due to the homogeneity in training status.

2.5.3. Summary

Despite the development in the number of fitness tests, there are few which have been extensively examined in the literature. Due to the complex activity pattern and physiological demands in soccer it is difficult for any fitness test to accurately predict physical performance in soccer match-play. At present, only the Yo-Yo tests seem to be the best field test to measure soccer-specific endurance.

2.6 Overview

It is very difficult to quantify the energy production and the physiology of soccer directly in match-play. Nevertheless, several field and laboratory based intermittent exercise protocols have been developed to replicate the intermittent exercise pattern in soccer. What makes assessment of soccer-specific fitness difficult is that soccer is very unpredictable and exercise and rest periods are not evenly distributed in a match. At best, test protocols replicate the duration of the average exercise and recovery periods observed in a match but not the specific pattern. One of the most important parameters of soccer-specific fitness is the ability to perform repeated bouts of high-intensity exercise. Coaches should prioritise assessment of soccer players' ability to recover between high-intensity exercise bouts. Any new test protocol should therefore be based on the duration and distance of the high-intensity bouts during the game. To increase the physical demand, the duration and distance of the high-speed runs can also be adapted. Coaches should also have the option of assessing soccer-specific endurance through sub-maximal or maximal components. At present, there is no field test that consists of a sub-maximal stage and maximal stage where performance can be evaluated from heart rate measurements and number of bouts completed respectively. Not only could such a test be utilised for assessment of soccer-specific endurance but could also be incorporated as a separate conditioning drill. No test of soccer-specific endurance, which consists of a separate sub-maximal and maximal stage, has undergone extensive reliability, validity and sensitivity to an experimental intervention analysis.

Chapter 3

General Methodology

3.0. General Methodology

The aim of this section is to summarise the procedures and techniques used throughout this thesis. These include a description of standardised anthropometric measurements, as well as the field and laboratory tests used. Prior to performing any physical tests, the subjects' demographic characteristics were always recorded to generate baseline measurements.

3.1. Anthropometric Measurements

The subjects' statures were measured when the subjects were standing in the Franfort plane using a stadiometer (Seca, Birmingham, UK). Body mass was recorded with the subjects wearing shorts on a calibrated weighing scale (Seca, Birmingham, UK). These procedures were in accordance to the International Association for the Advancement of Kinanthropometry guidelines (Eston and Reilly, 2001).

3.2. Field Tests

3.2.1 The 20-m Shuttle Run

The test was developed by Ramsbottom *et al.* (1988) and was used to estimate $\dot{V}O_{2max}$ and determine peak heart rate (HR_{peak}). The test consisted of repeated shuttle running between two lines 20 m apart. Initially, the running speed was 8 km.h^{-1} with the speed increasing by 0.5 km.h^{-1} every minute and dictated via audio "bleeps" from a CD. The aim of the test was to complete as many shuttles as possible. If the subject failed to reach the line in time for the "bleep" on consecutive shuttles, the test leader would disqualify the subject and the level and number of shuttles completed was recorded as the subject's test performance. The subjects level and shuttle was then converted to an estimated $\dot{V}O_{2max}$ score from a conversion table. The subject could also voluntary stop the test. Heart rate was measured every 5 s via short-range telemetry with the Polar Team system (Polar Electro Oy, Kempele, Finland). The highest heart rate reached for each individual subject during the test was recorded as the HR_{peak}.

3.2.2 The Yo-Yo Intermittent Recovery Test

The Yo-Yo Intermittent Recovery Test was developed by Bangsbo (1993). The Level 1 version of the test was used for all studies in this thesis. The test consisted of repeated intermittent shuttle running between two lines 20 m apart. After each pair of 20-m shuttles there was a 10-s recovery period before the start of the next shuttle. During this recovery period, the subjects jogged 5 m, turned and jogged back 5 m ready to start the next shuttle. The test course is shown in Figure 3.1. The running speed was incremental and dictated via a series of audio "bleeps" from a CD. If the subject twice failed to reach the line in time with the bleeps, they would have to stop the test and their final level and shuttle recorded. Heart rate was measured every 5 s via short-range telemetry with the Polar Team system (Polar Electro Oy, Kempele, Finland). The highest heart rate reached for each individual subject during the test was recorded as the HR_{peak}.

3.2.3 The 15-50 Protocol

The 15-50 protocol consisted of a sub-maximal stage (Part 1) and a maximal stage (Part 2). Performance in Part 1 was evaluated by recording heart rate responses to the exercise protocol. Performance in Part 2 was based on the number of completed runs. The maximum number of runs that could be completed was 10. A detailed illustration of the test course for Part 1 and Part 2 is shown in Figures 3.2 and 3.3.

Part 1 was divided into 4 blocks with each block consisting of 5 running cycles of short (2 x 15 m) and long (50 m) high-speed runs with a 90-s rest period in between blocks. The structure of one running cycle is described below. This running cycle was then repeated 5 times in Part 1.

One running cycle: 30-m short run (2 x 15 m), 3-s rest, 50-m long run (no turn), 42-s passive rest x 5.

The mean running speed during the short (2 x 15-m) and long (50-m) high-speed runs was 18 $km.h^{-1}$ and 20 $km.h^{-1}$, respectively. During Part 1, the subjects performed 20 turns at 180°. The duration of Part 1 was 24 min 30 s with a 30-s rest period prior to the start of Part 2. The mean running speed during Part 2 was 19.2 $km.h^{-1}$ for each bout but with a longer exercise time (15-s) allowed for each bout compared to Part 1. The subjects also performed two turns at 180° in each bout. A description of the test course for Part 2 is shown in Figure 3.3.

3.2.4 The 15-30 Protocol

The 15-30 protocol consisted of a sub-maximal stage (Part 1) and a maximal stage (Part 2). Performance during Part 1 was evaluated by recording heart rate responses during this stage and performance in Part 2 was based on the number of shuttles completed. The test course for Part 1 and Part 2 of the 15-30 protocol is shown in Figures 3.4 and 3.5.

Part 1 was divided into 5 exercise blocks with one block consisted of 7 running cycles of short (15 m + 13 m) and long (30 m) high-speed runs interspersed with a 90-s passive recovery period between each block. The make-up of one running cycle is described below. This running cycle was then repeated 7 times for one exercise block. Five exercise blocks were performed in total in Part 1.

One running cycle: 30-m short run (15 m + 13 m), 6-s passive rest, 30-m long run (no turn), 12-s passive rest

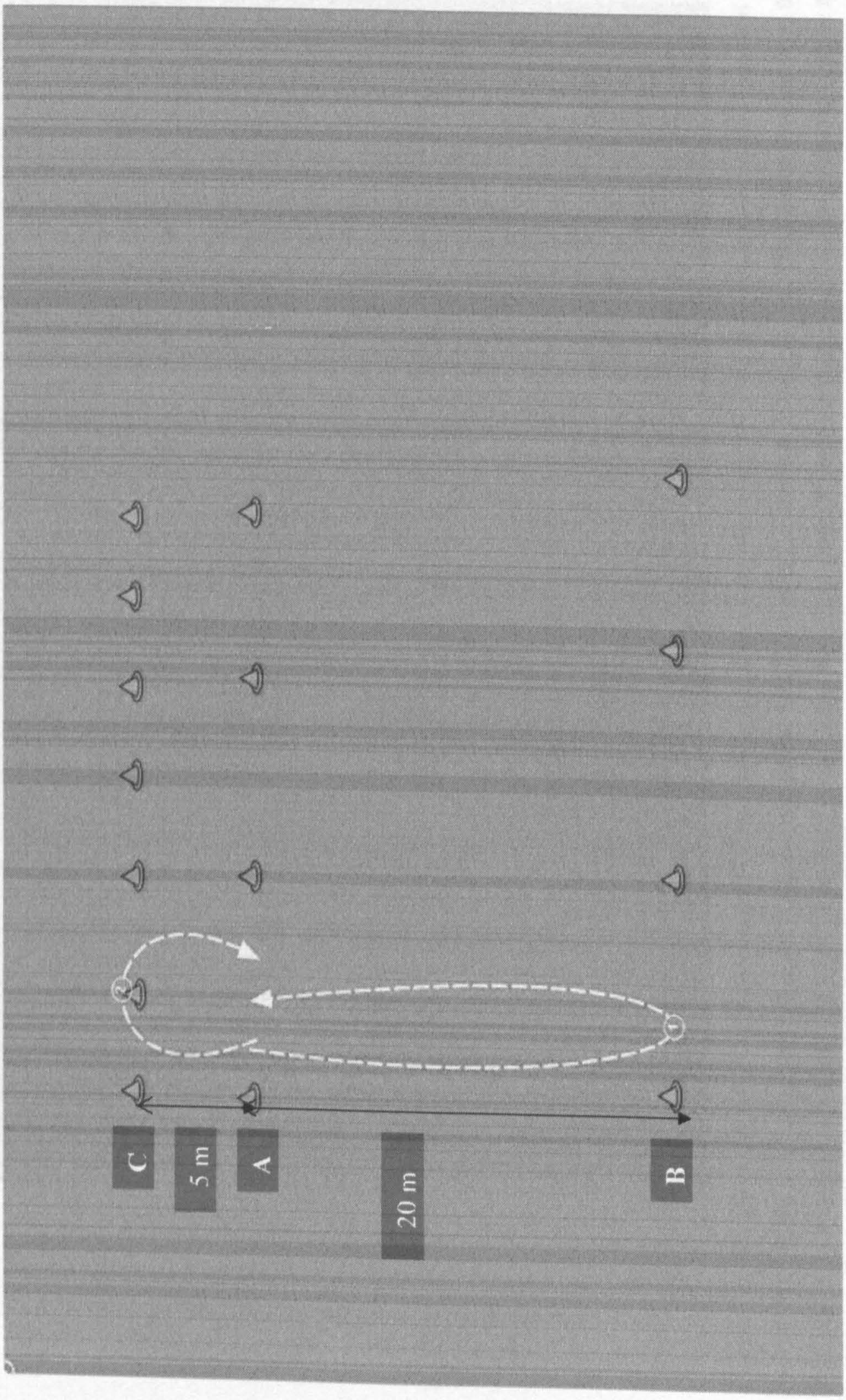


Figure 3.1. Test course for the Yo-Yo Intermittent Recovery Test (Level 1). The subjects started at A, ran up to B, turned and ran back to A (run 1). A 10-s recovery period followed where the subjects jogged around the cone at C and back to A in time for the next run (run 2).

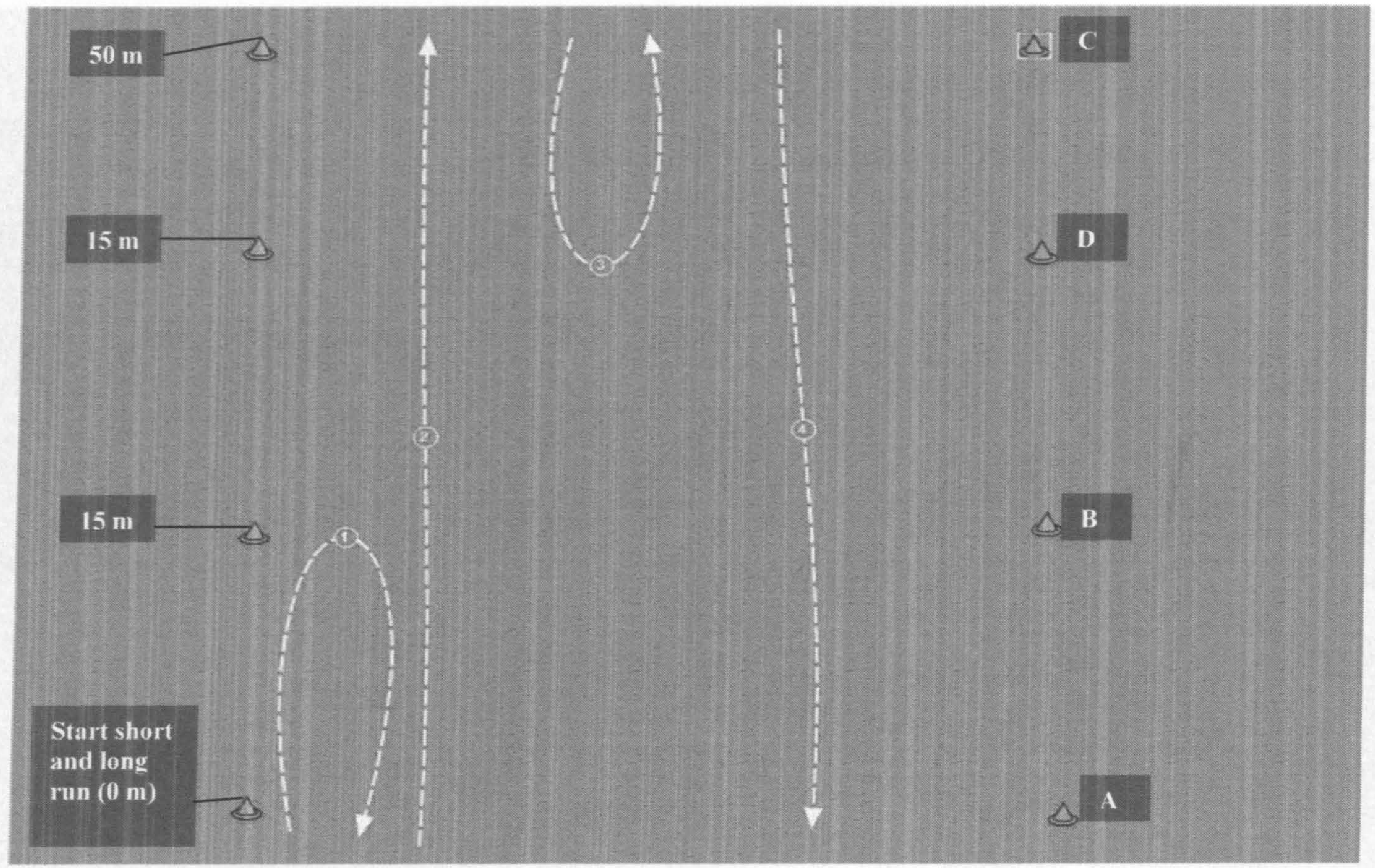


Figure 3.2. Test course for the 15-50 protocol (Part 1). The subjects started at A from which they ran 15-m to B, turned at the marker cones and ran back 15-m to A (run 1). This run had to be completed in 6 s. A 3-s passive rest period then followed before the start of the next run. The subjects then ran 50 m from A to C (run 2) which had to be completed in 9 s, followed by a 42-s recovery period before the subject started the next running cycle. This cycle started at C where they ran to D, turned and ran back to C in 6 s (run 3), followed by a 3-s passive rest period after which they ran from C to A in 9 s (run 4). One exercise block (400 m) consisted of 5 running cycles where one cycle was 80 m. The subjects completed 4 exercise blocks in total. The total distance covered in the 4 blocks was 1600 m (400 m x 4) in Part 1.

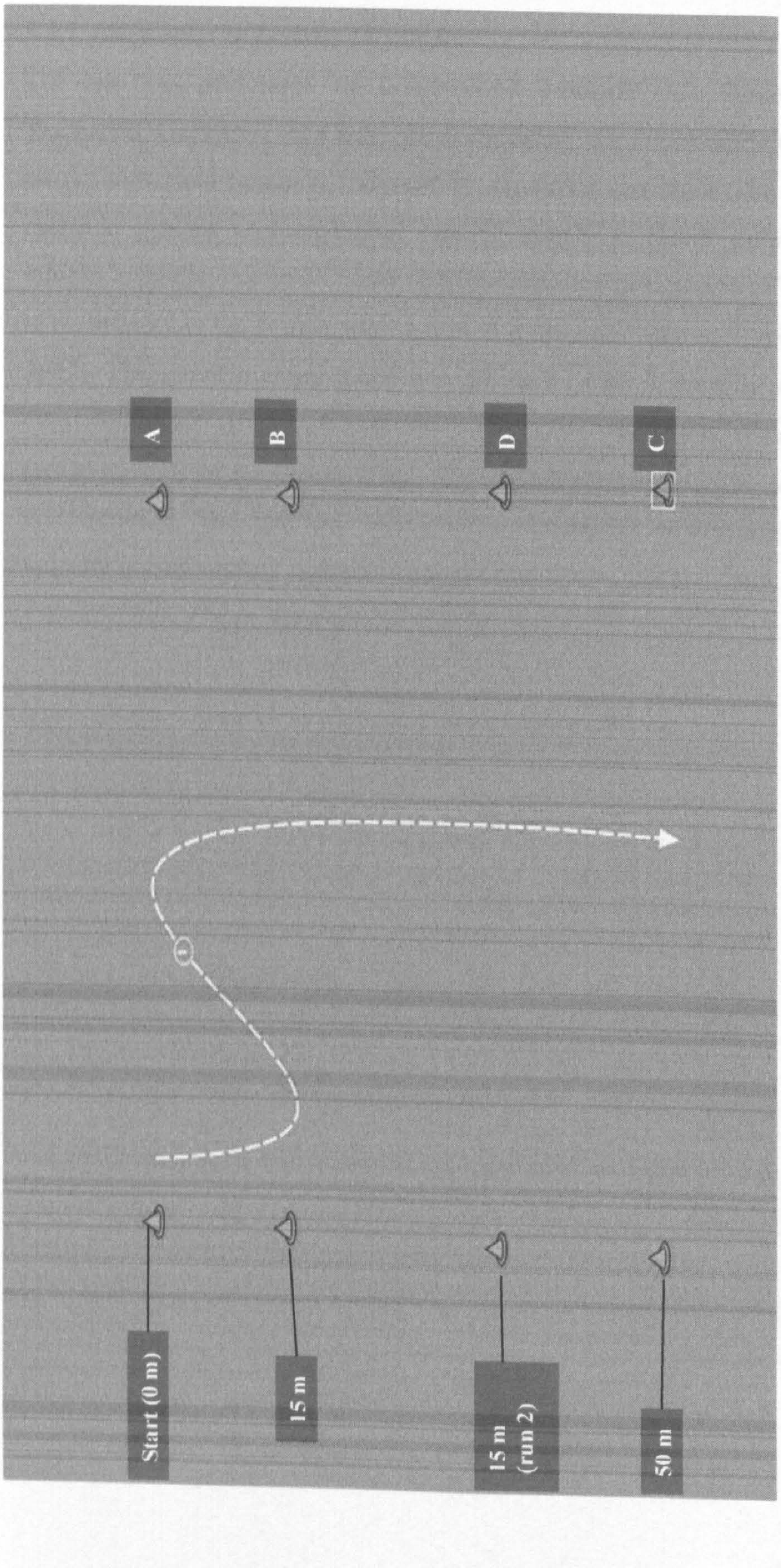


Figure 3.3. Test course for the 15-50 protocol (Part 2). The subjects started Part 2 at A from which they ran 15 m to B, turned at the marker cones, then ran 15 m back to A, turned and ran to C (run 1). This run had to be completed in 15 s. A 15-s passive rest period then followed before the start of the next run at C. The subjects followed the same running pattern as in run 1 where they started at C, ran to D, turned, ran back to C, turned and finally ran to A followed by a 15 s passive recovery period (run 2). One run was 80 m and the aim was to complete as many runs as possible.

3.3. Laboratory Tests

3.3.1. Assessment of Lactate Threshold

The test was performed on a motorised treadmill (h/p Cosmos Pulsar, Nüssdorf-Traunstein, Germany). The next phase consisted of a 5-min warm-up running at 8 $km.h^{-1}$ on the motorised treadmill followed by stretching exercises. The test consisted of sub-maximal running at incremental running speeds to detect lactate threshold at the 2 $mmol.l^{-1}$ and the 4 $mmol.l^{-1}$ onset of blood lactate accumulation (V-4 $mmol.l^{-1}$) velocities in accordance to the British Association of Sport and Exercise Science's criteria (BASES, 1997). The initial running speed was 10 $km.h^{-1}$ with a stepwise increment of 1 $km.h^{-1}$ every 4 minutes. After each stage there was a 30-s rest period where the subject put their feet to the side of the treadmill and a blood sample was taken to determine blood lactate concentration. The test was stopped on completion of the next stage following the velocity corresponding to the V-4 $mmol.l^{-1}$ mark.

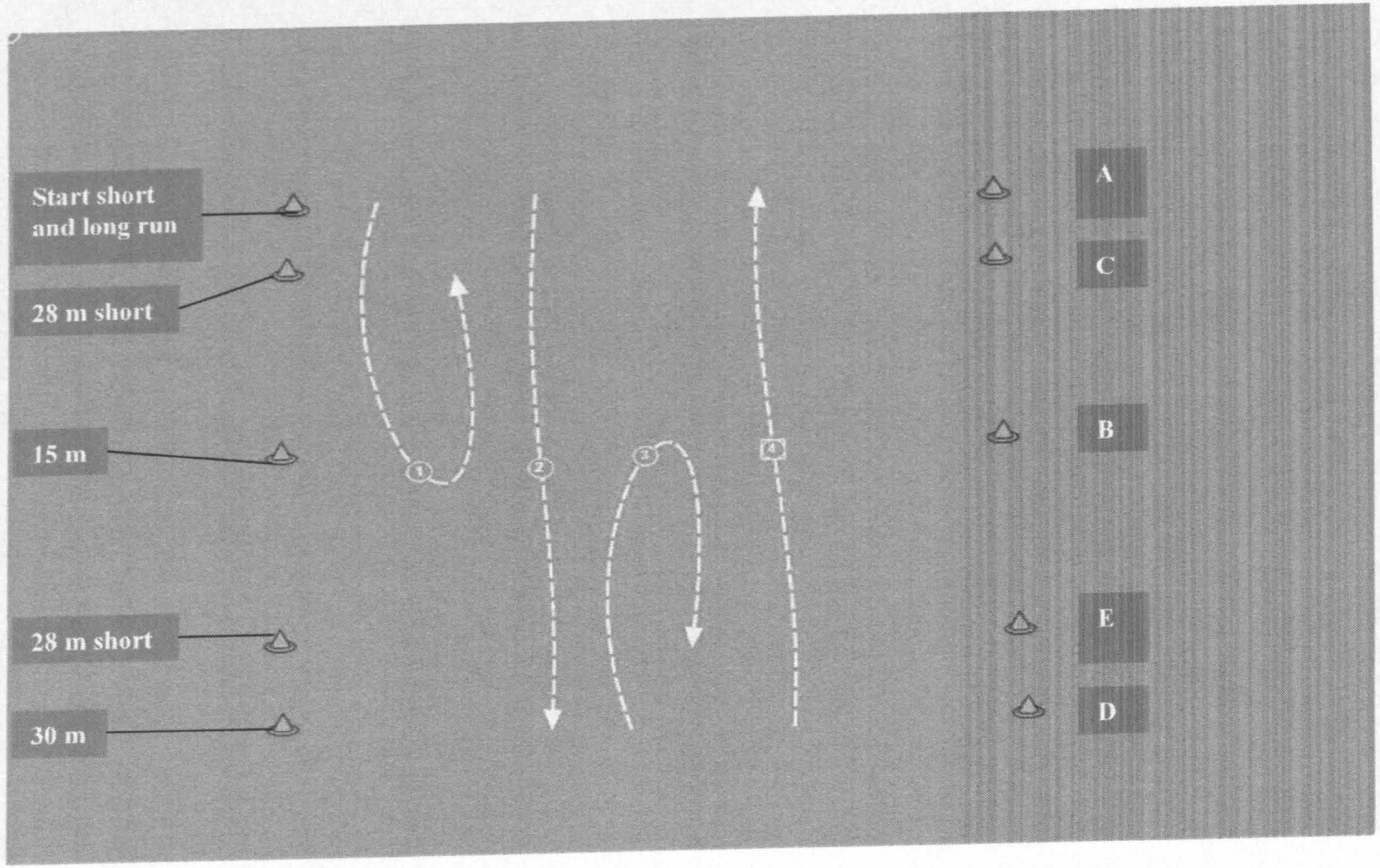


Figure 3.4. Test course for the 15-30 protocol (Part 1). The subjects started at A from which they ran to B, turned at the marker cones and ran back to C (run 1). This run had to be completed in 6 s. A 6-s passive rest period then followed before the start of the next run. The subjects then ran 30-m from A to D (run 2), which also had to be completed in 6-s. The subsequent recovery period was 12-s before the subject started the next running cycle at D where they ran to B, turned and ran back to E in 6-s (run 3), followed by a 6 s passive rest period and a run from D to A (run 4) in 6 s. One exercise block (406 m) consisted of 7 running cycles. The subjects completed 5 exercise blocks in total. The total distance covered in the 5 blocks was 2030 m (406 m x 5) in Part 1.

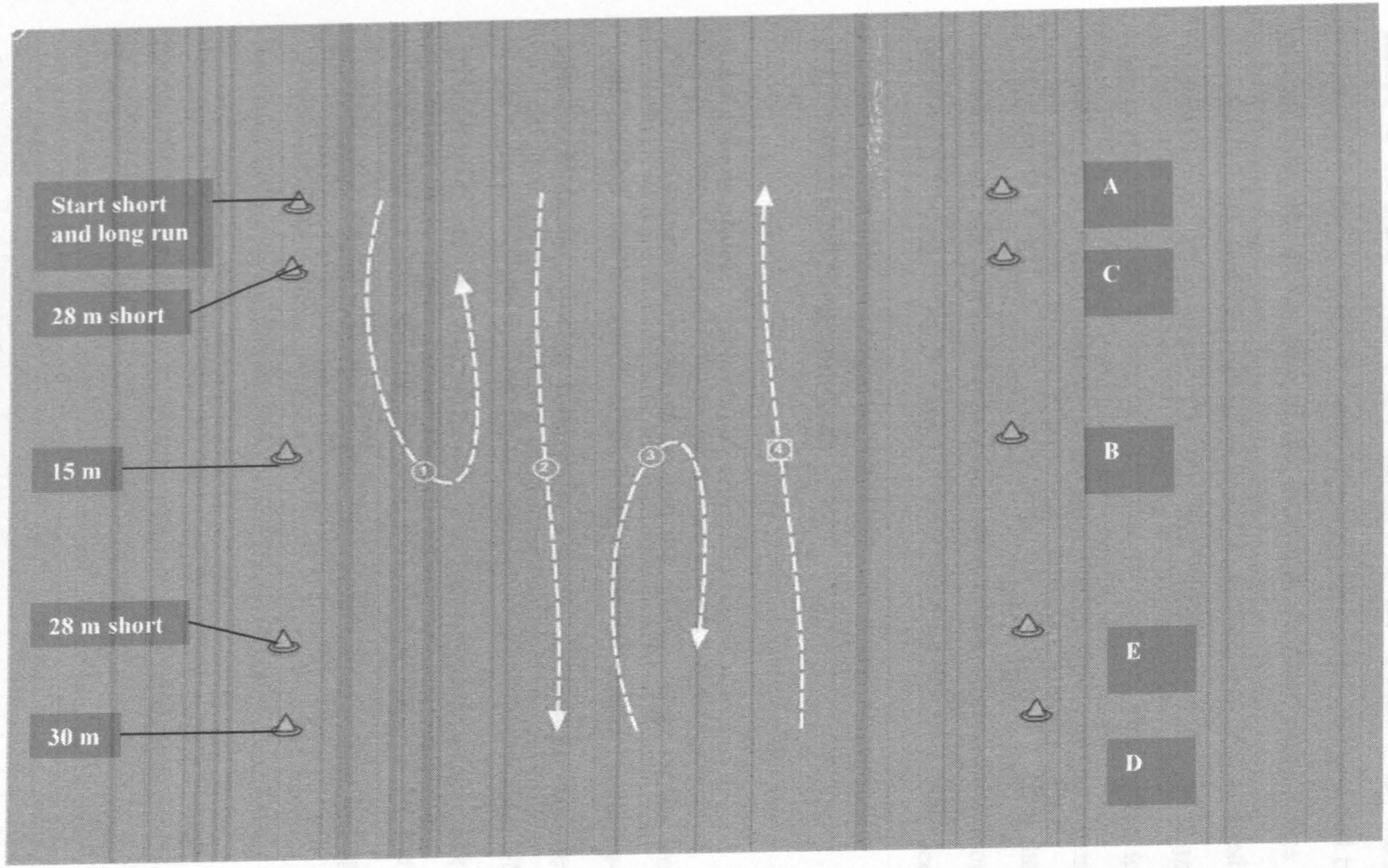


Figure 3.5. Test course for the 15-30 protocol (Part 2). The subjects started at A where they ran to B, turned in line with the cones and then ran back to C. This run had to be completed within 6-s. A 6-s passive rest period then followed after which they ran from A to D within 6-s. After the run a 6-s passive rest period followed. These two runs made up one exercise bout. The total distance covered for one bout was 58-m. The subjects then started the next bout at D where they ran to B, turned and ran back to E, 6-s passive rest and then ran from D to A followed by another 6-s passive rest. The subjects repeated these exercise bouts until they no longer could complete the runs within the allocated time period.

3.3.2. Assessment of Maximal Oxygen Consumption

The $\dot{V}O_{2max}$ test was performed 1 minute after the end of the lactate threshold test. The second part consisted of a maximal incremental test to exhaustion. The running speed started at 16 $km.h^{-1}$ with a 2% increase in the incline every minute. The test was terminated when the subjects voluntary stopped the test and grabbed both handlebars and putting their feet on the side of the treadmill. A blood sample was taken immediately after the test had finished. Maximal oxygen consumption was defined as the highest $\dot{V}O_2$ obtained in any 10-s period. The test was defined as maximal if any of the following criteria was achieved: failure of heart rate to increase with further increases in exercise intensity, RER >1.15, plateau of oxygen consumption despite increases in workload, post-exercise blood lactate concentration of >8 $mmol.l^{-1}$, final heart rate within 10 $beats.min^{-1}$ of age-predicted maximum and a rating of perceived exertion of 19 or 20 on the Borg 6-20 scale (British Association of Sport and Exercise Sciences, 1997).

3.4. Physiological Measurements

3.4.1. Gas Analysis

During the lactate threshold stage and the $\dot{V}O_{2max}$ stage of the treadmill test, oxygen consumption was measured continuously with an online breath-by-breath gas analysis system (MetaMax, Cortex Biophysik, Leipzig, Germany). The device was calibrated using a 3-l calibration syringe (MedGraphics, St Paul, Minnesota, USA) as well as gases of known O_2 and CO_2 concentrations. The subjects wore a facemask (Hans Rudolph Inc, Kansas City, USA) during the test that was connected to the gas analyser. The experimental set-up with one subject wearing the gas analyser during the treadmill test is shown in Figure 3.6.

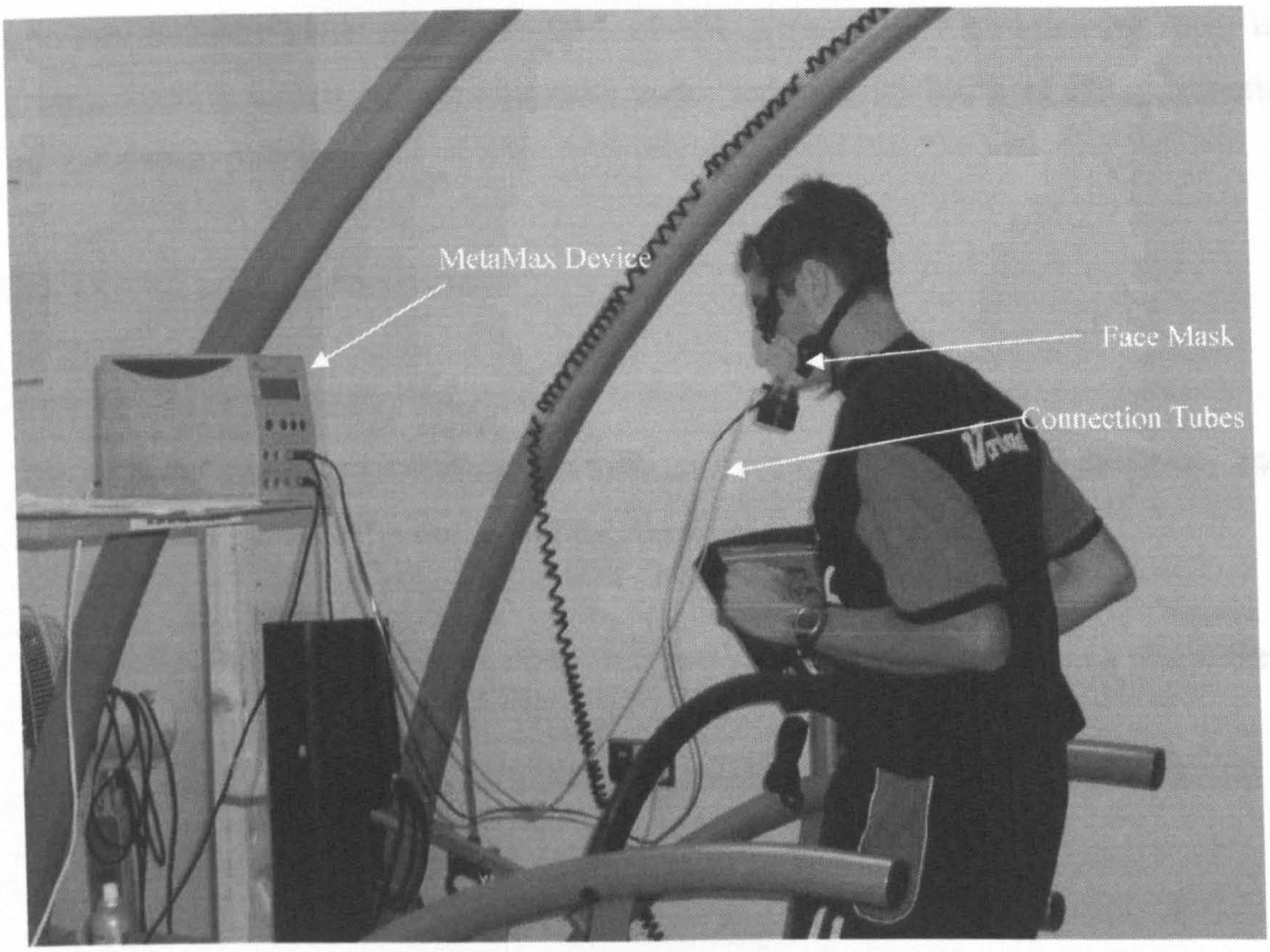


Figure 3.6. The experimental set-up during the laboratory treadmill test.

3.4.2. Blood Sampling

In order to establish the blood lactate concentration, a fingertip blood sample was carried out. The fingertip was first wiped with a medical swipe. The skin was then punctured at the fingertip using a Lancet and wiped off using a medical wipe. A small (2 μl) blood sample was then collected onto a test strip and analysed using a Lactate Pro blood lactate analyser (Arkray, Kyoto, Japan). The device displayed the lactate concentration within 60 s. Duplicate test strips was always used for every measurement with the mean value taken from the two measurements. The reliability of the Lactate Pro has been described elsewhere (Pyne *et al.*, 2000).

3.4.3. Heart Rate

Heart rate was measured every 5 s via short-range telemetry with either the Polar Team System (Polar Electro Oy, Kempele, Finland) during the field tests or Polar S810 (Polar Electro Oy, Kempele, Finland) during the laboratory tests. The heart rate data were then stored and analysed on a personal computer (Dell Latitude D600, Round Rock, Texas, USA). Heart rate was also classified in six zones and colour coded; 0-60% of HR_{peak} (recovery zone: blue); 60-75% of HR_{peak} (light intensity zone: green); 75-85% of HR_{peak}

(medium intensity zone: green); 85-90% of HR_{peak} (medium high-intensity zone: light green); 90-95% of HR_{peak} (high-intensity zone: red) and 95-100% of HR_{peak} (maximal intensity zone: pink).

3.5. Psychological Measurements

3.5.1. Ratings of Perceived Exertion

The subjects' perceived exertion was measured using a 6-20 Borg scale (Borg, 1998). The Borg scale used in the studies for this thesis is shown in Table 3.5.1.

Table 3.5.1. Borg scale used to rate the subjects' perceived exertion during and at the end of exercise.

Rating	*Description*
6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Chapter 4

The Reliability of a New High-Intensity Intermittent Running Protocol

4.1.1 Introduction

An important characteristic of soccer fitness is the ability to recover from periods of high-intensity exercise and be able to perform these over a prolonged period of time (Bangsbo, 1994b). This particular fitness component can be referred to as soccer-specific endurance. During a match there are periods where the aerobic energy system is maximally taxed leading to situations in the game where fatigue temporarily occurs (Krustrup *et al.*, 2006). Moreover, in the 5-min period following the most intense period during a match, it has been reported that the high-intensity work performed was below average for the game (Mohr *et al.*, 2003a). A priority for coaches and practitioners should therefore be to train and conveniently assess this particular component whenever possible.

The most practical method for coaches to assess soccer-specific endurance capacity is to use various field tests. Although laboratory tests of, for example, maximal aerobic power will convey very detailed information on the players aerobic fitness such tests are often time consuming and expensive compared to field tests. Recently, a number of field tests designed to evaluate soccer-specific endurance has been developed (Ekblom, 1989; Bangsbo, 1993b; Lemmink and Visscher, 2003). The more popular test has been the Yo-Yo tests which have been examined for reliability, validity (internal and external) and sensitivity to detect changes in training status. The duration of the majority of these tests is between 6-25 minutes where the running speed starts slowly and gradually increases until the participants reach exhaustion. With the incremental tests, it means that the time spent in very high-intensity exercise may be brief or about half test duration.

A test where the running speed is constant from the start and contains brief exercise periods interspersed with short recovery periods would reflect the high-intensity bouts characterised in the game. With separate sub-maximal and maximal components on a test, coaches can have the option of the intensity of the assessment. Based on these principles, a new unique high-intensity intermittent running protocol- the "15-50 protocol"- has been developed. The unique structure of the sub-maximal stage separates this stage into exercise blocks with a short passive rest period between blocks. The duration of the sub-maximal stage is also sufficient for the use as a conditioning drill allowing in addition to an assessment protocol. This unique structure and running pattern of the 15-50 protocol makes it distinct from other soccer-specific fitness tests.

By designing the 15-50 protocol, an attempt has been made to produce a test protocol that is different from the existing field tests. The aims of this study were to

1) examine the reliability of the protocol
2) assess the physiological responses during the protocol
3) evaluate the effectiveness of the protocol to be used for assessing soccer-specific endurance.

4.1.1.1 Limitations

- In two of the subject groups, the 15-50 protocol was performed outdoors on an artificial grass turf. As a result, some of the environmental conditions may have influenced the physiological responses during each test.
- The subjects were asked to refrain from any vigorous physical activity the day before the test. However, it is possible some subjects may have performed heavy exercise, which may have influenced the physiological responses during each test.
- The female elite players only performed Part 1 of the 15-50 protocol due to the tests being conducted in-season.
- Some subjects had to be removed from the study due to illness or injury.
- Blood lactate was only measured in the male recreational and male semi-professional groups due to lack of Lactate Pro test strips.
- Some heart rate data files were lost due to technical error with the Polar Team System belts.

4.1.1.2 Delimitations

- The subjects performed one experimental protocol (the 15-50 protocol) and one criterion protocol (the 20-m shuttle run).
- The subjects performed a series of test with each test occasion delimited by 3-6 days.
- The subject groups chosen were delimited male recreational players from Liverpool John Moores University, male semi-professional players from a Division 2 team in Sweden and female elite players from a women's team in the Swedish Premier League.

- The physiological measurements were delimited to heart rate and blood lactate.
- The psychological measurement was delimited to rating of perceived exertion.

4.1.2 Methods

4.1.2.1 Subjects

Twelve male recreational soccer players from the Liverpool John Moores University soccer team (Group 1), ten male semi-professional soccer players from a Swedish Division 2 team (Group 2) and eight female semi-professional players from a Swedish Premier League team (Group 3) were recruited as subjects for the reliability study of the 15-50 protocol. During the course of this reliability study, 5 subjects (2 from the male recreational group and 3 from the male semi-professional group) did not complete all the tests due to either injury or illness. These subjects were excluded from the data analysis. In total, 10 subjects from Group 1 and 7 from Group 2 completed the study and their physical characteristics are shown in Table 4.1.2.1. All of the subjects were informed of the benefits, risks and stresses before giving their written consent to take part in the study. Ethical approval was received from the Ethics Committee of Liverpool John Moores University.

Table 4.1.2.1. Physical characteristics of the different subject groups.

Subjects	*Age*	*Height (m)*	*Body mass (kg)*	*Stages of 15-50 protocol performed*	*Number of 15-50 trials (excluding familiarisation)*
Group 1 (N = 10)	23.9 ± 1.9	1.77 ± 0.04	71.0 ± 4.9	Part 1 + Part 2	3
Group 2 (N = 7)	24.4 ± 5.7	1.76 ± 0.04	66.6 ± 5.0	Part 1 + Part 2	3
Group 3 (N = 8)	22.4 ± 3.8	1.69 ± 0.06	60.7 ± 5.4	Part 1	3

4.1.2.2 Test Location and Procedure

The 20-m shuttle run was performed either indoors on a tartan running track at Liverpool John Moores University (Group 1), indoors on an artificial grass turf (Group 2) or indoors in a sports hall with wooden floor (Group 3). The 15-50 protocol was conducted either outdoors on an artificial grass turf at I.M. Marsh campus, Liverpool John Moores University (Group 1) and Behrn Arena, Örebro SK, Sweden (Group 3) or indoors on a artificial grass turf at Elajohallen, Oskarshamns AIK, Sweden (Group 2).

4.1.2.3. Field Tests

4.1.2.3.1. The 20-m Shuttle Run

Initially the subjects performed the 20-m shuttle run to estimate $\dot{V}O_{2max}$ and establish peak heart rate (HR_{peak}). The details of the 20-m shuttle run have been described in section 3.1.1.

4.1.2.3.2. The 15-50 Protocol

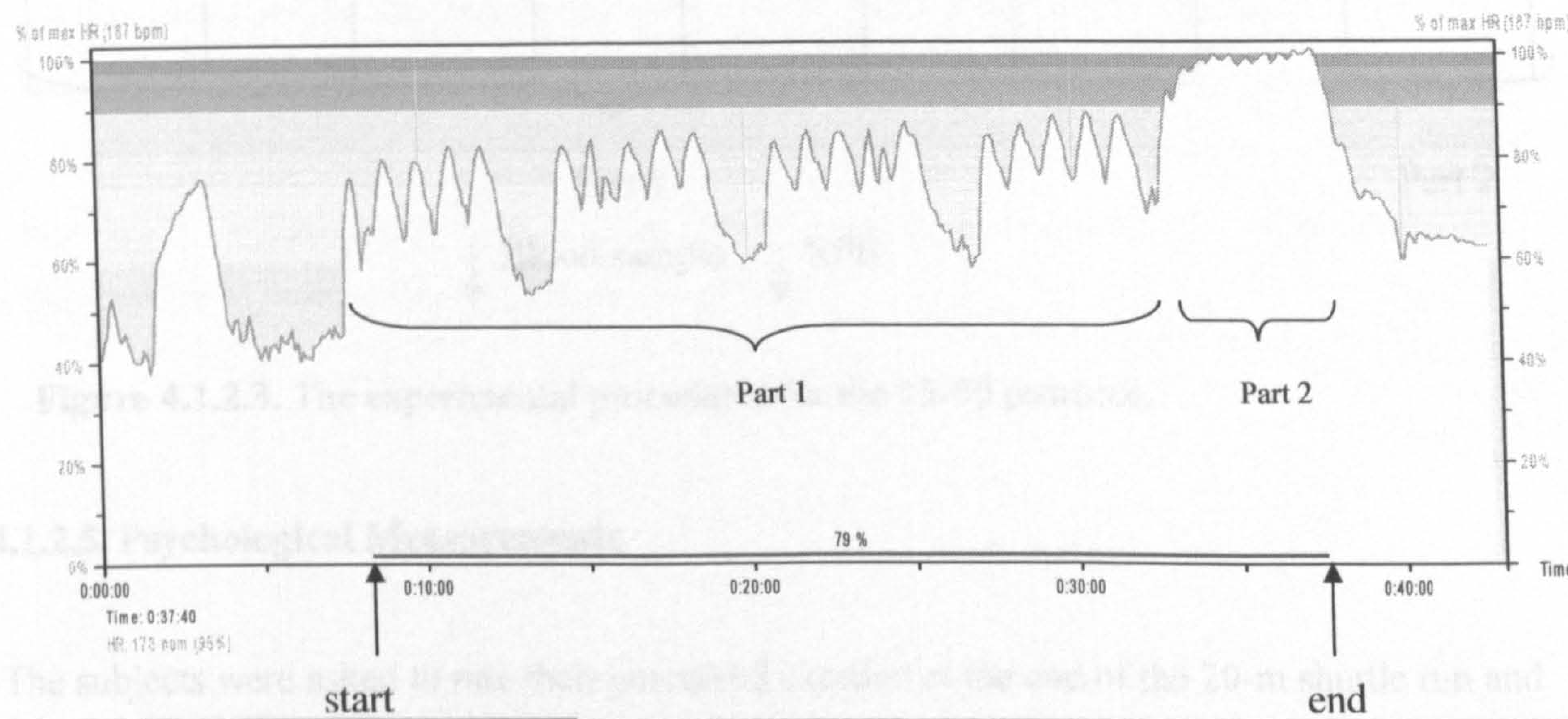
One week following completion of the 20-m shuttle run the subjects performed the 15-50 protocol. This initial test was completed to familiarise the subjects with the test protocol and procedures. Upon completion of this test, all subject groups then performed the 15-50 protocol on three further occasions (i.e. Test 1, Test 2 and Test 3) with 3-6 days separating each trial. The test course for the 15-50 protocol has been described in section 3.1.3. The test course was adapted for the female players where they ran 2 x 13 m for the short run and 46 m for the long run.

Figure 4.1.2.1. Two subjects from Group 2 performing the 15-50 protocol.

4.1.2.4. Physiological Measurements

4.1.2.4.1. Heart Rate

For all the tests, heart rate was measured every 5 s via short-range telemetry with the Polar Team system (Polar Electro Oy, Kempele, Finland) as described in section 3.4.3. Firstly, the mean heart rate was expressed as the entire duration of Part 1 with the total duration 24 min 30 s (including exercise block and rest periods). Secondly, the heart rate for each individual exercise block and rest period was analysed separately to allow comparison of heart rate between blocks.



Person	[redacted]	Date	2004-11-08	Heart rate average	148 (79%)	
Exercise	2004-11-08 15:09	Time	15:09:13	Heart rate max	189 (101%)	
Sport	Running	Duration	0:42:35.0			
Note	Test 2			Selection	0:08:20 - 0:37:40 (0:29:20.0)	

Figure 4.1.2.2. Heart rate profile of one subject during the 15-50 protocol from the Polar Precision Performance Software version 4.0.

Heart rate data were also divided into heart rate zones as shown in Figure 4.1.2.2. Each zone and the corresponding colour were defined as: recovery zone (blue): <60% of HR_{peak}; low-intensity zone (yellow): 60-75% of HR_{peak},; medium intensity zone (green): 75-85% of HR_{peak},; medium high-intensity zone (light green): 85-90% of HR_{peak},; high-intensity zone (red): 90-95% of HR_{peak},; maximal zone (pink): 95-100% of HR_{peak}, *4.1.2.4.2. Blood Lactate*

Blood samples were taken at rest and immediately after the last completed exercise bout in Part 2. The same procedure was also performed immediately after the last completed exercise bout in Part 2. Blood samples were only taken from Group 1 (N = 10) and Group 2 (N = 7). A description of the experimental protocol during the 15-50 protocol is shown in Figure 4.1.2.3.

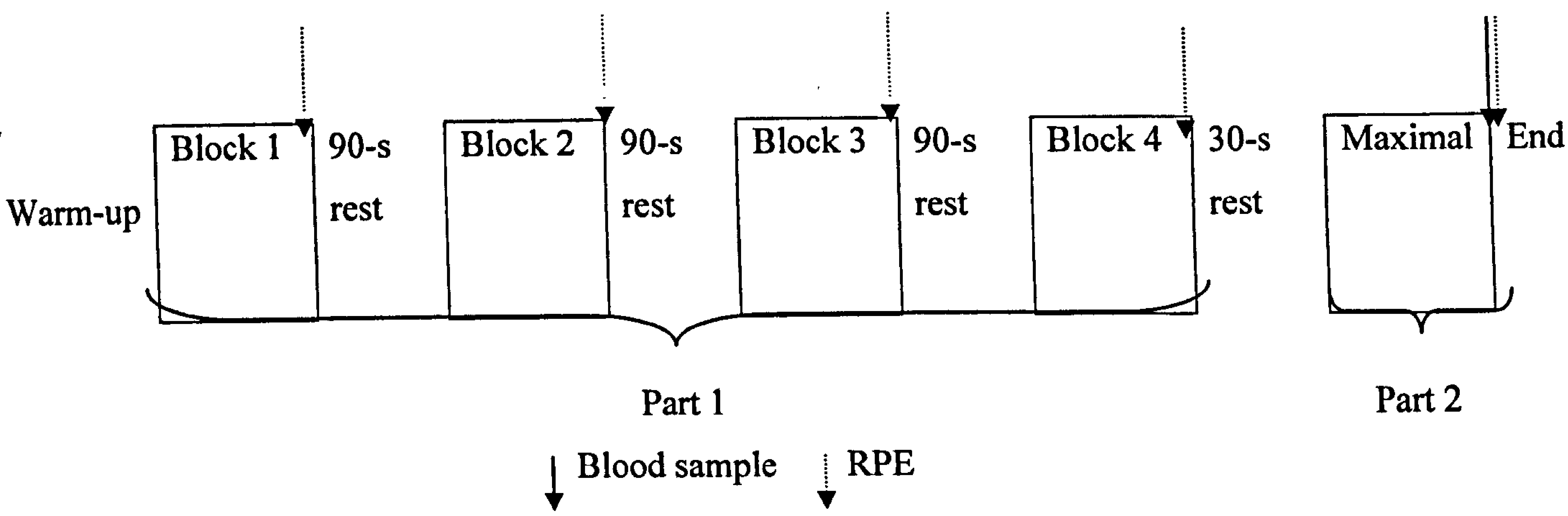


Figure 4.1.2.3. The experimental procedures for the 15-50 protocol.

4.1.2.5. Psychological Measurements

The subjects were asked to rate their perceived exertion at the end of the 20-m shuttle run and at the end of each exercise block in Part 1 and at the end of Part 2 using the Borg scale described in section 3.5.1.

4.1.2.6. Statistical Analysis

The current study was a repeated measures design. All the data were expressed as means ± SD unless otherwise stated. The data were tested for normality using the Shapiro-Wilk test after which the appropriate statistical test was chosen. Comparisons of distance covered and estimated $\dot{V}O_{2max}$ in the 20-m shuttle run between the subject groups, mean heart rate in Part 1 and Part 2, HR_{peak} in Part 2, distance covered in Part 2, blood lactate at rest and after Part 2 between the three tests were made using analysis of variance (one-way ANOVA). A repeated analysis of variance (two-way ANOVA) was used to compare the heart rate during each test stage (block and rest periods), ratings of perceived exertion between blocks and time spent in each heart rate zone. The Mann-Whitney U-Test was used to test for differences in distance covered in Part 2 between the male recreational group and the male semi-professional group. When Mauchley's test of sphericity indicated a minimal level of violation (>0.75) the degrees of freedom was corrected using the Huynh-Feldt adjustment. When sphericity was <0.75, the Greenhouse Geiser correction was used.

The 95% limits of agreement with Bland and Altman plots were selected to represent the within-individual error and provide an indication of the systematic bias and random error by examining the direction and magnitude of the scatter around the zero reference line (Bland and Altman, 1986). Coefficient of variation was calculated using the formulae $SD_{diff}/\sqrt{2}$/grand mean. Statistical power was calculated using MINITAB for Windows. Statistical significance was set at $p<0.05$ for all tests apart from $p<0.01$ for the Pearson's product moment correlation. All the statistical analysis was performed using SPSS for Windows version 12.0.1 (Chicago, IL, USA) apart from the estimated sample size which was calculated using MINITAB for Windows (State College, PA, USA).

4.1.3 Results

4.1.3.1. 20-m Shuttle Run

The results from the 20-m shuttle run are shown in Table 4.1.3.1. A significant difference was reported between Group 1 and Group 3 in the estimated $\dot{V}O_{2max}$ ($F_{2\,21} = 6.027$, $p<0.05$) and distance covered ($F_{2\,21} = 7.346$, $p<0.05$) respectively.

Table 4.1.3.1. Results from the 20-m shuttle run in the three subject groups.

Subject group	*Distance covered (m)*	*Estimated $\dot{V}O_{2max}$ (ml.kg^{-1}.min^{-1})*	*HR_{peak} (beats.min^{-1})*
Group 1 (N = 10)	2132 ± 329	53.5 ± 5.3	193 ± 9
Group 2 (N = 7)	2406 ± 200	57.8 ± 2.8	195 ± 7
Group 3 (N = 8)	1866 ± 200†	50.3 ± 2.9†	194 ± 4

†significant different ($p<0.05$) to Group 2

4.1.3.2. 15-50 Protocol- Part 1

All the subjects in the three groups completed Part 1 and covered a total distance of 1600 m in each test. The heart rate data for Part 1 of the 15-50 protocol for all subject groups is shown in Table 4.1.3.2. The heart rate data are the mean of the full duration of Part 1 including all blocks and rest periods analysed together. Although there was a trend for heart rate to be lower for each test, no significant difference was reported for Group 1 ($F_{2\,27} = 0.092$, $p>0.05$), Group 2 ($F_{2\,18} = 1.626$, $p>0.05$) or Group 3 ($F_{2\,21} = 2.168$, $p>0.05$). The mean coefficient of variation for heart rate in Part 1 between Test 2-Test 3 was 5.3% for Group 1, 5.4% for Group 2 and 4.7% for Group 3.

Table 4.1.3.2. Heart rate responses during Part 1 in the three subject groups.

	Heart rate (beats.min^{-1}; % of HR_{peak})		
Subject group	*Test 1*	*Test 2*	*Test 3*
Group 1 (N = 10)	152 ± 12	150 ± 12	150 ± 12
	(78.7 ± 3.6)	(78.0 ± 3.9)	(77.8 ± 4.3)
Group 2 (N = 7)	164 ± 7	159 ± 10	152 ± 9
	(81.3 ± 3.2)	(77.9 ± 3.6)	(76.9 ± 1.7)
Group 3 (N = 8)	162 ± 8	153 ± 13	152 ± 8
	(81.9 ± 3.2)	(77.5 ± 6.1)	(77.3 ± 3.9)

The systematic bias and random error and the upper and lower limits of agreement for heart rate between Test 2-Test 3 were 0.3 ± 5.9 and 12 to -11 beats.min^{-1} respectively for Group 1. For Group 2 these were 1.4 ± 5.0 and 11 to -8 beats.min^{-1} with 0.8 ± 6.1 and 13 to -11 beats.min^{-1} for Group 3. The upper and lower limits of agreement represent a maximal "worst case" scenario in the three subject populations. For example, if a subject from Group 2 had a heart rate of 150 beats.min^{-1} during Part 1, the heart rate during a retest on a given day might be as low as 143 beats.min^{-1} or as high as 158 beats.min^{-1}.

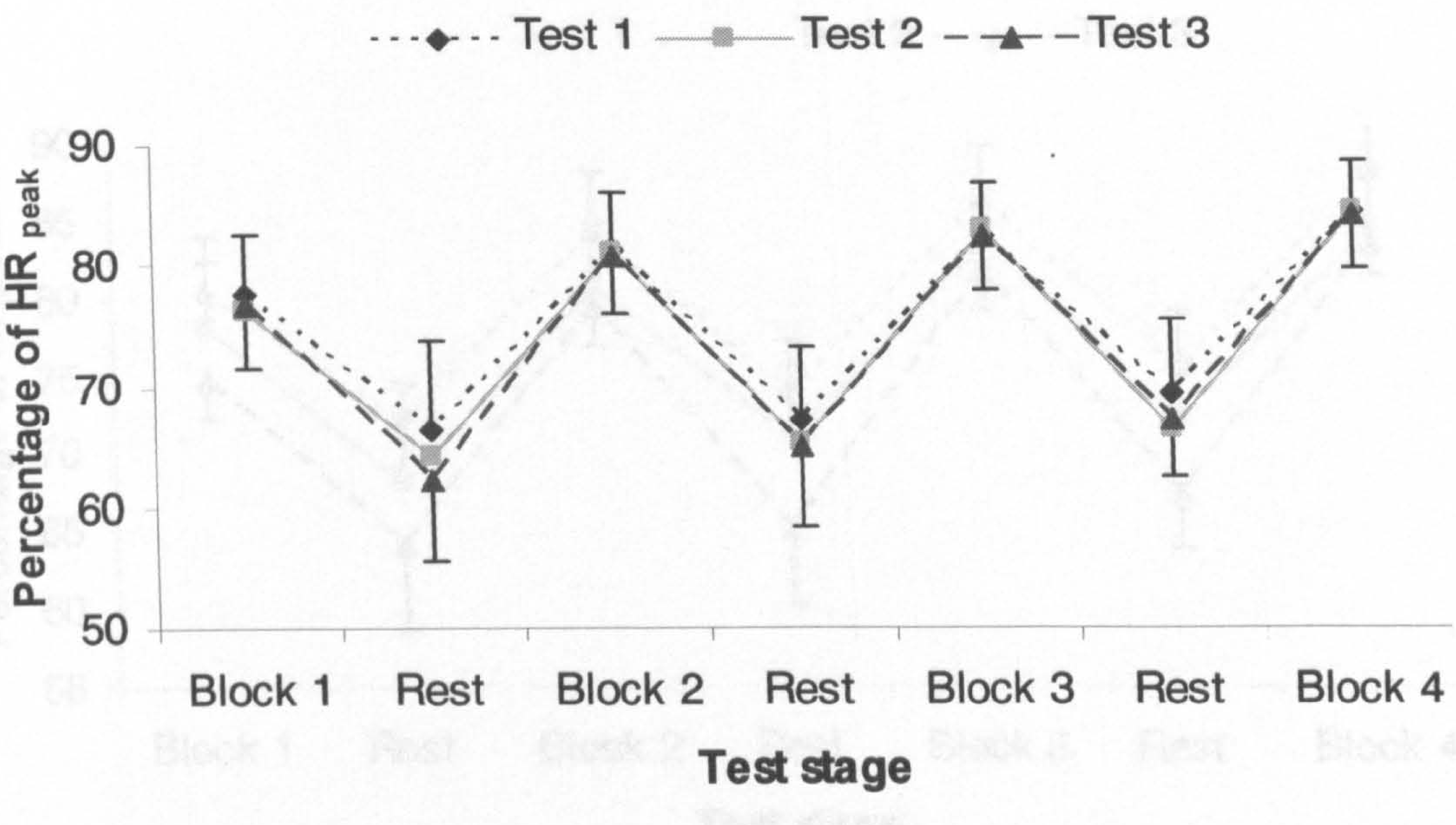


Figure 4.1.3.1. Mean heart rate (% of HR_{peak}) for Group 1 during the different test stages in Part 1 of the 15-50 protocol (*significant difference block-rest period).

There was no significant difference ($F_{2\ 18} = 1.60$, $p>0.05$) in the mean heart rate during Part 1 between the three tests in Group 1 as shown in Figure 4.1.3.1. There was a significant difference ($F_{8\ 72} = 100.85$, $p>0.05$) in heart rate between the different test stages (exercise and rest periods). Post-hoc analysis revealed that each rest period was significantly different from the exercise periods. There was no significant interaction ($F_{16\ 144} = 1.03$, $p>0.05$) between each test and the test stages of the 15-50 protocol.

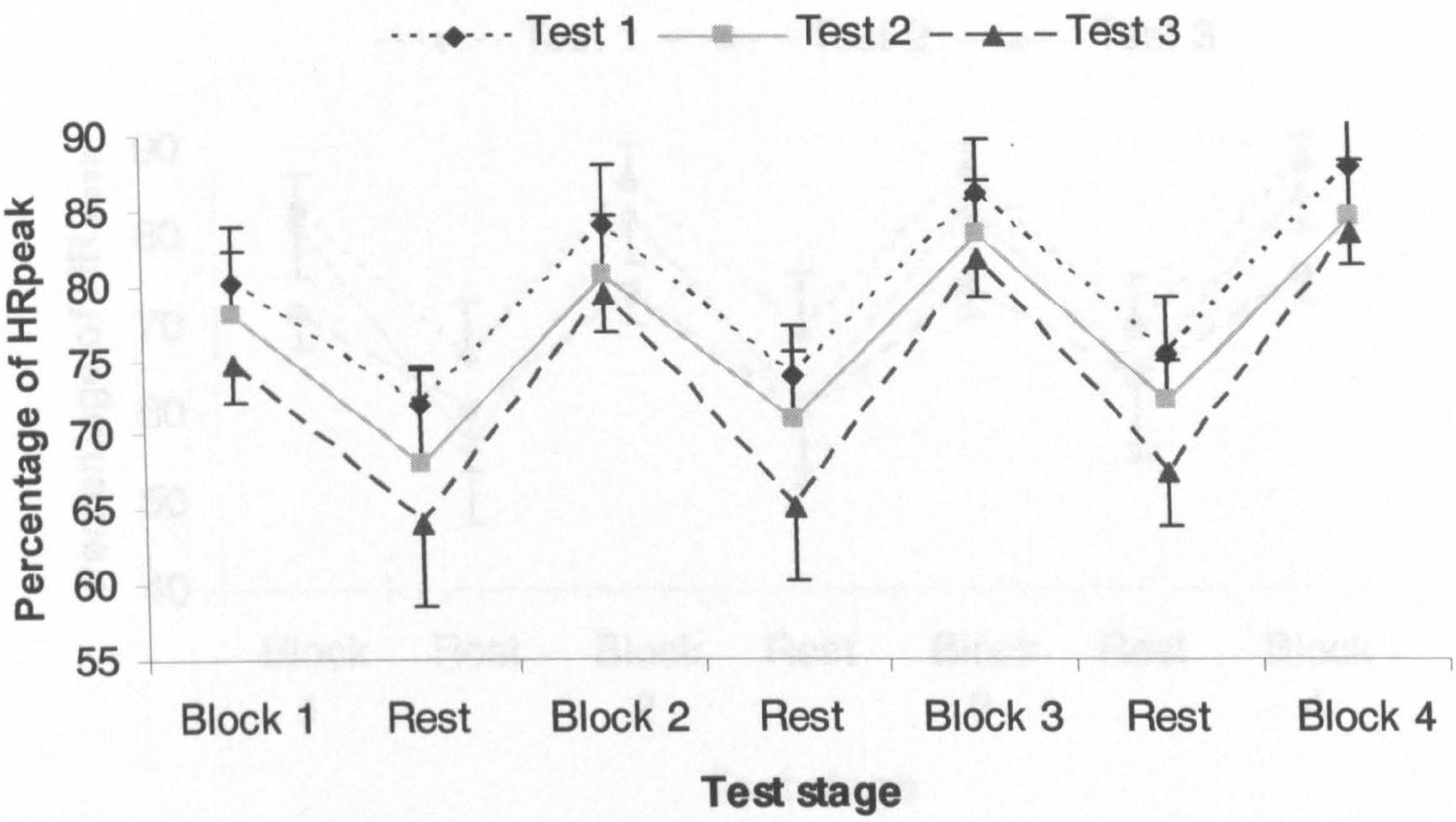


Figure 4.1.3.2. Mean heart rate (% of HR_{peak}) for Group 2 during the different test stages in Part 1 of the 15-50 protocol (*significant difference tests and block-rest period).

For Group 2, there was a significant difference ($F_{2\ 12} = 34.044$, $p<0.05$) in the mean heart rate for the test stages between the three tests as shown in Figure 4.1.3.2. The differences occurred between Test 1-Test 2, Test 1-Test 3 and Test 2-Test 3. A significant difference ($F_{6\ 36} = 104.12$, $p<0.05$) in the heart rate was also found between most test stages in Part 1. There was no significant interaction ($F_{12\ 72} = 1.15$, $p>0.05$) between test and the test stage of the 15-50 protocol.

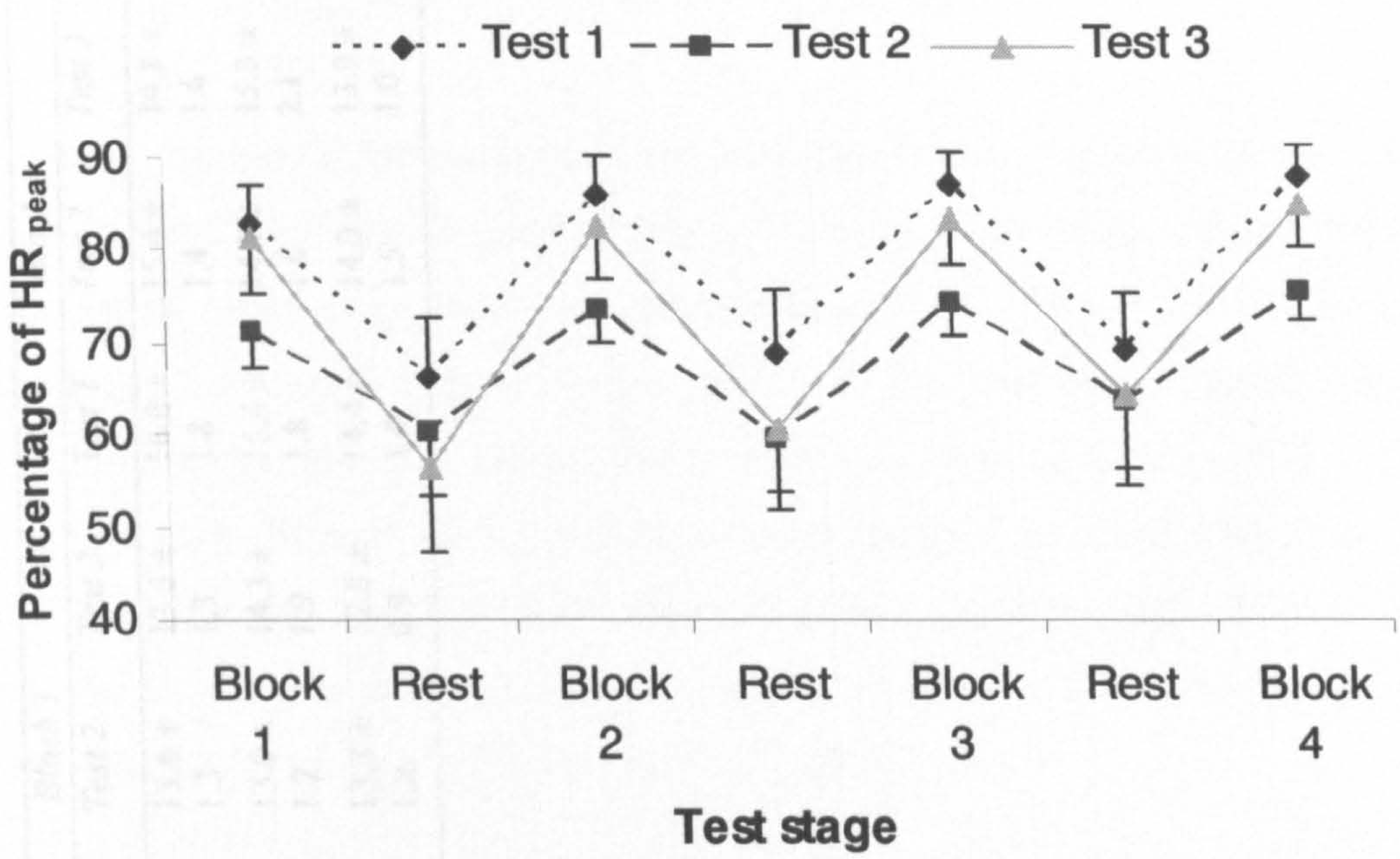


Figure 4.1.3.3. Mean heart rate (% of HR_{peak}) for Group 3 during the different test stages in Part 1 of the 15-50 protocol (*significant difference tests, block-rest periods.

There was a significant difference in mean relative heart rate for Group 3 between the tests ($F_{2\ 14} = 6.50$, $p<0.05$), as shown in Figure 4.1.3.3. Post-hoc analysis revealed that the significant differences occurred between Test 1-Test 3. There was also a significant difference in the mean relative heart rate between each block ($F_{3\ 21} = 34.62$, $p<0.05$). A significant interaction was also reported between test and block ($F_{6\ 42} = 4.60$, $p<0.05$).

Perceived exertion was significantly lower ($F_{2\ 18} = 10.27$, $p<0.05$) in Test 3 compared to Test 1 for Group 1, as shown in Table 4.1.3.3. There was no significant difference reported in the mean perceived exertion for either Group 2 ($F_{2\ 12} = 0.541$, $p>0.05$) or Group 3 ($F_{2\ 14} = 2.91$, $p>0.05$) between the three tests as shown in Table 4.1.3.3.

Table 4.1.3.3. Ratings of perceived exertion during Part 1 of the 15-50 protocol for the three subject groups.

	Block 1			Block 2			Block 3			Block 4		
Subject group	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*
Group 1 (N = 10)*	12.6 ± 1.3	11.9 ± 0.7	11.4 ± 1.3	13.7 ± 1.2	12.8 ± 0.6	12.6 ± 1.0	14.9 ± 1.6	13.6 ± 1.3	13.6 ± 1.3	16.0 ± 1.8	15.4 ± 1.4	14.8 ± 1.6
Group 2 (N = 7)	12.3 ± 1.1	12.1 ± 1.1	12.1 ± 1.7	13.4 ± 1.1	13.1 ± 1.1	13.4 ± 1.9	14.4 ± 1.6	13.9 ± 1.2	14.3 ± 1.9	15.4 ± 1.8	14.7 ± 1.6	15.3 ± 2.1
Group 3 (N = 8)	12.5 ± 1.1	11.6 ± 1.7	11.3 ± 1.4	13.4 ± 1.3	12.1 ± 1.8	12.3 ± 1.1	14.1 ± 1.5	13.3 ± 1.8	12.8 ± 0.9	14.4 ± 1.4	14.0 ± 1.5	13.0 ± 1.0

*significant difference Test 1-Test 3

4.1.3.2 The 15-50 Protocol- Part 2

There was no significant difference in the mean heart rate in Part 2 between the three tests for Group 1 ($F_{2\,27}$ = 0.25, p>0.05) or Group 2 ($F_{2\,18}$ = 0.26, p>0.05), as shown in Table 4.1.3.2. The coefficient of variation for heart rate between Test 2-Test 3 was 2.7% for Group 1 and 1.7% for Group 2. Group 3 only performed Part 2 in the final trial (Test 3) where they covered a total distance of 567 ± 170 m. The mean HR_{peak} reached during Part 2 in Group 1 was not significantly different ($F_{2\,27}$ = 0.54, p>0.05) between the three tests (Test 1: 98 ± 3.5%, Test 2: 99.4 ± 3%, Test 3: 98.9 ± 2.6%) of the HR_{peak} reached in the 20-m shuttle run. The HR_{peak} for Group 2 was also not significant different ($F_{2\,18}$ = 0.47, p>0.05) between the tests (Test 1: 98.6 ± 1.4%, Test 2: 98 ± 2.2%, Test 3: 99 ± 2.2%).

Table 4.1.3.4. Heart rate responses during Part 2 in the three subject groups.

	Heart rate (beats.min^{-1}) (% of HR_{peak})		
Subject group	*Test 1*	*Test 2*	*Test 3*
Group 1 (N = 10)	182 ± 6 (93.1 ± 5.3)	184 ± 7 (95.2 ± 2.6)	183 ± 7 (94.9 ± 2.4)
Group 2 (N = 7)	186 ± 7 (95.4 ± 2.0)	187 ± 5 (95.7 ± 1.5)	188 ± 5 (96.4 ± 1.5)
Group 3 (N = 8)	x	x	192 ± 6 (98.1 ± 1.6)

The performance data from Part 2 of the 15-50 Protocol are shown in Table 4.1.3.6. The percentage improvement in distance covered in Part 2 between Test 1-Test 2 and Test 2-3 was 10.7% and 2.9% (Group 1) and 31.1% and 10.1% (Group 2). No significant difference was found between the three tests for either Group 1 ($F_{2\,18}$ = 0.19, p>0.05) or Group 2 ($F_{2\,18}$ = 3.44, p>0.05). The mean coefficient of variation for distance covered between Test 2-Test 3 was 29.9% for Group 1 and 13.4% for Group 2 respectively. For Group 1, there was no significant difference in the blood lactate concentration between the tests at rest ($F_{2\,27}$ = 0.12, p>0.05) or at the end of Part 2 ($F_{2\,27}$ = 0.16, p>0.05). There was also no significant difference ($F_{2\,9}$ = 0.52, p>0.05) in the blood lactate concentration at the end of Part 2 between the tests for Group 2. The upper and lower limits of agreement for heart rate, distance covered and blood lactate in Part 2 are shown in Table 4.1.3.5. For example, in terms of the distance covered, if someone performs 10 shuttles in Part 2, the retest score on a given day may be as few as 7 shuttles (~240 m) or as many as 11 shuttles (~80 m).

The rated perceived exertion at the end of Part 2 for Group 1 was 20.0 ± 0 (Test 1), 20.0 ± 0 (Test 2) and 20.0 ± 0 (Test 3) respectively with no significant difference between tests. For Group 2, there was also no significant change in the perceived exertion between the three tests (Test 1: 19.9 ± 0.1; Test 2: 20.0 ± 0; Test 3: 20.0 ± 0).

Table 4.1.3.5. Upper and lower 95% limits of agreement with the systematic bias and random error between Test 2-Test 3 in the performance variables for Part 2 in Group 1 and Group 2.

	Systematic bias± random error		*Upper and lower 95% limits of agreement*	
Performance variable	*Group 1 (N = 10)*	*Group 2 (N = 7)*	*Group 1 (N = 10)*	*Group 2 (N = 7)*
Heart rate (beats.min^{-1}) in Part 2	0.7 ± 2.9	-1.7 ± 3.2	6 to -5	5 to -8
Distance covered (m) Part 2	-12 ± 84	-68 ± 85	153 to -177	99 to -235
Blood lactate (mmol.l^{-1}) after Part 2	-0.5 ± 1.5	#	2.5 to -3.5	#

Table 4.1.3.6. Performance data from Part 2 in the 15-50 protocol from Group 1 and Group 2 (no blood samples were taken in Group 3).

	Test 1			*Test 2*			*Test 3*		
Subject group	*Distance covered (m)*	*Blood lactate ($mmol.l^{-1}$) pre-test*	*Blood lactate ($mmol.l^{-1}$) post-test*	*Distance covered (m)*	*Blood lactate ($mmol.l^{-1}$) pre-test*	*Blood lactate ($mmol.l^{-1}$) post-test*	*Distance covered (m)*	*Blood lactate ($mmol.l^{-1}$) pre-test*	*Blood lactate ($mmol.l^{-1}$) post-test*
Group 1 (N = 10)	372 ± 233	1.2 ± 0.6	13.0 ± 2.9	412 ± 171	1.4 ± 0.7	13.2 ± 2.8	424 ± 192	1.3 ± 0.5	13.7 ± 2.4
Group 2 (N = 7)	514 ± 210	1.5 ± 0.4	13.0 ± 1.9	674 ± 172	#	14.0 ± 2.8	743 ± 100	#	14.4 ± 1.4

#no resting blood lactate data due to technical problems during blood sampling, †N = 4

4.1.4 Discussion

The main finding of this study was that several familiarisation sessions were needed to reduce the learning effect on the 15-50 protocol in all the subject groups. The physiological responses during the 15-50 protocol showed that there was a moderate to high aerobic load in Part 1 and a high anaerobic load in Part 2.

4.1.4.1 Reliability

Several tests were needed to familiarise the subjects in the three groups fully to the 15-50 protocol. There was evidence for a physiological adaptation in the groups following each test from the performance measures in Part 1 and Part 2. The learning effect seemed to have subsided after Test 3. The mean heart rate in Part 1 was gradually lower for each of the tests in the three subject groups as shown in Table 4.1.3.2. However, this decrease in heart rate was not significant. When comparing mean heart rates at the different test stages in Part 1, there was a significant difference for Group 2 and Group 3, as shown in Figures 4.1.3.2 and 4.1.3.3. The lower heart rate may be due to an improved running economy due to a familiarisation effect. There was also a trend for the perceived exertion in the three groups to be lower with each test as shown in Table 4.1.3.3. Distance covered in Part 2 was also improved for each trial in the three tests but these improvements were not significant as shown in Table 4.1.3.6. It is important to consider that the subjects only had to perform 10 runs in Part 2. The subjects also achieved similar peak blood lactate concentration and peak heart rate at the end of Part 2 for each test. These findings show that the subjects performed maximally at each test. Taken together, it seems that there was a strong learning effect present but the magnitude of the learning effect was reduced at Test 3. However, it is important to consider that Part 2 was terminated after 10 runs. Therefore, the players may have been able to perform a few more runs at Test 3, which may have underestimated the true learning effect. As a result, the reliability of the 15-50 protocol should be further examined through more familiarisation sessions.

The limits from the LOA analysis for the two protocols in the subject groups may not be narrow enough for the test to be of practical use. For example, the upper and lower

LOA for the mean heart rate data during Part 1 for Group 2 may not lie within acceptable limits to detect a change following an experimental/training intervention. If a player records a mean heart rate of 160 beats.min^{-1} during Part 1, the retest heart rate must be lower than 152 beats.min^{-1} or higher than 171 beats.min^{-1} to be confident that the change is attributed to a change in test performance and not measurement error in the test. The upper and lower LOA for number of runs in Part 2 in Group 2 corresponded closely with the Ramsbottom *et al.* study (1 to 3 runs and 5 to 7 runs respectively). In fact these LOA also compared favourably to those reported by Nicholas *et al.* (2000) for Part B of the LIST.

4.4.2 Physiological Responses

The aim of Part 1 was to develop a sub-maximal assessment of soccer-specific endurance capacity. From the mean heart rate during Part 1 in Table 4.1.3.2, it shows that the load was sub-maximal. There was also a gradual increase in mean heart rate for each exercise block in Part 1 as shown in Figures 4.1.3.1-4.1.3.3. Another interesting finding is that mean heart rate for each of the subject groups did not exceed 90% of HR_{peak} in any of the exercise blocks. A method to increase the intensity in Part 1 would be to increase the distance for either of the two high-speed runs or change the exercise:rest ratio. It is likely that the 1:3 exercise:rest ratio in Part 1 allowed for sufficient time to recover in each 60 s running cycle with 15 s exercise and 45 s rest.

The aim of Part 2 was to develop a maximal assessment of soccer-specific endurance. The results from the physiological variables supported the maximal nature of Part 2. The mean heart rate in Part 2 ranged between 93-98% of HR_{peak} for the three subject groups as shown in Table 4.3.1.4. It seems that Part 2 can be used to determine peak heart rate as both Group 1 and Group 2 reached 98-99% of HR_{peak} in each test. These values correspond to other field tests where peak heart rate could be determined; The Yo-Yo Intermittent Recovery (Krustrup *et al.*, 2003) and Intermittent Endurance (Krustrup *et al.*, 2006) tests.

The 1:1 exercise:rest ratio (15 s exercise, 15 s rest) in Part 2 leads to a completely different and very highly taxing challenge compared to Part 1. It is likely that this exercise pattern of high-speed running will lead to shift from aerobic to more anaerobic energy use in Part 2. As expected, blood lactate concentration at the end of the test ranged between 13-14 mmol.l^{-1} in both Group 1 and Group 2 as shown in Table 4.1.3.6. These lactate values are compatible and in some cases higher than those reported for other soccer-specific tests that closely resembles the 15-30 protocol (Lemmink and Visscher, 2003; Krustrup *et al.*, 2003).

4.1.4.3. Practical Applications

It is recommended that several familiarisation trials are performed so that the players are fully familiar with the protocol. In Part 1, the 42-s rest period after the long high-speed run could be changed to active instead of passive to make assessment more realistic to soccer. The administration of the protocol would probably be restricted for use in indoor sports halls because of the long distance of the long high-speed run (50 m). In addition, a deceleration distance of about 2 m would be needed either side. The 15-50 protocol may be better suited for use in interval conditioning training rather than a test protocol of soccer-specific endurance. In the current format, the 15-50 protocol needs to be revised to make the exercise pattern more specific to soccer and making assessment more practical.

4.1.4.4. Conclusion

In conclusion, several familiarisation sessions are needed for the 15-50 protocol in order to reduce any learning bias. The current study supports the reliability of the 15-50 protocol although the pre-set number of runs in Part 2 needs to be taken into consideration. Part 1 is a predominantly aerobic stage based on the heart rate responses from the subject groups with Part 2 eliciting a high anaerobic energy turnover. The protocol needs to be modified to be more applicable for soccer-specific endurance assessment.

Chapter 4

The Reliability of the 15-30 Protocol

4.2.1 Introduction

In the previous chapter, the 15-50 protocol was developed as a new test used to assess soccer-specific endurance. Although the protocol was reliable and taxed the aerobic energy system almost maximally, the protocol needed further refinement to be able to be used effectively in the assessment of soccer-specific endurance. To develop the same concept further and refine the original protocol, another test protocol was developed through pilot work- the "15-30 protocol". The general design of the 15-30 protocol is similar to the 15-50 protocol with a sub-maximal Part 1 and a maximal Part 2. In Part 1, performance is evaluated via heart rate measurements meaning that the test can also be implemented as a conditioning drill in training. The performance measure in Part 2 is the number of completed runs.

The 15-30 protocol was further modified from the 15-50 protocol to reflect the physical demands of match-play. The protocol is based on the average duration and speed of the high-intensity bouts (<15 $km.h^{-1}$) observed during match-play (Bangsbo *et al.*, 1991; Mohr *et al.*, 2003). The duration of the high-intensity bouts in the 15-30 protocol is increased to 6 s to create a more physically demanding protocol. The distance of each high-speed run was derived from pilot work. Due to the unpredictable nature of the frequency of the high-intensity running bouts in match-play, a exercise:rest ratio of 1:1.5 in Part 1 and 1:1 in Part 2 was chosen. The protocol is also divided into set exercise blocks for Part 1, which also makes the protocol suitable as a conditioning drill. The total distance in Part 1 (2030 m) also reflects the distance covered in high-intensity running in match-play (Mohr *et al.*, 2003; The structure of Part 2 is adapted to enable assessment of maximal performance. The exercise:rest ratio is 1:1 and the players perform the high-speed running bouts until failure. Part 2 is also not divided into exercise blocks but the players perform repeated high-speed running bouts, which increases the physical load. These unique characteristics make the 15-30 protocol completely different from other soccer-specific tests such as the Yo-Yo tests (Bangsbo, 1993b).

There are several changes in the specific make-up of the 15-30 protocol compared to the 15-50 protocol; shorter duration of each running cycle (30 s *vs.* 60 s), a reduced exercise:rest ratio for each running cycle (1:1.5 *vs.* 1:3), a shorter distance for the long high-speed run (30 m *vs.* 50 m), a greater distance covered in Part 1 (2030 m *vs.* 1600 m), more blocks in Part 1 (5 *vs.* 4), shorter rest period after the long high-speed run (12 s *vs.* 42 s) and open-ended number of runs in Part 2. Previous pilot work on the 15-30 protocol has also been described in a recent review by Svensson and Drust (2005).

When developing a new fitness test, its reliability must be established if the test is to be used routinely for regular assessment of physical fitness. Reliability refers to "the absence of measurement error" (Atkinson and Nevill, 1998) and is examined through repeated measurements in the same subjects. The statistical analysis of repeated measures should not only be based on the statistical significance of such tests but also assessed for it's effectiveness for practical use by coaches and practitioners. Therefore it is important to distinguish between a test's statistical and practical significance (Atkinson, 2003). Therefore, the aims of this study were to;

1) examine the reliability of the 15-30 protocol;
2) evaluate the physiological responses during the 15-30 protocol;
3) assess the effectiveness to use the 15-30 protocol for the assessment of soccer-specific endurance.

4.2.1.1 Limitations

- In two of the subject groups, the 15-30 protocol was performed outdoors on an artificial grass turf. As a result, some of the environmental conditions may have influenced the physiological responses during each test.
- The subjects were asked to refrain from any vigorous physical activity the day before the test. However, it is possible some subjects may have performed heavy exercise, which may have influenced the physiological responses during each test.
- The female elite players only performed Part 1 of the 15-30 protocol due to the tests being conducted in-season.
- The male elite U-15 group only performed Part 2 of the 15-30 protocol due to the limited time available for testing.
- Some subjects had to be removed from the study due to illness or injury.
- Blood lactate was only measured in the male recreational group due to lack of Lactate Pro test strips.

- Some heart rate data files were lost due to technical error with the Polar Team System belts.

4.2.1.2 Delimitations

- The subjects performed one experimental protocol (the 15-30 protocol) and one criterion test (the 20-m shuttle run).
- The subjects a series of tests with each test occasion delimited and separated by 3-6 days.
- The subject groups chosen were delimited to male recreational players from Liverpool John Moores University, male professional youth scholars from a Coca-Cola League 1 team in England, female elite players from a women's team in the Swedish Premier League and male elite U-15 players from a Coca-Cola League 2 team.
- The physiological measurements were delimited to heart rate and blood lactate.
- The psychological measurement was delimited to ratings of perceived exertion.

4.2.2 Methods

This section outlines the experimental procedures for Study 2. The aim was to recruit a diverse range of experimental groups ranging from recreational to male and female elite players. Due to the tests being conducted in-season some elite groups could not complete both parts of the 15-30 protocol, as shown in Table 4.2.2.1.

4.2.2.1 Subjects

Sixteen male recreational soccer players from Liverpool John Moores University (Group 1), seven female semi-professional soccer players from a Swedish Premier League team (Group 2), seven male professional youth scholars from a Coca-Cola League One team (Group 3) and eight male U-15 players from a Coca-Cola League Two team (Group 4) were used as subjects for this study. Three of the male recreational players did not complete all the tests due to injury and were excluded from the data analysis. The physical characteristics of all subject groups are shown in Table 4.2.2.1. All of the subjects were informed of the benefits, risks and stresses of the study before giving their written consent to take part. This study received ethical approval from the Ethics Committee of Liverpool John Moores University.

Table 4.2.2.1. The physical characteristics of the subject groups used in the study.

Subject	*Age*	*Height (m)*	*Body mass (kg)*	*Stages of 15-30 protocol performed*	*Number of 15-30 trials (excluding familiarisation)*
Group 1 (N = 13)	24.5 ± 1.9	1.78 ± 0.05	75.2 ± 9.8	Part 1 + Part 2	3
Group 2 (N = 7)	21.0 ± 3.0	1.68 ± 0.04	61.6 ± 4.7	Part 1 + Part 2	3
Group 3 (N = 7)	16.1 ± 0.4	1.71 ± 0.06	67.9 ± 5.7	Part 1	2
Group 4 (N = 8)	14.5 ± 0.5	1.67 ± 0.05	57.5 ± 7.4	Part 2	2

4.2.2.2 Test Location and Procedure

The 20-m shuttle run test and the 15-30 protocol was conducted either indoors on a tartan running track at Liverpool John Moores University (Group 1), outdoors on an artificial grass surface at Behrn Arena, Örebro SK, Sweden (Group 2), indoors on a artificial grass surface at Prenton Park, Tranmere Rovers FC (Group 3) and outdoors on an artificial grass surface at St Mary's Sports Centre, Middleton, Rochdale AFC (Group 4).

4.2.2.3. Field Tests

4.2.2.3.1. The 20-m Shuttle Run

The 20-m shuttle run was initially conducted to estimate $\dot{V}O_{2max}$ and determine HR_{peak} of the subjects. The test is described in detail in section 3.1.3. Blood samples were taken before the test and immediately after the subjects stopped the test to determine the blood lactate concentration (Group 1 only).

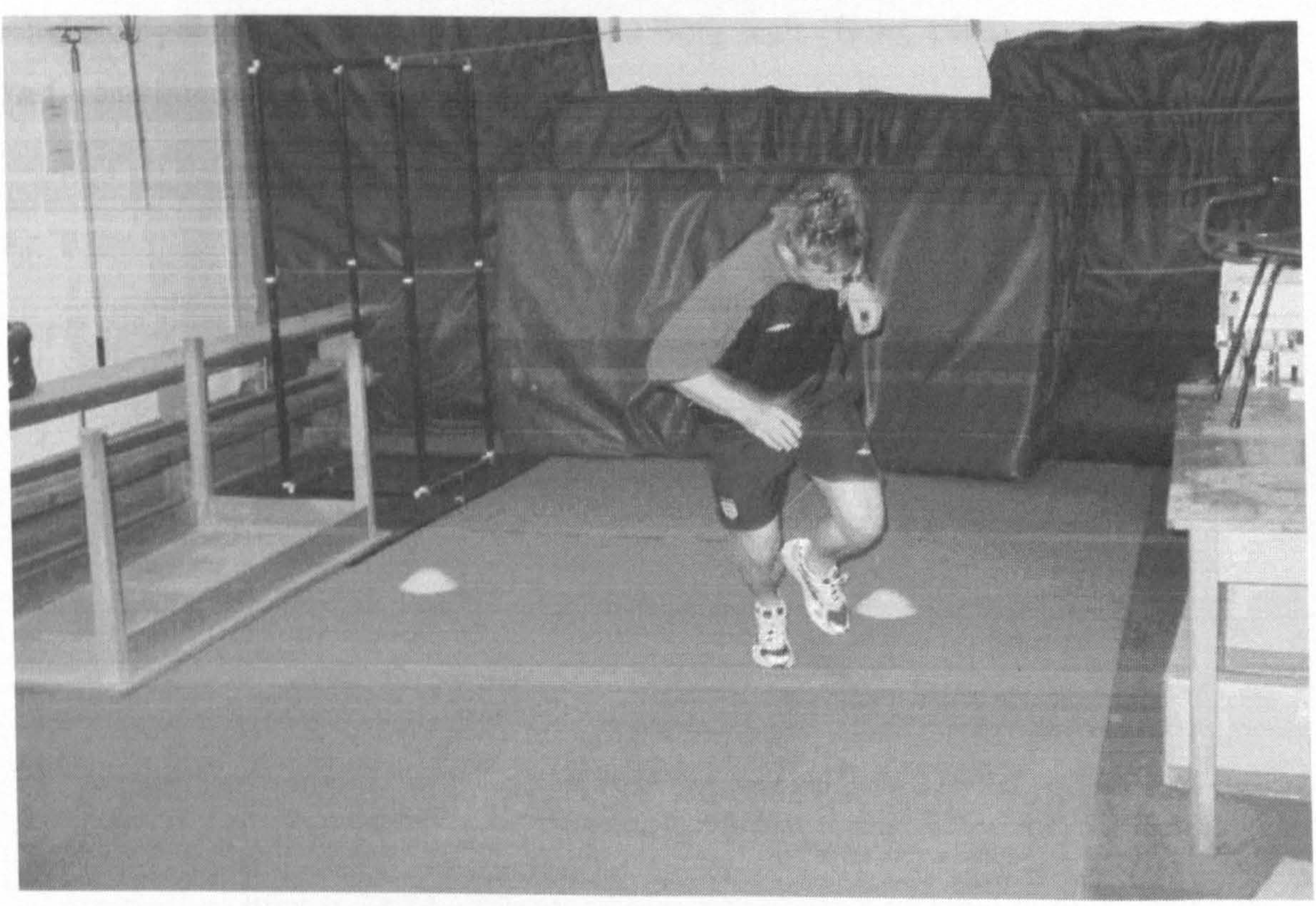


Figure 4.2.2.1. One subject from Group 1 performing the 20-m shuttle run.

4.2.2.3.2. The 15-30 Protocol

One week upon completion of the 20-m shuttle run, Group 1 and Group 2 performed the 15-30 protocol on four separate occasions (i.e. Familiarisation, Test 1, Test 2 and Test 3). The details of the test procedure is described in section 3.1.4. The trials performed for each subject group is shown in Table 4.2.2.1. An outline of the experimental procedures is shown in Figure 4.2.2.2. Group 3 and Group 4 performed the test twice.

4.2.2.4. Physiological Measurements

4.2.2.4.1. Heart Rate

Heart rate was measured every 5-s during all tests with short-range telemetry via the Polar Team System (Polar Electro Oy, Kempele, Finland) as described in section 3.4.3. A typical heart rate curve from the software is shown in Figure 4.2.2.3. Mean heart rate was analysed in two ways in Part 1. Firstly, mean heart rate was expressed as the entire duration of Part 1 (23 min 30 s) including all exercise blocks and rest periods. Secondly, the mean heart rate for each test stage in Part 1 was analysed separately. The subjects also rated their perceived exertion from the 6-20 Borg scale (Borg, 1988) after each block in Part 1 and immediately after Part 2.

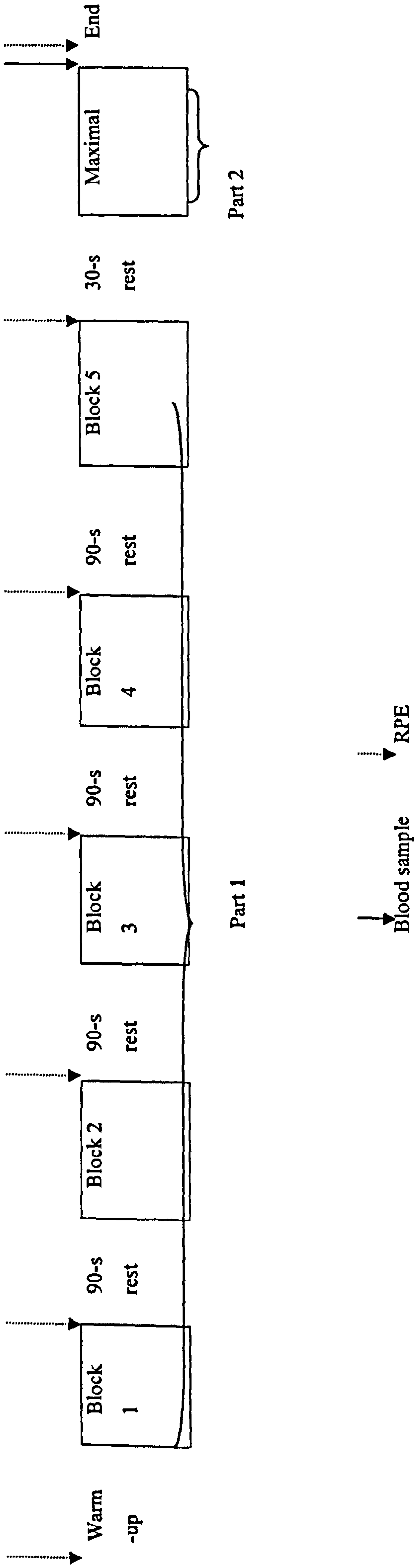
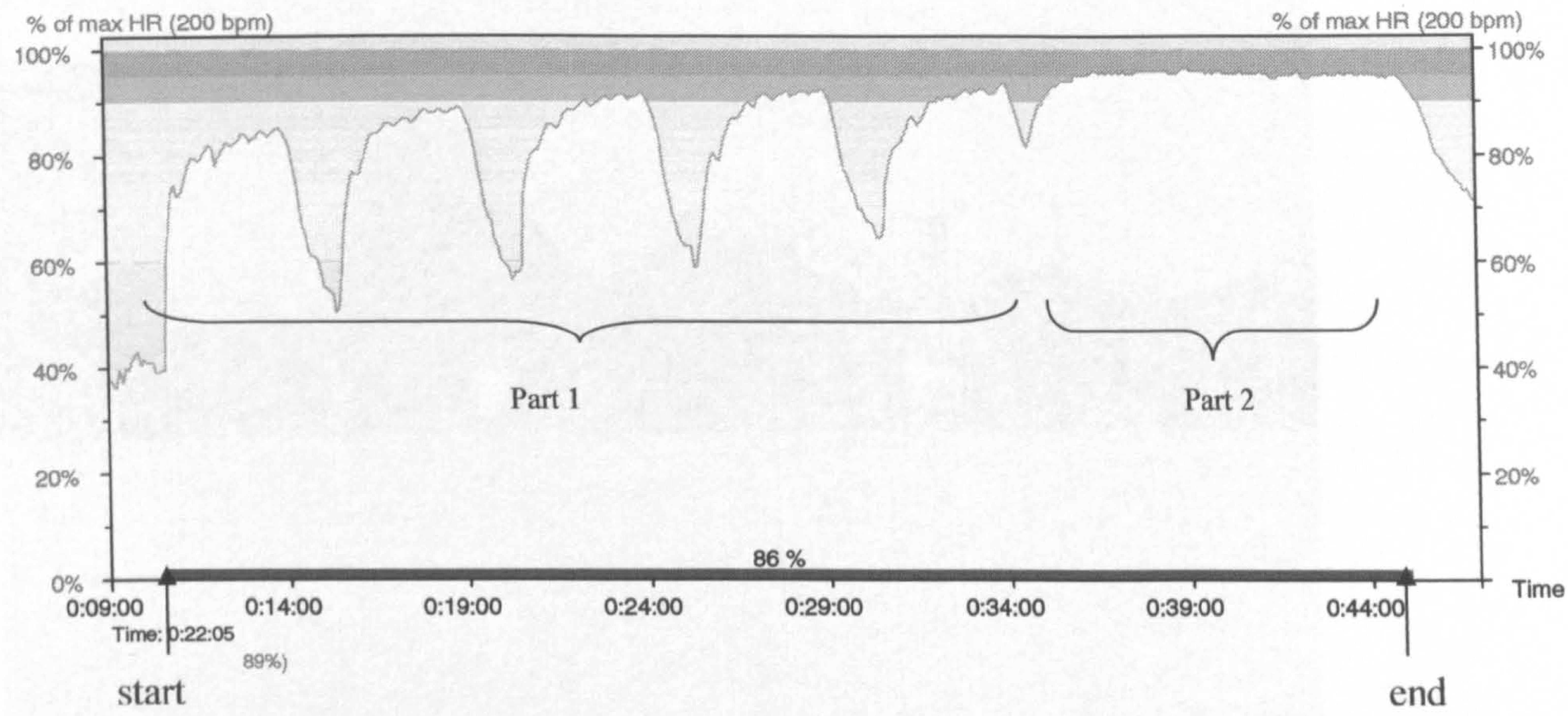


Figure 4.2.2.2. The experimental protocol for the 15-30 protocol.



Person	[redacted]	Date	2005-07-06	Heart rate average	171 (86%)
Exercise	2005-07-06 17:33	Time	17:33:42	Heart rate max	193 (97%)
Sport	Running	Duration	0:52:20.0		
Note	Test 3			Selection	0:10:30 - 0:45:05 (0:34:35.0)

Figure 4.2.2.3. Heart rate profile of one subject from Group 1 during the 15-30 protocol from the Polar Precision Performance Software (version 4.0).

4.2.2.4.2. Blood Lactate

A blood sample was taken at rest and at the end of the 20-m shuttle run and the 15-30 protocol for the determination of blood lactate using the procedure described in section 3.4.2. Blood samples were taken in Group 1 only.

4.2.2.5. Psychological Measurements

The subjects were asked to rate their perceived exertion at the end of the 20-m shuttle run, at the end of each exercise block in Part 1 and at the end of Part 2 using the Borg scale described in section 3.5.1.

Figure 4.2.2.4. One subject from Group 1 performing the 15-30 protocol.

4.2.2.6. Statistical Analysis

This study was a repeated measures design. All the data were expressed as means (±SD), (Group 1: N = 13, Group 2: N = 7, Group 3: N = 7, Group 4: N = 8) unless otherwise stated. After being tested for normality using the Shapiro-Wilk test for normality, the appropriate statistical analysis was chosen. For Group 1 and Group 2, comparisons between the tests of distance covered and estimated $\dot{V}O_{2max}$ in the 20-m shuttle run between the subject groups, mean heart rate in Part 1 and Part 2, peak heart rate in Part 2, distance covered in Part 2 (Group 1 only), blood lactate at rest and after Part 2 (Group 1 only) were made using analysis of variance (one-way ANOVA). A repeated-measures analysis of variance (two-way ANOVA) was used to compare the heart rate during each test stage (block and rest periods), ratings of perceived exertion between blocks and time spent in each heart rate zone. When Mauchley's test of sphericity indicated a minimal level of violation (>0.75) the degrees of freedom was corrected using the Huynh-Feldt adjustment. When sphericity was <0.75, the Greenhouse Geiser correction was used. Where a significant difference occurred, Tukey's and

Bonferroni's post-hoc tests were selected to assess for any systematic bias between the tests.

The 95% limits of agreement with Bland and Altman plots were selected to represent the within-individual error and provide an indication of the systematic bias and random error by examining the direction and magnitude of the scatter around the zero reference line (Bland and Altman, 1986). Coefficient of variation was calculated using the formulae $SD_{diff}/\sqrt{2}$/grand mean. Correlation coefficients were determined and tested for significance using the Pearson's product moment correlation. Statistical power was calculated using MINITAB for Windows. Statistical significance was set at $p<0.05$ for all tests apart from $p<0.01$ for the Pearson's product moment correlation. All the statistical analysis was performed using SPSS for Windows version 12.0.1 (Chicago, IL, USA) apart from the estimated sample size which was calculated using MINITAB for Windows (State College, PA, USA).

4.2.3 Results

4.2.3.1 20-m Shuttle Run

The results from the 20-m shuttle run for all the subject groups are shown in Table 4.2.3.1. There was no significant difference between the different subject groups in either the estimated $\dot{V}O_{2max}$ ($F_{3\ 29}$ = 0.20, p>0.05) or the distance covered ($F_{3\ 29}$ = 0.47, p>0.05) from the 20-m shuttle run. The blood lactate concentration at the end of the 20-m shuttle run in Group 1 was 1.5 ± 0.5 $mmol.l^{-1}$ at rest and 13.7 ± 2.7 $mmol.l^{-1}$ at the end of the test.

Table 4.3.2.1. 20-m shuttle run performance in the different subject groups.

Subject group	*Distance covered (m)*	*Estimated $\dot{V}O_{2max}$ ($ml.kg^{-1}.min^{-1}$)*	*HR_{peak} ($beats.min^{-1}$)*
Group 1 (N = 13)	2177 ± 274	54.6 ± 3.7	197 ± 5
Group 2 (N = 7)	2167 ± 95	54.6 ± 1.2	197 ± 3
Group 3 (N = 7)	2297 ± 400	53.3 ± 5.4	200 ± 7
Group 4 (N = 8)	2137 ± 250	54.1 ± 3.5	201 ± 6

4.2.3.2 15-30 Protocol- Part 1

Heart rate was significantly ($F_{2\ 36}$ = 4.24, p<0.05) lower in Test 3 compared to Test 1 for Group 1, as shown in Table 4.2.3.2. No significant difference was reported in the mean heart rate for Group 2 ($F_{2\ 20}$ = 1.24, p>0.05) or Group 3 (t (6) = 2.175, p>0.05). The coefficient of variation between Test 2-Test 3 in mean heart rate for Part 1 was 3.2%. For Group 2 and Group 3, the coefficient of variation for heart rate during Part 1 was 4.5% for Test 1-Test 2 and 2.3% between Test 2-Test 3. The time spent in respective heart rate zones during Part 1 of the 15-30 protocol is shown in Table 4.2.3.3. No significant difference was reported for the time spent in each heart rate zone between the tests for either Group 1 ($F_{2\ 18}$ = 0.965, p>0.05), Group 2 ($F_{2\ 12}$ =1.11, p>0.05) or Group 3 ($F_{1\ 6}$ = 3.33, p>0.05).

Table 4.2.3.2. Heart rate data from Part 1 of the 15-30 protocol in the different subject groups.

	Heart rate (beats.min^{-1}) (% of HR_{peak})		
Subject Group	*Test 1*	*Test 2*	*Test 3*
Group 1 (N = 13)	164 ± 7 (83.3 ± 3.8)	159 ± 7 (81.2 ± 3.2)	155 ± 9 (78.8 ± 4.4)†
Group 2 (N =7)	170 ± 4 (85.9 ± 2.4)	168 ± 4 (84.8 ± 2.0)	166 ± 7 (83.6 ± 3.9)
Group 3 (N = 7)	159 ± 3 (79.3 ± 4.4)	154 ± 11 (77.9 ± 6.2)	x

† = significant (p<0.05) to Test 1

Table 4.2.3.3. Upper and lower 95% limits of agreement with the systematic bias and random error between Test 2-Test 3 for heart rate in Part 1.

	Heart rate (beats.min^{-1})	
	Systematic bias ± Random error	*Upper and lower 95% limits of agreement*
Group 1 (N = 13)	4.6 ± 7.0	18 to -9
Group 2 (N = 7)	3.6 ± 6.1	13 to -6
Group 3 (N = 7)	2.7 ± 3.3	9 to -4

The upper and lower limits of agreement shown in Table 4.2.3.3 represent a maximal "worst case" scenario. For example, if a player in Group 1 has a heart rate of 160 beats.min^{-1} during Part 1, the heart rate during a retest on a given day might be as low as 151 beats.min^{-1} or as high as 178 beats.min^{-1}.

There was a significant difference in the time spent between the individual heart rate zones in Table 4.2.3.3 for Group 1 ($F_{5\ 45}$ = 13.39, p<0.05), Group 2 ($F_{5\ 30}$ = 19.46, p<0.05) and Group 3 ($F_{5\ 30}$ = 8.49, p>0.05).

Table 4.2.3.4. Percentage of time spent in each heart rate zone during Part 1 of the 15-30 protocol for Group 1-Group 3.

	<60% of HR_{peak}			*60-75% of HR_{peak}*			*75-85% of HR_{peak}*			*85-90% of HR_{peak}*			*90-95% of HR_{peak}*			*95-100% of HR_{peak}*		
Subject group	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*
Group 1 (N = 13)*	3.2	5.0	8.5	16.3	18.9	22.7	24.2	25.8	37.4	22.0	24.0	19.9	26.8	23.6	8.0	7.5	2.7	3.5
SD	3.7	5.3	7.0	4.5	5.1	8	9.2	12.4	16.0	7.5	6.7	11.2	8.7	14.4	11.3	15	5.4	11
Group 2 (N = 7)*	1.6	1.6	3.8	10.8	14.4	12.4	16.2	16.7	21.1	25.1	23.3	33.7	44.8	37.4	25.3	1.5	5.6	3.9
SD	4.2	2.3	7.5	5.7	2.7	5.9	5.1	5.9	6.4	9.6	8.7	16.6	9.6	8.9	18.1	3.3	8.9	10.5
Group 3 (N = 7)'	5.9	10.4	x	20	22.9	x	29.8	23.6	x	35.3	30.7	x	9.0	12.3	x	0	0.3	x
SD	7.5	8.1	x	1.4	16.1	x	13.8	8.5	x	16.4	16.3	x	10.6	17.7	x	0	0.8	x

*significant difference tests, heart rate zones

Table 4.2.3.5. The sample size required to detect a given change in heart rate (beats.min^{-1}) in Part 1 for Group 1-Group 3.

Change in heart rate (beats.min^{-1})	*Sample size required* Group 1 (N = 13)	Group 2 (N = 7)	Group 3 (N = 7)
1	388	185	88
2	99	48	24
3	45	23	12
4	27	14	8
5	18	10	6

In Table 4.2.3.5, for example, to detect a change of 4 beats.min^{-1} during Part 1 in Group 1, a sample size of 27 would be required for that particular group. To detect a change of 3 beats.min^{-1} in Group 3 a sample size of 12 would be needed.

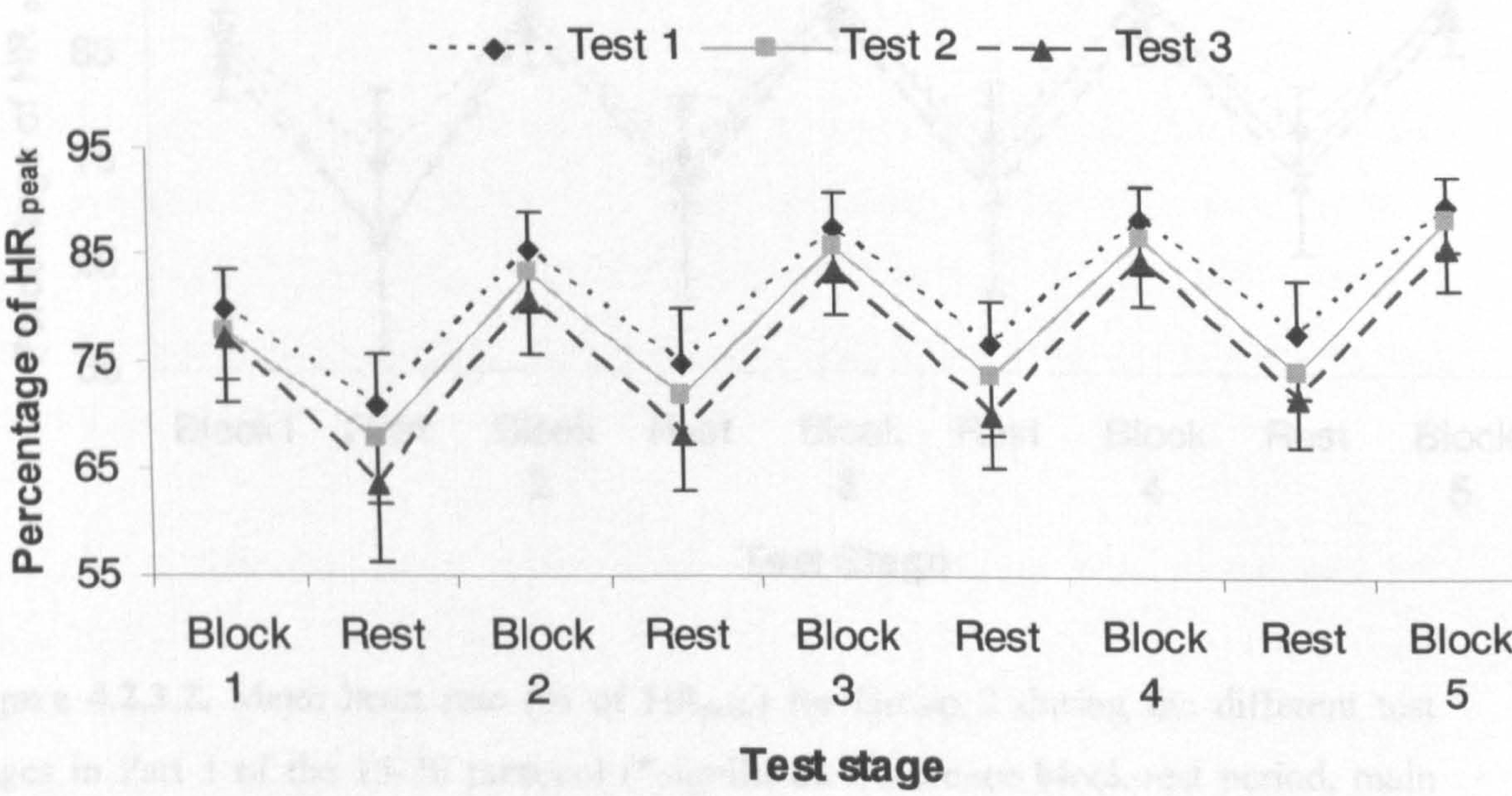


Figure 4.2.3.1. Mean heart rate (% of HR_{peak}) for Group 1 during the different test stages in Part 1 of the 15-30 protocol (*significant difference tests, block-rest period, main effect test-test stage).

There was a significant difference ($F_{2\ 18} = 12.87$, $p<0.05$) in the mean heart rate during the 15-30 protocol between Test 1-Test 3 in Group 1 as shown in Figure 4.2.3.1. There was also a significant difference ($F_{20\ 180} = 2.83$, $p<0.05$) in heart rate between the different test stages. A significant interaction was observed between test and the test stages ($F_{20\ 180} = 2.83$, $p<0.05$). The interaction between test and test stages was most prominent in the first 90-s rest period. There was no significant difference ($F_{2\ 24} = 1.18$, $p>0.05$) between the three tests in the time spent in each heart rate zone during Part 1 ($F_{2\ 18} = 0.97$, $p>0.05$) or Part 2 ($F_{2\ 16} = 1.00$, $p>0.05$) as shown in Table 4.2.3.4 and 4.2.3.6. A significant difference was observed between heart rate zones both in Part 1 and Part 2 ($F_{5\ 40} = 15.33$, $p>0.05$). There was also a significant interaction between test and heart rate zone for Part 1 ($F_{10\ 90} = 5.46$, $p<0.05$) and Part 2 ($F_{10\ 80} = 3.78$, $p<0.05$).

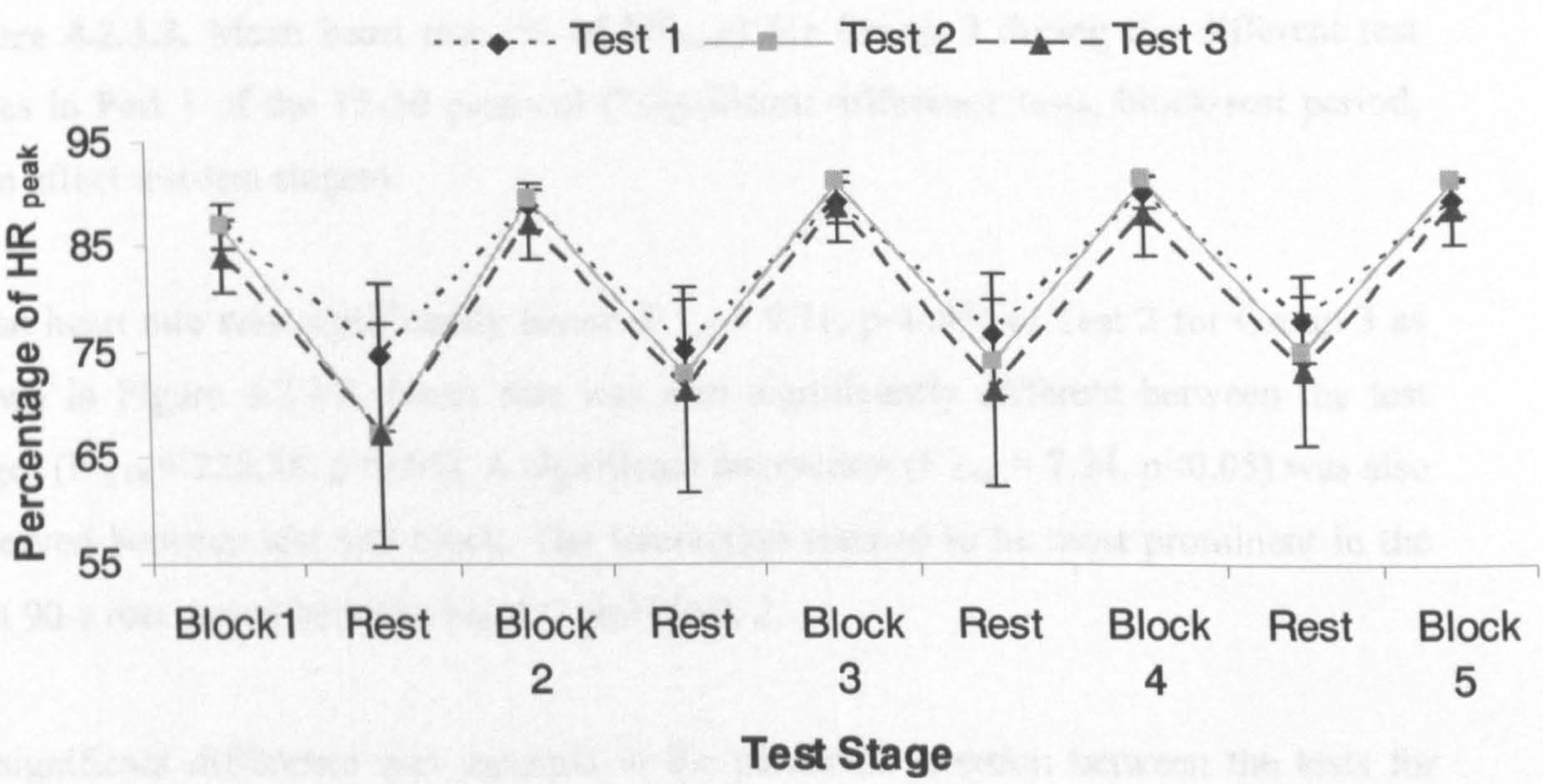


Figure 4.2.3.2. Mean heart rate (% of HR_{peak}) for Group 2 during the different test stages in Part 1 of the 15-30 protocol (*significant difference block-rest period, main effect test-test stage).

There was no significant difference ($F_{2\ 10} = 3.35$, $p>0.05$) in the percentage of HR_{peak} during the 15-30 protocol between the three tests for Group 2 as shown in Figure 4.2.3.2. A significant difference ($F_{8\ 40} = 44.48$, $p<0.05$) was observed between the different test stages. There was also a significant interaction ($F_{16\ 80} = 14.05$, $p<0.05$) between test and block.

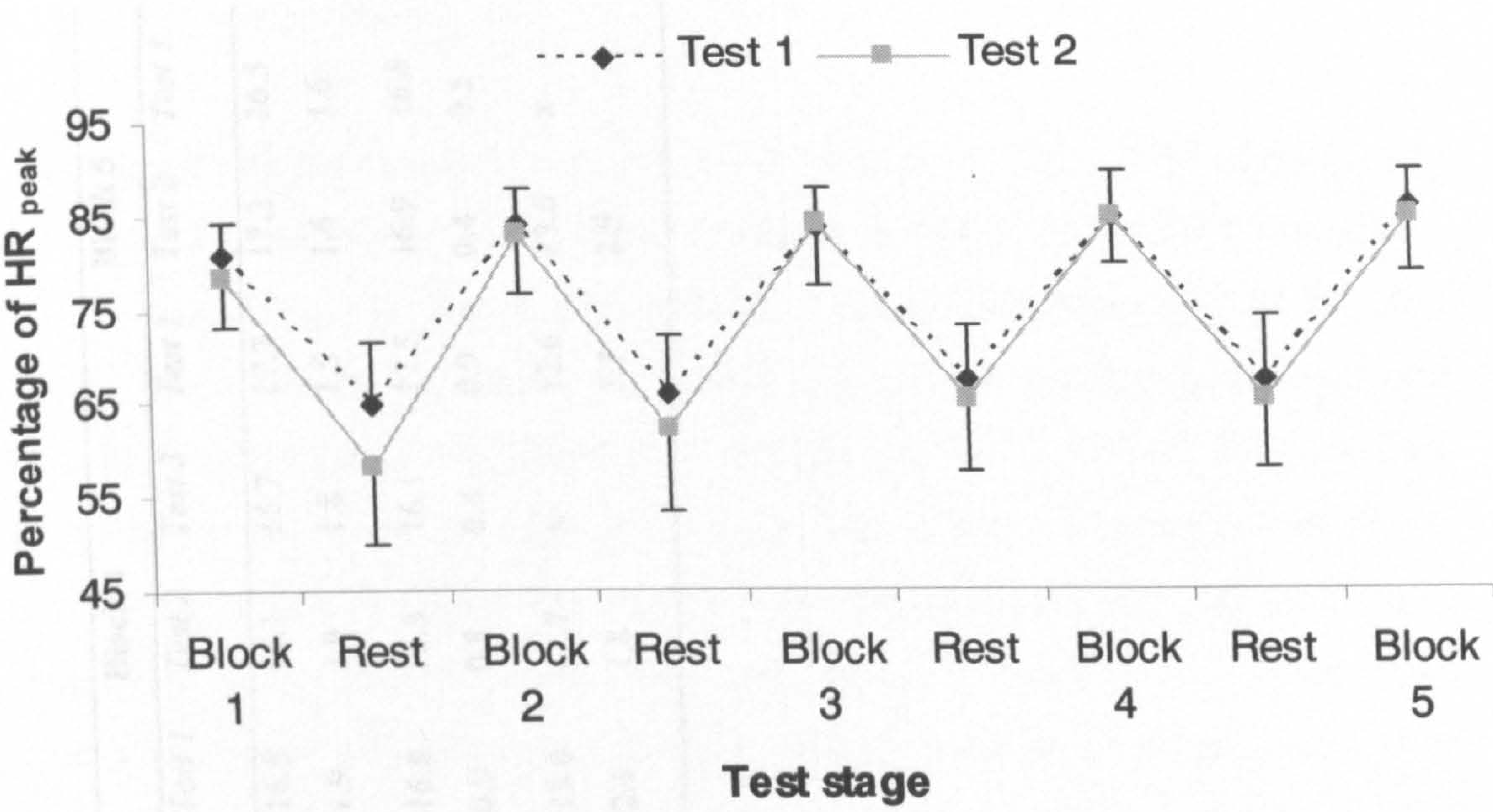


Figure 4.2.3.3. Mean heart rate (% of HR_{peak}) for Group 3 during the different test stages in Part 1 of the 15-30 protocol (*significant difference tests, block-rest period, main effect test-test stages).

Mean heart rate was significantly lower ($F_{1\ 6} = 9.71$, $p<0.05$) in Test 2 for Group 3 as shown in Figure 4.2.3.3. Heart rate was also significantly different between the test stages ($F_{8\ 48} = 225.38$, $p<0.05$). A significant interaction ($F_{8\ 48} = 7.24$, $p<0.05$) was also observed between test and block. The interaction seemed to be most prominent in the first 90-s rest period between block 1 and block 2.

A significant difference was reported in the perceived exertion between the tests for Group 2 ($F_{2\ 12} = 10.88$, $p<0.05$) and Group 3 ($F_{2\ 12} = 10.88$, $p<0.05$) with no difference ($F_{2\ 22} = 2.06$, $p>0.05$) for Group 1. Perceived exertion was also significant difference between the different blocks for Group 1 ($F_{5\ 55} = 143.81$, $p<0.05$), Group 2 ($F_{4\ 24} = 61.42$, $p>0.05$) and Group 3 ($F_{4\ 24} = 61.42$, $p<0.05$).

Table 4.2.3.6. Ratings of perceived exertion in Part 1 for Group 1-Group 3.

	Block 1			Block 2			Block 3			Block 4			Block 5		
Subject group	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*
Group 1 (N = 13) †	12.6	12.4	12.2	13.9	13.7	13.3	15.5	15.1	14.4	16.5	16.1	15.7	17.7	17.2	16.5
SD	1.7	1.6	1.7	2.0	1.9	1.6	2.4	1.9	1.8	1.9	1.9	1.8	1.5	1.6	1.6
Group 2 (N = 7)* †	14.7	12.3	12.6	15.6	14.1	14.0	16.1	15.6	15.1	16.8	16.3	16.1	17.5	16.9	16.6
SD	0.5	1.5	1.0	0.8	0.7	0.6	1.2	0.5	0.4	0.9	0.8	0.4	0.9	0.4	0.5
Group 3 (N = 7)* †	10.5	9.8	x	11.0	10.5	x	11.6	11.7	x	13.0	12.7	x	12.6	13.6	x
SD	1.9	1.2		1.9	1.0		2.1	1.0		2.1	1.8		1.7	2.9	

*= significant difference tests, †= significant difference block

4.2.3.3 15-30 Protocol- Part 2

The mean heart rate for Group 1 was 187 ± 6 beats.min^{-1} (95.2 ± 2.9% of HR_{peak}) in Test 1, 184 ± 8 beats.min^{-1} (93.6 ± 4.1% of HR_{peak}) in Test 2 and 185 ± 8 beats.min^{-1} (93.8 ± 3.2% of HR_{peak}) in Test 3. The coefficient of variation between Test 2-Test 3 was 3.2%. There was no significant change ($F_{2\ 36}$ = 0.37, p>0.05) in peak heart rate between the three tests in Group 1 (188 ± 6 beats.min^{-1} or 98.1 ± 3.3% of HR_{peak} in Test 1; 184 ± 7 beats.min^{-1} or 97.2 ± 3.2% of HR_{peak} in Test 2; 185 ± 7 beats.min^{-1} or 97.1 ± 3.1% of HR_{peak} in Test 3). There was no significant difference ($F_{2\ 16}$ = 1.00, p>0.05) in the time spent in the different heart rate zones shown in Table 4.2.3.7. There was, however, a significant difference ($F_{5\ 40}$ = 15.33, p<0.05) between the different heart rate zones.

The coefficient of variation for Group 1 for distance covered in Part 2 was 34% between Test 2-Test 3. The percentage improvement in distance covered in Part 2 was 51% between Test 1-Test 2 and 63% between Test 2-Test 3 as shown in Table 4.2.3.6. The players in Group 1 covered a significantly ($F_{2\ 36}$ = 5.482, p<0.05) greater distance in Test 3 compared to Test 1 and Test 2, as shown in Table 4.2.3.6. The limits of agreement analysis are shown in Table 4.2.3.8. For example, if a player performs 25 high-speed runs (1450 m) on one occasion, a retest performance on a separate occasion may be as low as 2 runs (160 m) or as many as 32 runs (1856 m). Furthermore, to detect a difference of 1 run in Part 2 for Group 1, a sample size of 464 would be needed, 118 to detect 2 runs, 54 to detect 3 runs, 31 to detect 4 runs and 21 to detect 5 runs.

Table 4.2.3.7. Performance data from Part 2 of the 15-30 protocol for the different subject groups.

	Test 1			Test 2			Test 3		
Subject group	*Distance covered Part 2 (m)*	*Blood lactate ($mmol.l^{-1}$) pre-test*	*Blood lactate ($mmol.l^{-1}$) post-test*	*Distance covered Part 2 (m)*	*Blood lactate ($mmol.l^{-1}$) pre-test*	*Blood lactate ($mmol.l^{-1}$) post-test*	*Distance covered Part 2 (m)*	*Blood lactate ($mmol.l^{-1}$) pre-test*	*Blood lactate ($mmol.l^{-1}$) post-test*
Group 1 (N = 13)	468 ± 317	1.8 ± 0.8	12.8 ± 2.7	705 ± 408	1.5 ± 0.7	11.1 ± 2.9	1146 ± 760†	1.5 ± 1.0	10.7 ± 3.2
Group 4 (N = 8)	740 ± 246	x	x	805 ± 276	x	x	x	x	x

†significant difference ($p<0.05$) to Test 3

Table 4.2.3.8. Percentage of time spent in each heart rate zone during Part 2 of the 15-30 protocol for Group 1.

	<60% of HR_{peak}			*60-75% of HR_{peak}*			*75-85% of HR_{peak}*			*85-90% of HR_{peak}*			*90-95% of HR_{peak}*			*95-100% of HR_{peak}*		
Subject group	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*	*Test 1*	*Test 2*	*Test 3*
Group 1 (N = 13)	0	0	0	0	0	0.1	10.0	2.2	2.5	6.8	24	10.0	20.8	21.8	34.6	69.8	68.9	50.1
SD	0	0	0	0	0	0.3	10.6	2.9	3.8	7.7	6.7	10.6	23.4	21.7	23.5	33.0	33.4	37.8

Table 4.2.3.9. Upper and lower 95% limits of agreement with the systematic bias and random error between Test 2-Test 3 in the different performance variables for Part 2.

Performance variable	*Systematic bias± Random error*	*Upper and lower 95% limits of agreement*
Heart rate (beats.min^{-1})	0 ± 5.1	10 to -10
Distance covered (m)	-441 ± 445	431 to -1313
Blood lactate concentration (mmol.l^{-1})	0.5 ± 4.0	8.3 to -7.3

There was no significant difference in the mean blood lactate concentration for Group 1 at rest ($F_{2\ 33}$ = 1.77, p>0.05) or after Part 2 ($F_{2\ 33}$ = 0.614, p>0.05) between the three tests. The coefficient of variation for blood lactate concentration after Part 2 between Test 2-Test 3 was 26%. The mean perceived exertion at the end of Part 2 for Group 1 was not significant ($F_{2\ 33}$ = 0.68, p>0.05) between the three tests (Test 1: 19.4 ± 0.7; Test 2: 19.3 ± 0.8; Test 3: 19.5 ± 0.7).

For Group 4, there was an 8.8% improvement in distance covered between Test 1-Test 2 as shown in Table 4.2.3.6. The coefficient of variation between Test 1-Test 2 was 22%. In order to detect a difference of 1 run during Part 2, a sample size of 91 would be required, 25 for 2 runs, 12 for 3 runs, 8 for 4 runs and 6 for 5 runs. The upper and lower 95% limits of agreement for the distance covered between Test 2-Test 3 was 314 m to -447 m. The systematic bias and random error for Test 2-Test 3 were –65.25m and 194.7 m. The mean perceived exertion at the end of Part 2 was 18.0 ± 1.9 in Test 1 and 16.1 ± 2.1 in Test 2.

4.2.4 Discussion

The aim of this study was to assess the reliability, physiological responses and the practical application of a soccer-specific endurance test- the 15-30 protocol. The main finding of the study was that several familiarisation trials for both Part 1 and Part 2 of the 15-30 protocol need to be performed before the protocol can be used for regular assessment of soccer-specific endurance. Another relevant finding was that elite players needed fewer familiarisation trials compared to recreational players. The reliability of the 15-30 protocol was established for elite players but more familiarisation trials would be needed for recreational players. These results show that if possible, reliability studies on any new test that evaluates high-intensity intermittent exercise performance should use a good standard of players to ensure results are not attributed to a training effect and minimise any systematic bias. This study together with Study 1 is also unique in that it is the only study to the authors knowledge which has thoroughly examined the reliability of soccer-specific fitness tests using a wide range of reliability statistics.

4.2.4.1 Reliability

There was a systematic bias or learning effect for most of the performance variables in Part 1 and Part 2 on the 15-30 protocols for all subject groups. It seemed that the magnitude of the learning effect differed between the groups. As showed in Table 4.2.3.2, Group 1 experienced the greatest learning effect in Part 1 with a lower mean heart rate for each test. The same trend was also observed for their perceived exertion as shown in Table 4.2.3.6. However, these differences were not significant. Heart rate did not change to such a great extent in either Group 2 or Group 3. It may be argued that the decrease in heart rate may be due to the elite players in Group 2 and Group 3 being more familiar with high-intensity training. Therefore, they would need fewer familiarisation trials on the 15-30 protocol. When analysing heart rate at the different test stages in Part 1, the same trend appears, as shown in Figures 4.2.3.1-4.2.3.3. Although heart rate was significantly lower for Group 2, the learning effect seemed to be minimal as the curve for the two tests are very similar as shown in Figure 4.2.3.3. The lower heart rate at each test stage may be explained by more efficient running economy during the exercise blocks, which may also have resulted in a lower heart rate in the 90 s rest period. Similar findings was also reported for the 15-50 protocol. The coefficient of variation (CV) for heart rate in Part 1 was also lower for Test 2-Test 3 compared to Test 1-Test 2 also confirmed the learning effect. These CV are slightly higher than the 1% those reported for a 6 min sub-maximal Yo-Yo Intermittent Recovery Test (Mohr *et al.*, 2003b).

The 95% limits of agreement (LOA) have recently been identified as one of the more important reliability statistics to assess systematic bias for repeated measurements (Bland and Altman, 1986; Atkinson and Nevill, 1998). The LOA describes a "worst case scenario" if the same individual was tested on separate occasions and the retest falls within acceptable limits (Atkinson and Nevill, 1998). The broad LOA between Test 2-Test 3 in Part 1 for Group 1 in Table 4.2.3.4 seemed to further support that the recreational players had the greatest learning effect of the three groups. The LOA in Part 1 was narrower for Group 3 than the other two groups. In terms of the practical application of the LOA, the upper and lower LOA for Group 1 (18 to -9 beats.min^{-1}) is unpractical. If coaches are to detect minor changes in heart rate (i.e. 3 beats.min^{-1}) on the 15-30 protocol following training, heart rate on a retest must be 18 beats.min^{-1} higher or 9 beats.min^{-1} lower to be confident that any change in heart rate is not attributed to test error. More practical LOA were reported for the professional youth scholars in Group 3 but it may be argued that these are too broad as well.

In addition to the LOA, another important informative statistic is the minimal sample size needed to detect a worthwhile change in performance on performance tests (Dalton and Keating, 2000; Atkinson, 2003). It can be seen in Table 4.2.3.5 that the sample sizes required to detect a change in heart rate of 1 beat.min^{-1} are not realistic. When testing elite athletes, a test must be sensitive enough to detect very small changes in performance between trials (Hopkins *et al.*, 2000). In soccer, it may be argued what a worthwhile change in heart rate may be. Therefore, any change in heart rate on a test must bear a resemblance to and reflect what would be the normal physiological adaptations to a period of training. For example a significant change in heart rate of 4 beats.min^{-1} on the Yo-Yo Intermittent Recovery Test following training was reported by Mohr *et al.* (2003b) in players from the Danish national team. So when analysing the estimated sample size that would be needed to detect a set change in heart rate of 4 beats.min^{-1} in Part 1, the sample sizes in Table 4.2.3.5 are more practical especially for Group 2 and Group 3.

Group 1 and Group 4 only completed Part 2 of the 15-30 protocol. Group 2 and Group 3 were not allowed to perform Part 2 by the coaching staff due to the testing being conducted in-season. The results showed a similar trend as in Part 1 with Group 1 where distance covered increased for each test, as shown in Table 4.2.3.6. The CV was also very high with 51% from Test 1-Test 2 and 63% from Test 2-Test 3. Perceived exertion, peak heart rate and blood lactate concentration values was similar between the three tests and supported that the subjects performed maximally on each test occasion. These results seem to support an improved familiarity for Group 1 with each trial. Group 4 performed Part 2 only and the distance covered in the two tests was very similar as shown in Table 4.2.3.6.

The upper and lower LOA between Test 2-Test 3 for heart rate and distance covered in Group 1 were very broad and not practical. For example, the LOA for distance covered were 431 m to -1313 m, which corresponded to 8 and 22 runs in Part 2 respectively. These calculated LOA may not be considered to be repeatable in male recreational players. For Group 4, more acceptable limits that corresponded to 5 and 7 runs respectively were reported. The large variation in distance covered for Group 1 may also be explained by inconsistent pacing strategies in the earlier tests. As their pacing strategy improved, they could perform more runs. It is likely that the elite players in Group 4 had a more efficient pacing strategy. Another explanation for the large differences between Test 2-Test 3 is that the subjects performed best on the last trial with increased motivation to beat their previous score. This has been referred to as the last trial phenomenon (Russell *et al.*, 2004). It is also important to consider that the performance criteria in Part 2 were changed to open-ended compared to the 15-50 protocol where the subjects stopped Part 2 after the completion of 10 runs.

4.2.4.2. Physiological Responses

The overall global mean heart rate in Part 1 for the subject groups in Table 4.2.3.2 showed that the intensity was sub-maximal. It seemed that Group 2 experienced a higher physical loading compared to the other subject groups. The female players in Group 2 performed the test with a reduced distance for each high-speed run in order to achieve similar sub-maximal responses to male players. The distances for the high-speed runs had previously been established through pilot studies. When examining the heart rate for each exercise block, the mean exercise intensity for each block seemed to be around 85% of HR_{peak} for all three groups, as shown in Figures 4.2.3.1-4.2.3.3. The intensity seemed to be greater with each subsequent block. It is important to consider that in some situations heart rate measurements may not detect any anaerobic contribution to test performance. As a result, the physical load for the subjects may have been underestimated in some situations during Part 1. For comparison, the overall mean heart rate in Part 1 seemed to be similar to that in soccer match-play with values between 77-85% of HR_{peak} reported (Rohde and Espersen, 1988; Van Gool *et al.*, 1988; Krustrup *et al.*, 2003; Mohr *et al.*, 2004). However, the duration of Part 1 is considerably shorter (23 min 30 s) than a match, which can make comparisons difficult.

The majority of the time in Part 1 was spent in heart rate zones corresponding to an intensity of 75-85% of HR_{peak} in the three groups as shown in Table 4.2.3.3. It is important to consider that this calculation is based on the total time for Part 1 including the 90-s rest periods, where heart rate was much lower. In addition, the perceived exertion at the end of each block in Table 4.2.3.6 for the groups showed that Group 1 and Group 2 perceived Part 1 to be harder than Group 3. Taken together, these findings support both objectively from the heart rate data and subjectively from the perceived exertion that the intensity was sub-maximal in Part 1.

The heart rate in Part 2 for Group 1 ranged between 93.6-95.2% of HR_{peak} which showed that the physical demand was very different compared to Part 1. Almost the entire duration of Part 2 was spent in heart rate zones >90% of HR_{peak} for Group 1, as shown in Table 4.2.3.8. These results suggested that the aerobic energy system was heavily taxed during Part 2. At exhaustion, peak heart rate was 97-98% of the HR_{peak} attained in the 20-m shuttle run. Together with the maximal perceived exertion, it seems that the subjects in Group 1 elicited maximal responses. It is likely that the anaerobic energy production was increased during Part 2. An increased anaerobic energy production is indicated by a higher rate of muscle glycogen utilisation, which reflects a higher rate of glycolysis. The blood lactate concentration at exhaustion in Table 4.2.3.7 ranged between 10.7-12.2 $mmol.l^{-1}$ between the three tests, which reflects an increased rate of lactate production at the end of the test. In fact, blood lactate concentrations may underestimate the lactate produced in the muscle (Hermansen and Stensvold, 1972; Bangsbo, 1990). The high lactate concentration may have been a reflection of the short rest period (6 s) after each high-speed run, which would have eventually resulted in a mismatch between lactate clearance and production (Ballor and Volovsek, 1992).

The blood lactate concentration from Group 1 in Part 2 fulfilled the criterion used to confirm maximal effort in $\dot{V}O_{2max}$ tests where the blood lactate concentration should be >9 $mmol.l^{-1}$ (Withers *et al.*, 2000). It seems that the lactate concentration at exhaustion in Part 2 (10.7-12.8 $mmol.l^{-1}$) compared favourably with blood lactate concentration reported at the end of the YIRT-1 (10.1 $mmol.l^{-1}$; Krustrup *et al.*, 2003), YIRT-2 (13.6 $mmol.l^{-1}$; Krustrup *et al.*, 2006) and YIET-1 (13.1 $mmol.l^{-1}$; Aziz *et al.*, 2005) but higher than in the interval shuttle run test (7.6 $mmol.l^{-1}$; Lemmink and Visscher, 2003) and the interval field test (7.8 $mmol.l^{-1}$; Bangsbo and Lindqvist, 1992). The blood lactate concentration only reflects the period immediately preceding the measurement (Bangsbo, 1990) so it is important to consider that the energy metabolism during these tests may be markedly different. For comparison, the lactate values in Part 2 were also higher then lactate values reported immediately after the second half in soccer match-play (Gerisch *et al.*, 1988; Ekblom, 1989; Smith *et al.*, 1993). However, comparisons with match-play may not be valid as the lactate concentration will not reflect the pattern of energy use during the entire match (Bangsbo, 1993a).

4.2.4.3. Practical Applications

The 15-30 protocol offer's a more practical assessment of high-intensity intermittent exercise performance compared to the 15-50 protocol. The distances for each high-speed run allows assessment in most indoor sports halls and assessment of a whole squad can be performed easily. The coach has the option of terminating the protocol after Part 1 for a sub-maximal assessment or to proceed with Part 2 where the players perform repeated high-intensity exercise. The players have to be fully familiar with the protocol before any assessment. With the constant running speed, the 15-30 protocol can be integrated as a conditioning drill in training where the players will also be familiar with the test procedures.

4.2.4.4. Conclusions

There was evidence for systematic bias between the repeated trials for the 15-30 protocol. Elite players needed fewer familiarisation trials for the learning effect to dissipate than the recreational players. The 15-30 protocol is reliable for elite players but recreational players should perform more than 4 tests to accurately determine how many trials needed. Improvements in test performance between trials may be due to a more efficient running economy. It seems that there was a predominant aerobic energy production in Part 1 whereas the loading in Part 2 was more aerobic-anaerobic supported by the heart rate and blood lactate data. For further development of the 15-30 protocol, the relationship to physical performance during match-play and other standardised field and laboratory tests of physical performance needs to be examined.

Chapter 5

The Relationship between Performance on the 15-30 Protocol and Field Tests, Aerobic Endurance and Work-Rate in Soccer Match-Play

5.1 Introduction

The activity profile of a soccer game reveals that the game consists of repeated periods of high-intensity exercise interspersed with periods of activities at a lower intensity (Bangsbo, 1994a). Hence, a soccer player's endurance capacity should reflect their ability to recover rapidly from periods of high-intensity exercise. This may lead to more high-intensity periods performed in a game (Bangsbo and Lindqvist, 1992; Verheijen, 2003). In order to evaluate soccer-specific endurance and detect changes in training status specific fitness tests should be administrated. Before any test can be applied to the sport, the test should be examined both for internal and external validity (Hopkins *et al.*, 1999; Atkinson and Nevill, 2001).

To avoid time-consuming and expensive laboratory testing, simple field tests can offer a better alternative for coaches to evaluate endurance capacity in soccer. Recently, intermittent endurance tests with an activity pattern similar to soccer have been developed such as the Yo-Yo tests (Bangsbo, 1993b), the interval shuttle run test (Lemmink and Visscher, 2003) and the 15-30 protocol. Both the YIRT and YIET have been examined for internal and external (YIRT only) validity. Krustrup *et al.* (2003) reported a significant relationship between high-intensity running in a match and YIRT-1 performance in professional Danish soccer players. There was also a significant relationship between $\dot{V}O_{2max}$ and YIRT-1. However, there were large interindividual differences in the players $\dot{V}O_{2max}$ scores compared to the YIRT-1 scores. Aziz *et al.* (2005) reported a modest relationship between the 20-m shuttle run and YIET-2. However, there was no relationship between $\dot{V}O_{2max}$ and YIET-2. These results show that the YIRT-1 examines the ability to perform repeated aerobic high-intensity exercise. The YIET-2 evaluates the ability to perform repeated intense intermittent exercise with more periods of anaerobic work. By examining the internal and external validity of the two tests, a better understanding of the physiology of the tests are given. Moreover, comparisons of test performance to competitive match-play further examine the external validity.

It is of interest to utilise a similar thorough examination of the internal and external validity of the 15-30 protocol. This is especially important when comparing any possible differences in the physiology of Part 1 and Part 2. It is important to consider that the structure of the 15-30 protocol is different compared to other soccer-specific endurance tests such as the Yo-Yo tests. This study would therefore provide a new unique insight into a different component of evaluation of soccer-specific endurance.

Evaluation of match activities to determine work-rate during match-play can range from hand-based notation analysis (Rienzi *et al.*, 2000) to complex computerised models (Figueroa *et al.*, 2006) or global positioning systems (Kirkendall *et al.*, 2003). Using some of these methods, the work-rate profiles of elite senior players during soccer match-play have been well established (Reilly and Thomas, 1976; Mayhew and Wenger, 1985; Bangsbo *et al.*, 1991; Rienzi *et al.*, 2000).

At present, no comparisons have been made between 15-30 protocol performance and match-play and with other standardised field or laboratory tests commonly used to assess aerobic endurance performance in soccer. Therefore, the aims of the present study were to:

1) compare performance on the 15-30 protocol to other standardised sub-maximal and maximal tests of aerobic endurance;
2) examine the relationship between the 15-30 protocol and distance covered on the 20-m shuttle run and the YIRT-1;
3) investigate the relationship between the 15-30 protocol and physical performance during match-play.

5.1.1 Limitations

- Due to a lack of technical resources, three players could only be filmed at once during match-play.
- The professional youth scholars were asked to refrain from any vigorous physical activity the day before the field and laboratory tests. However, the subjects have performed a heavy training session the day prior to the tests, which could not be controlled. As a result, the physiological responses during the tests could have been affected.
- Blood lactate could not be measured in the field tests due to a lack of resources.
- Some subjects had to be removed from the study due to illness or injury.
- Some heart rate data files were lost due to technical error with the Polar Team System belts.

4.1.1.2 Delimitations

- The subjects performed one experimental test (the 15-30 protocol), three criterion tests (the 20-m shuttle run, the Yo-Yo Intermittent Recovery Test Level 1 and one laboratory test).
- The subject groups chosen were delimited to male professional youth scholars from a Coca-Cola League 1 team in England.
- The physiological measurements were delimited to oxygen uptake, heart rate and blood lactate during the laboratory tests and heart rate during the field tests.
- The psychological measurement was delimited to rating of perceived exertion during both the laboratory test and the field tests.
- The movement categories during match-play were delimited to standing, walking, side-ways and backwards walk, jogging, side-ways and backwards jog, cruising and sprinting.

5.2. Methodology

5.2.1. Subjects

Nineteen male young professional soccer players from a Coca-Cola Championship League One club in England were recruited as used as subjects for this study. During the course of the study, three players were released from the club and were excluded from the data analysis so sixteen players completed the study (age: 17.1 ± 0.8; height: 176.4 ± 6.5 cm, body mass: 72.1 ± 6.8 kg). All of the subjects refrained from caffeine and alcohol 24 hours prior to the tests. No strenuous training sessions were performed the day before any of the test sessions. The subjects were informed of the benefits, risks and stresses before giving their written consent to take part in the study. Ethical approval was received from the Ethics Committee of Liverpool John Moores University.

5.2.2. Test Location

All of the laboratory tests were carried out in the physiology laboratories at the Research Institute for Sport and Exercise Sciences, Liverpool John Moores University. The field tests were conducted in an indoor sports hall with a grass carpet at Prenton Park, Tranmere Rovers FC.

5.2.3. Field Tests

5.2.3.1. The 20-m Shuttle Run

The details of this test have previously been described in section 3.1.1. The subjects performed this test once.

5.2.3.2. The Yo-Yo Intermittent Recovery Test- Level 1

The details of this test have been described in section 3.1.2. The test was performed once, one week after completion of the 20-m shuttle run.

5.2.3.3. The 15-30 Protocol

The details of the 15-30 protocol have been described in section 3.1.4. The subjects performed two familiarisation sessions prior to the experimental trial. Both Part 1 and Part 2 of the protocol were performed.

5.2.4. Laboratory Test

The subjects performed a laboratory treadmill test to determine lactate threshold (T_{lac}), onset of blood lactate accumulation (V-4 mM) and maximal oxygen consumption ($\dot{V}O_{2max}$). The details of the treadmill test are described in section 3.2.1 and 3.2.2.

5.2.5. Physiological Measurements

5.2.5.1. Heart Rate Measurements

Heart rate was recorded in 5-s intervals using the Polar Team System (Polar Electro Oy, Kempele, Finland) during all the field tests according to the procedure in section 3.4.3. In Part 1 of the 15-30 protocol, when the heart rate for each test stage was analysed, the exercise periods was analysed separately from the rest periods. For the laboratory test, heart rate was recorded using a Polar S810 heart rate monitor (Polar Electro Oy, Kempele, Finland) and later analysed on the same personal computer.

5.2.5.2. Blood Sampling

Blood samples were taken at rest and immediately at the end of each running stage in the first part of the laboratory test (the T_{lac} test) using the technique described in section 3.3. A final blood sample was taken at the end of the second stage of the laboratory test (the $\dot{V}O_{2max}$ test).

5.2.6. Psychological Measurements

The subjects were asked to rate their level of perceived exertion according to the 6-20 Borg scale (Borg, 1988) at the end of the YIRT. In the first part of the laboratory test the subjects were asked to rate their perceived exertion after each stage and at the end of the second part of the test. For Part 1 of the 15-30 protocol, RPE was recorded at the end of each block and immediately at the end of Part 2.

5.2.7. Motion Analysis

5.2.7.1. Experimental Procedure

Sixteen players were filmed once in competitive matches during the 2005-2006 season to determine their activity pattern and work rate during match-play. The matches included youth team matches from the U-19 North West Youth Alliance League, FA Youth Cup matches and reserve team matches from the Pontins Holiday League West. During all the matches that were filmed, the team employed a 4-4-2 formation. The players had no prior knowledge that they were being filmed. Only players who played the full match were included in the analysis and goalkeepers were also excluded from the analysis. Three players were excluded from the final analysis so 13 players were used for this part of the study.

All the games were filmed using a digital video camera (Sony DCR-TRV50E, Tokyo, Japan) which was placed at a fixed, elevated position at the halfway line. Each player was filmed for one match. An example of the experimental set-up for the camera position is shown in Figure 5.2.1. Each game was then played back and analysed on a personal computer (Dell Latitude D600, Round Rock, Texas, USA). Five general movement categories were defined as static (standing), walking (including sideways and backwards), jogging (including sideways and backwards), cruising and sprinting. Times spent jumping, on the ground and jockeying was also recorded. Situations where the movement category could not be determined was categorised as unclassified. These categories were chosen in accordance to Reilly and Thomas (1976) and Drust *et al.* (2000). The data was then collated to provide information on the total distance covered during a match, total distance covered in each movement category, time spent in each movement category and a percentage of the total time spent in each category. All the analysis was carried out by the same observer.

Figure 5.2.1. The experimental set-up for the filming of individual players.

5.2.7.2. Repeatability and Objectivity

The repeatability (intra-reliability) of the classification of actions by the observer was examined by re-analysing 45 minutes of a pre-selected league match from the Pontins Holiday League West. The second analysis to establish the initial repeatability occurred 3 days after the initial analysis. This process was then repeated throughout the analysis period after every 5 games. In total, 16 matches were analysed so the observer's repeatability was checked 4 times in total. This process was carried out to establish the impact of any learning effects on the data collected.

In order to determine the objectivity (inter-reliability) of the motion analysis system another observer was used. Before the start of the objectivity analysis, both observers viewed some moments from another game and verbally coded the match activities to decide the operational definitions of the match activities.

Two different ways were used to assess the repeatability and the objectivity. The motion analysis system could only be repeatable and objective if there was an agreement between both the classifications of activities during the match and the distance covered for each activity. The number of exact agreements observed was used to determine the level of agreement between the activity classifications for both the repeatability and objectivity. The process involved a second-by-second breakdown of the results for the 45 min period analysed. The 2779 observations obtained for each analysis was recorded manually onto a Microsoft Excel spreadsheet in the form of a contingency table to allow the calculation of the number of exact agreements between the data sets to be compared. Both the intra- and inter-reliability of the 2779 observations was assessed by the Kappa analysis technique. In addition, the number of agreements that could be expected by chance was also calculated. This method of measure of agreement is Kappa. The Kappa statistic refers to the number of exact agreements observed to which can be expected by chance. A Kappa value of 1.0 is perfect and a value of zero is when the agreement is no better then what is expected by chance. Altman (1991) provided some guidelines in the assessment of Kappa agreement as shown in Table 5.2.1.

Table 5.2.1. Categories for the assessment of Kappa values (Altman, 1991).

Value of Kappa (*k*)	Strength of Agreement
<0.20	Poor
0.21-0.40	Fair
0.41-0.60	Moderate
0.61-0.80	Good
0.81-1.00	Very Good

The number of exact agreements, *k* values and strength of agreement according to Altman (1991) for the intra- (repeatability) and inter (objectivity) reliability assessments are shown in Table 5.2.2. All the percentages for the exact agreements for repeatability ranged between 83.7-87.5% with all assessments greater than 0.8 (80%). The strength of agreement for all the *k* values was either good or very good which demonstrated that there was an acceptable level of agreement in the observers classifications of actions. For the objectivity assessment the exact agreements was 90.8% and the *k* rating was very good.

Table 5.2.2. The number of exact agreements and Kappa (*k*) values for inter and intra reliability assessments for the motion analysis.

	Exact Agreements (%)	*k* value	Strength of Agreement
Initial repeatability	83.7	0.78	Good
Second assessment	87.5	0.83	Very Good
Third assessment	87.3	0.82	Very Good
Final assessment	84.1	0.80	Good
Objectivity	90.8	0.87	Very Good

Repeatability and objectivity of the total distance covered in each of the activity categories were examined using coefficients of variation, limits of agreement (Bland and Altman, 1986) and the coefficient of variation of the limits of agreement. If there was a significant bias detected, then the methodology should not be considered to be repeatable and objective. Differences between the first analysis and the subsequent set of analysis are shown on the Bland and Altman plots in Figures 5.2.2, 5.2.3, 5.2.4 and 5.2.5. The difference between the two observers for the objectivity assessment is shown in Figure 5.2.6. For the limits of agreement analysis, it is expected that 95% of the differences will lie within these limits.

The coefficient of variation, the limits of agreement and the coefficient of variation of the limits of agreement is shown in Table 5.2.3. The limits of agreement describe the "worst case" disagreement that could be found between the repeatability assessments. The upper and lower limits of agreement ranged from -99.98 m up to 86.15 m for the repeatability assessment and -51.3 m to 45.5 m for the objectivity assessment. At the initial repeatability check the coefficient of variation was 4.7% and increased up to 8.1% for the final assessment when 16 games had been analysed. The coefficient of variation for the limits of agreement for the repeatability also ranged between 3.3%-5.7%. Based on the values for repeatability and objectivity it would seem to suggest that the method used in the determination of distance covered and the total distance covered for each category is acceptable.

Table 5.2.3. Limits of agreement analysis for the distance covered measurements.

	Coefficient of variation (%)	Systematic bias and random error	Upper and lower limits of agreement for distance covered (m)	Coefficient of variation of the limits of agreement
Initial repeatability	4.7	18.58 ± 26.05	-32.48 to 69.62	3.3
Second assessment	4.4	3.32 ± 25.71	-47.07 to 53.71	3.1
Third assessment	6.0	-0.475 ± 35.45	-69.95 to 69.00	4.2
Final assessment	8.1	-6.85 ± 47.45	-99.85 to 86.15	5.7
Objectivity	4.1	-5.4 ± 23.42	-51.3 to 40.5	3.1

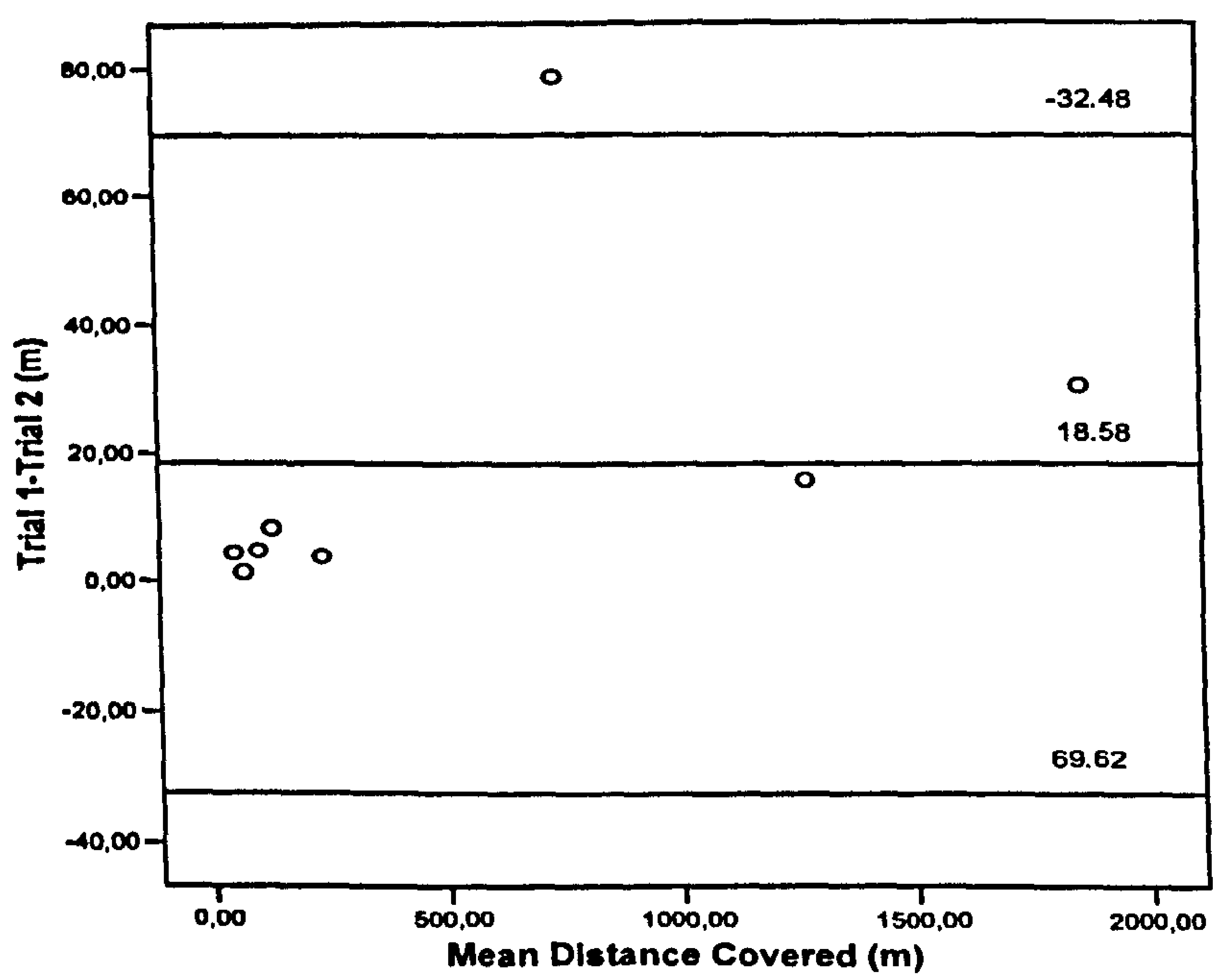


Figure 5.2.2. Bland and Altman plot displaying the upper and lower limits of agreement for the distance covered for the intra-reliability analysis for the initial repeatability.

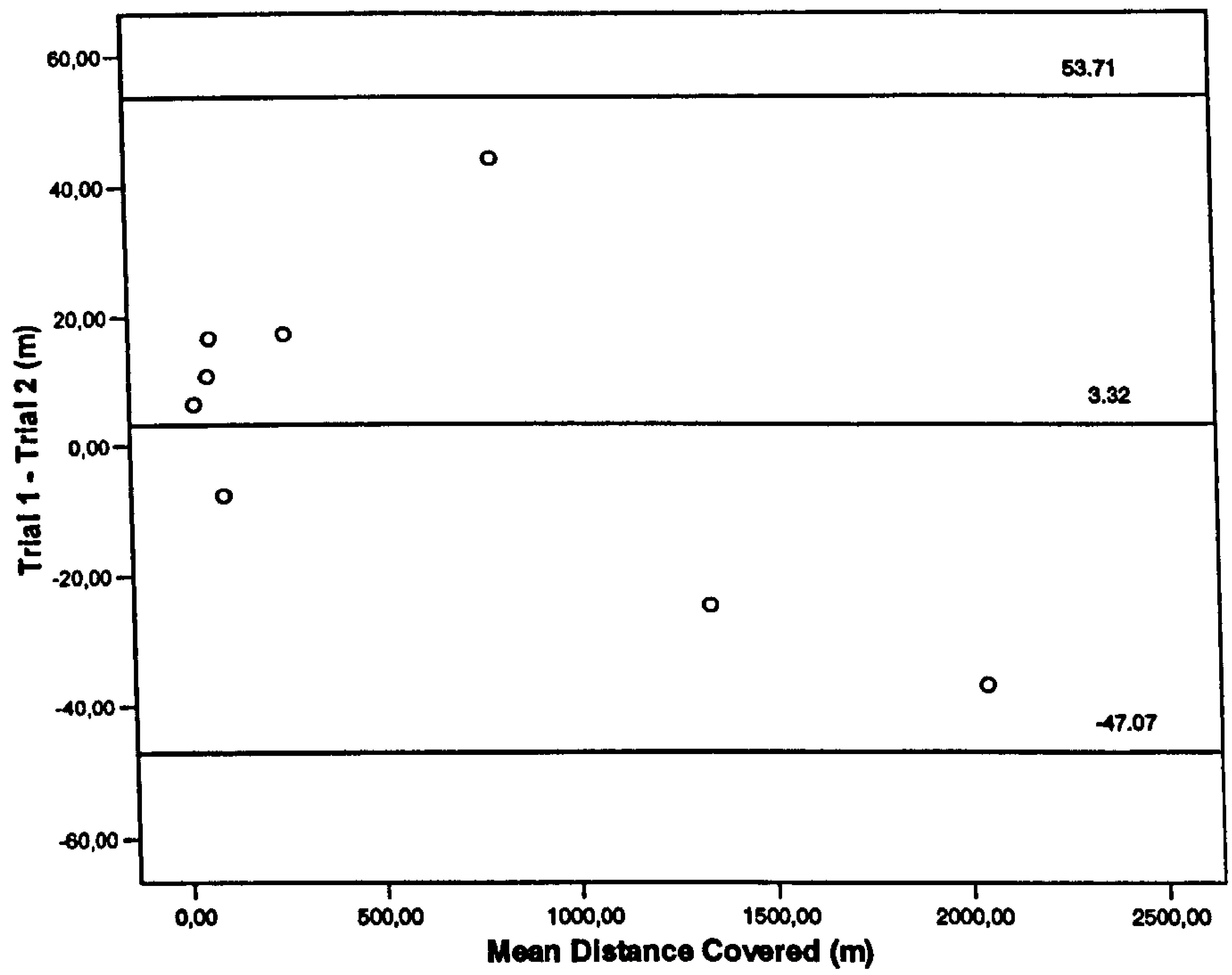


Figure 5.2.3. Bland and Altman plot displaying the upper and lower limits of agreement for the distance covered for the second repeatability assessment.

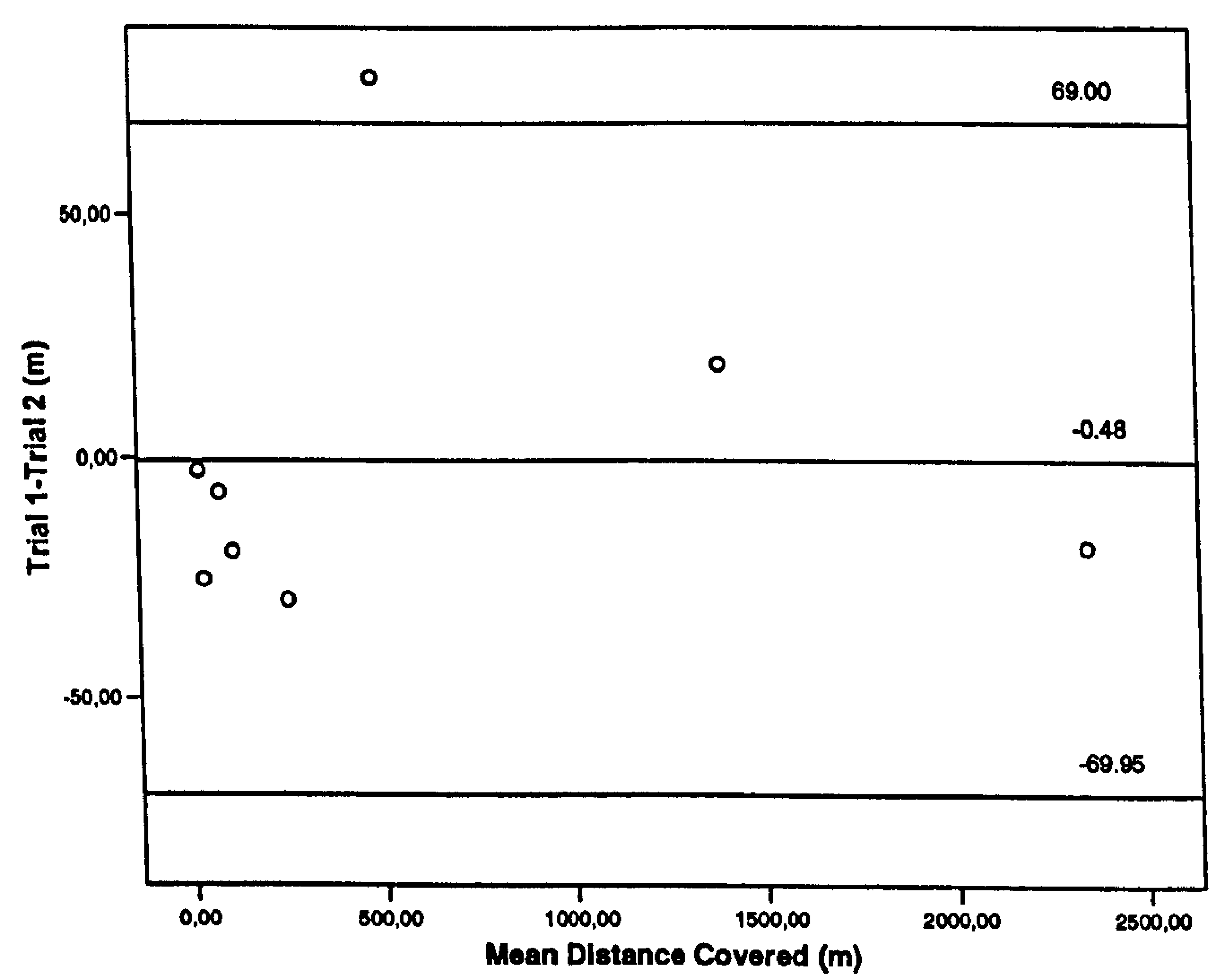


Figure 5.2.4. Bland and Altman plot displaying the upper and lower limits of agreement for the distance covered for the third repeatability assessment.

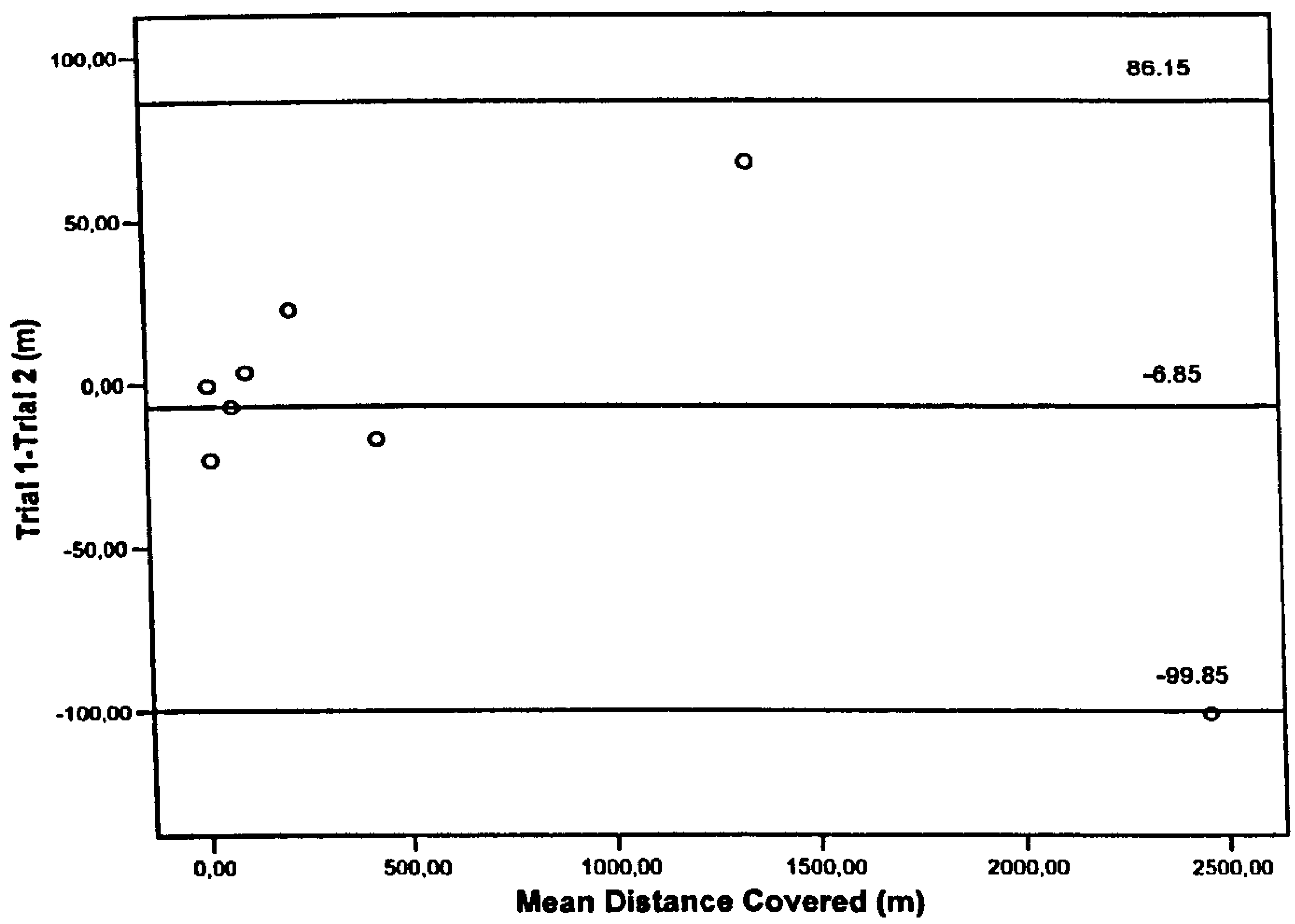


Figure 5.2.5. Bland and Altman plot displaying the upper and lower limits of agreement for the distance covered for the final repeatability assessment.

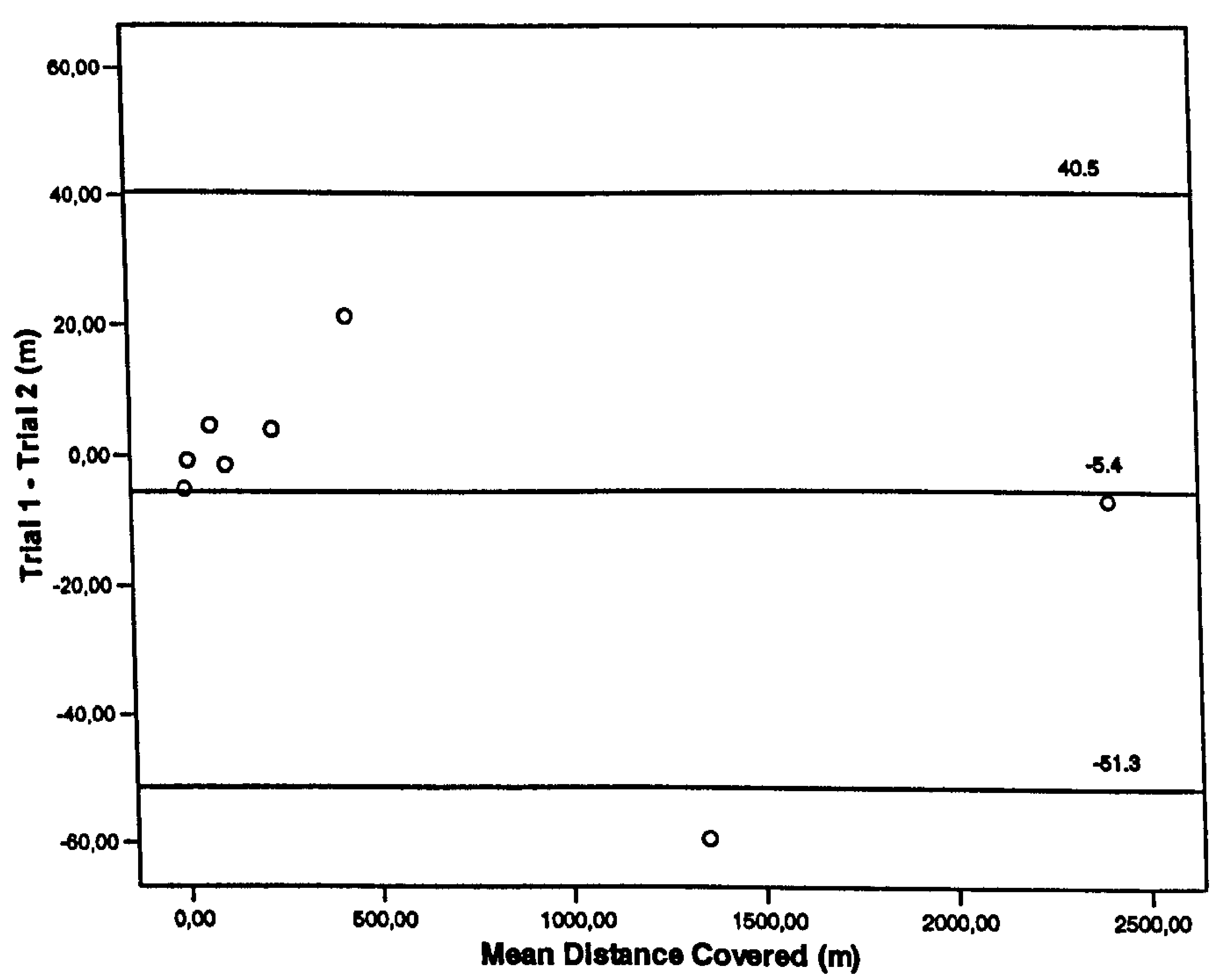


Figure 5.2.6. Bland and Altman plot displaying the upper and lower limits of agreement for the distance covered for the objectivity assessment.

5.3.8. Statistical Analysis

All the data is presented as means (±SD) unless otherwise stated. When exploring the relationships between different performance variables a Pearson's Correlation Coefficient was used. Differences between playing positions was explored using a one-way analysis of variance (ANOVA). To explore comparisons in the peak heart rates between the different field and laboratory tests, total distance covered during match play, distance covered in the different movement categories and the time spent in the different movement categories in match-play a Student's T-Test was used. If parametric assumption were not met, a Wilcoxon Signed Ranks Test was used. Statistical significance was set at $p<0.05$.

5.3. Results

5.3.1. Field Tests

5.3.1.1. The 15-30 Protocol

The mean heart rate in Part 1 and Part 2 was 166 ± 10 beats.min^{-1} (83.7 ± 3.9% of HR_{peak}) and 187 ± 8 beats.min^{-1} (94.3 ± 2.6% of HR_{peak}) respectively. There was a significant difference ($Z (16) = -3.52$, $p<0.05$) in the mean heart rate between Part 1 and Part 2. A significantly ($Z (16) = -3.41$, $p<0.05$) higher HR_{peak} was achieved in Part 2 (193 ± 9 beats.min^{-1} equivalent to 97.2 ± 2.5% of HR_{peak}) compared to Part 1 (187 ± 8 beats.min^{-1} equivalent to 93.5 ± 3.8% of HR_{peak}). The time spent in each heart rate zone in relation to playing position during Part 1 and Part 2 is shown in Tables 5.3.2 and 5.3.3. The estimated oxygen cost during Part 1 was significantly ($t (15) = -16.31$, $p<0.05$) higher in Part 2 (88.8 ± 6.7 % of $\dot{V}O_{2max}$) compared to Part 1 (74.2 ± 8.7% of $\dot{V}O_{2max}$) based on the HR-$\dot{V}O_2$ relationship established in the laboratory test. The players completed a mean of 23 ± 12 runs in Part 2 that corresponded to a distance covered of 1326 ± 663 m. Table 5.3.1 shows the performance in the 15-30 protocol from the professional youth scholars in relation to playing position.

Table 5.3.1. Performance in Part 1 and Part 2 of the 15-30 protocol in the professional youth scholars in relation to playing position.

Playing Position	*Heart rate (beats.min^{-1}) in Part 1 (% of HR_{peak})*	*Heart rate (beats.min^{-1}) in Part 2 (% of HR_{peak})*	*Number of runs in Part 2*	*Distance covered (m) in Part 2*
Goalkeepers (N = 2)	169 ± 1 (85.5 ± 0.7)	187 ± 5 (94.9 ± 1.4)	10 ± 4.2	580 ± 246
Defenders (N = 5)	172 ± 11 (86.2 ± 4.5)	190 ± 10 (95.6 ± 3.6)	21.8 ± 12.6	1264 ± 733
Midfielders (N = 5)	162 ± 12 (80.8 ± 3.2)	187 ± 9 (93.4 ± 1.8)	31 ± 13.1	1798 ± 758
Forwards (N= 4)	161 ± 3 (84.0 ± 2.3)	181 ± 3 (94.5 ± 2.9)	20.5 ± 2.1	1189 ± 121
Mean ± SD (N = 16)	166 ± 10 (83.9 ± 3.9)	186 ± 8 (94.4 ± 2.6)	22.9 ± 11.7	1327 ± 677

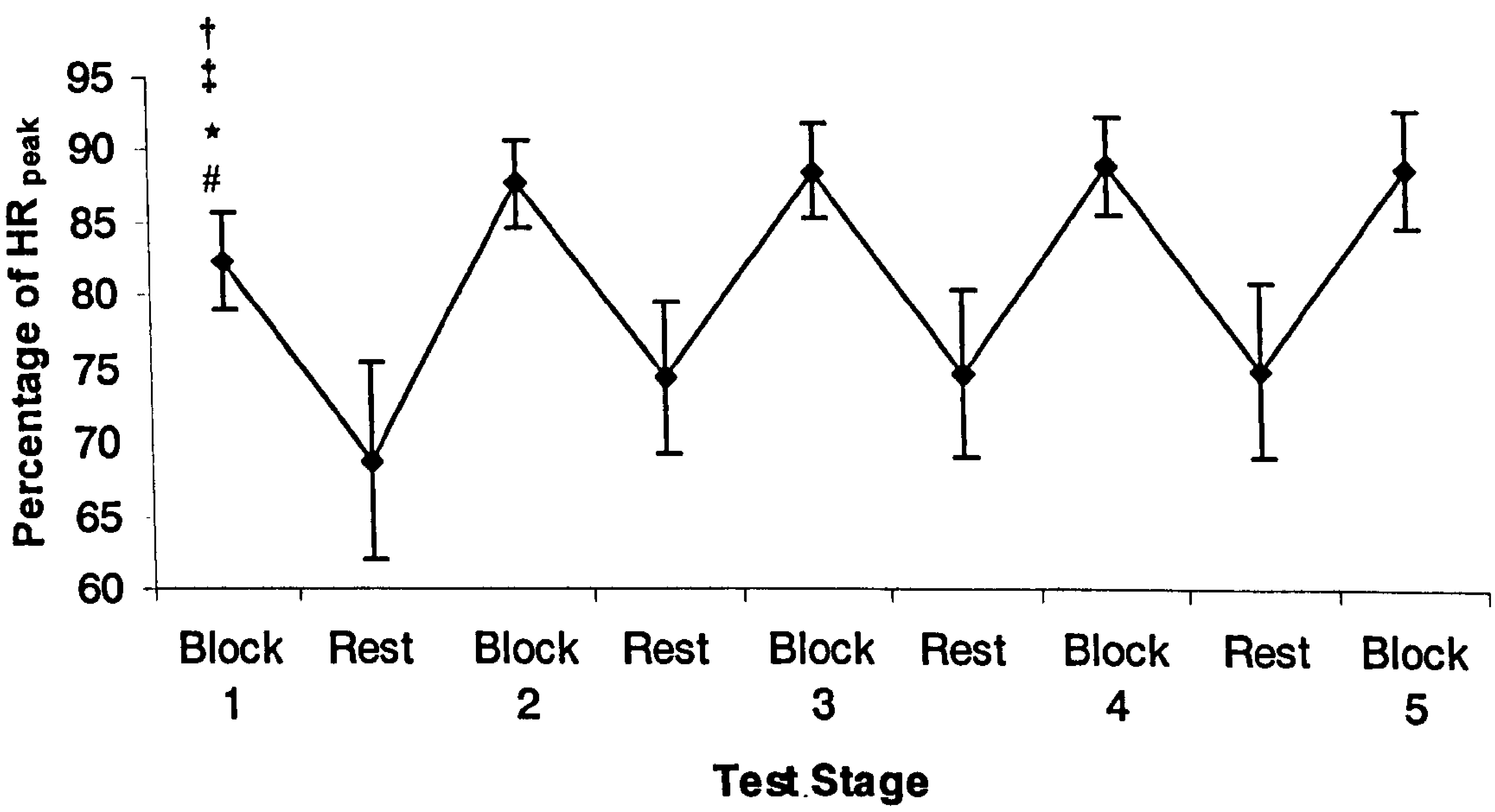
Table 5.3.2. Time spent in the different heart rate zones for the professional youth scholars during Part 1 of the 15-30 protocol in relation to playing position.

	<60% of HR_{peak}	60-75% of HR_{peak}	75-85% of HR_{peak}	85-90% of HR_{peak}	90-95% of HR_{peak}	95-100% of HR_{peak}
Goalkeepers (N = 2)	0 ± 0	14.8 ± 1.8	24.3 ± 1.8	27.5 ± 1.2	33.5 ± 1.3	0 ± 0
Defenders (N = 5)	0.6 ± 1.4	9.9 ± 8.1	23.5 ± 11.7	21.8 ± 8.7	33.5 ± 21.9	10.6 ± 15.3
Midfielders (N = 5)	5.5 ± 5.2	17.9 ± 2.7	25.9 ± 11.9	28.8 ± 7.9	22.7 ± 20.3	0 ± 0
Forwards (N = 4)	0.6 ± 1.2	17.6 ± 4.5	21.0 ± 8.4	33.1 ± 8.1	24.9 ± 16.9	2.9 ± 4.0
Mean ± SD (N = 16)	2.1 ± 3.7	14.9 ± 6.1	23.5 ± 9.5	27.5 ± 8.3	28.0 ± 17.9	4.0 ± 9.4

Table 5.3.3. Time spent in the different heart rate zones for the professional youth scholars during Part 2 of the 15-30 protocol in relation to playing position.

	<60% of HR_{peak}	60-75% of HR_{peak}	75-85% of HR_{peak}	85-90% of HR_{peak}	90-95% of HR_{peak}	95-100% of HR_{peak}
Goalkeepers (N = 2)	0 ± 0	0 ± 0	0 ± 0	6.3 ± 0.3	29.1 ± 16.5	64.6 ± 16.3
Defenders (N = 5)	0 ± 0	0 ± 0	0.7 ± 1.2	2.4 ± 3.7	26.9 ± 35.3	70.0 ± 39.9
Midfielders (N = 5)	0 ± 0	0 ± 0	0 ± 0	3.1 ± 4.3	38.4 ± 32.3	58.2 ± 34.9
Forwards (N = 4)	0 ± 0	0 ± 0	0.5 ± 1.1	1.8 ± 2.3	32.0 ± 40.7	65.7 ± 44.0
Mean ± SD (N = 16)	0 ± 0	0 ± 0	0.4 ± 0.9	3.0 ± 3.4	32.0 ± 31.4	64.6 ± 34.3

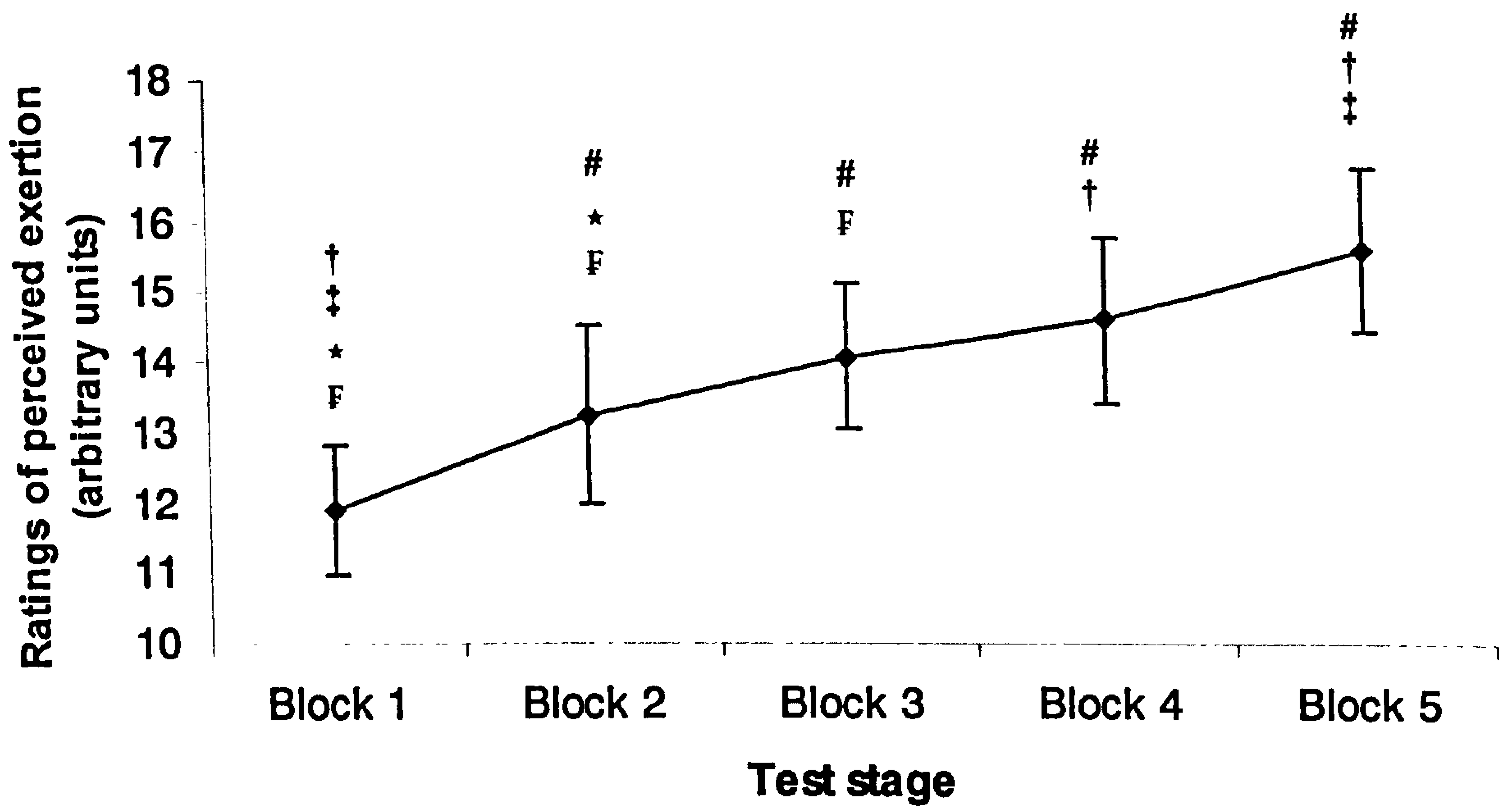
There was no significant difference between the playing positions (excluding GK) in the mean heart rate in Part 1 ($F_{2\ 11} = 2.90$, $p>0.05$) or Part 2 ($F_{2\ 11} = 0.74$, $p>0.05$) of the 15-30 protocol. There was also no significant difference ($F_{2\ 11} = 1.28$, $p>0.05$) between playing positions in the number of runs in Part 2.



† = significant ($p<0.05$) to block 2, ‡ = significant ($p<0.05$) to block 3, ★ = significant ($p<0.05$) to block 4, # = significant ($p<0.05$) to block 5

Figure 5.3.1. Heart rate in the different test stages during Part 1 of the 15-30 protocol in the professional youth scholars.

There was a significant difference in the mean heart rate between each exercise block in the professional youth scholars, as shown in Figure 5.3.1. Heart rate was significantly lower ($F_{4\ 60} = 8.06$, $p<0.05$) in block 1 compared to all the other blocks as shown in Figure 5.3.1. There was no significant difference ($F_{3\ 48} = 2.43$, $p>0.05$) in the mean heart rate between any of the 90-s rest periods in Part 1.



= significant (p<0.05) to block 1, † = significant (p<0.05) to block 2, ‡ = significant (p<0.05) to block 3, * = significant (p<0.05) to block 4, F = significant (p<0.05) to block 5

Figure 5.3.2. The perceived exertion of the professional youth scholars at the end of each block in the 15-30 protocol.

There was a significant difference ($F_{4\ 75} = 25.98$, $p<0.05$) in the mean ratings of perceived exertion at the end of the different exercise blocks. As shown in the Figure 5.3.2, differences occurred between most of the exercise blocks, and there was a trend for a gradual increase in the perceived exertion for each exercise block in Part 1.

5.3.1.2. The 20-m Shuttle Run

In the 20-m shuttle run, the professional youth scholars covered a total distance of 2271 ± 309 m. The estimated $\dot{V}O_{2max}$ was 53.08 ± 4.1 $ml.kg^{-1}.min^{-1}$. The peak heart rate reached during the test was 198 ± 8 $beats.min^{-1}$, which corresponded to 99% of HR_{peak} attained in the laboratory treadmill test. The estimated $\dot{V}O_{2max}$ in the 20-m shuttle run was significantly lower $t(16) = 8.731$, $p<0.05$) compared to the laboratory $\dot{V}O_{2max}$ (61.5 ± 5.0 $ml.kg^{-1}.min^{-1}$).

5.3.1.3. The Yo-Yo Intermittent Recovery Test

The total distance covered in the Yo-Yo Intermittent Recovery Test (Level 1) was 1857 ± 434 m. The HR_{peak} attained during the test was 194 ± 9 beats.min^{-1} which corresponded to 99 ± 6% of the HR_{peak} from the laboratory treadmill test. The mean ratings of perceived exertion immediately after the test were 19.1 ± 1.7.

5.3.2. Laboratory Test

During the first stage of the laboratory test, the players T_{lac} at 2-mmol.l^{-1} occurred at a mean running speed of 12.8 ± 1.1 km.h^{-1}. The mean heart rate at T_{lac} corresponded to 84.4 ± 3.9 % of HR_{peak}, which was equivalent to 73.8 ± 4.4% of $\dot{V}O_{2max}$. The V-4 mM occurred at a running speed corresponding to 14.1 ± 1.0 km.h^{-1}. The heart rate at V-4 mM was 89.8 ± 2.7 % of HR_{peak} or 83.2 ± 5.2 % of $\dot{V}O_{2max}$. During the second or incremental stage of the laboratory test the players ran for a mean duration of 191.4 ± 44.2 s. During the second stage of the laboratory test, the players' mean absolute, relative and scaled $\dot{V}O_{2max}$ was 4.4 ± 0.4 l.min^{-1}, 61.5 ± 5.0 ml.kg^{-1}.min^{-1} and 178.9 ± 14.0 ml.kg$^{-0.75}$.min^{-1} respectively. The HR_{peak} recorded during this stage was 197 ± 11 beats.min^{-1} and this was used as a reference value for the field tests.

Table 5.3.4. Laboratory test result for the professional youth scholars in relation to playing position.

Playing Position	*Running speed (km.h⁻¹) at T_{lac}*	*Running speed (km.h⁻¹) at V-4 mM*	$\dot{V}O_{2max}$ *(l..min⁻¹)*	$\dot{V}O_{2max}$ *(ml.kg⁻¹.min⁻¹)*	$\dot{V}O_{2max}$ *(ml.kg⁻⁰·⁷⁵.min⁻¹)*	*HR_{peak} (beats.min⁻¹)*	*Time to exhaustion (s)*
Goalkeepers (N = 2)	11.5 ± 0.7	13.6 ± 0.7	4.03 ± 0.2	56.31 ± 1.0	169.5 ± 1.0	199 ± 4	160.5 ± 30.4
Defenders (N = 5)	13.4 ± 0.9	14.5 ± 0.6	4.43 ± 0.4	63.03 ± 5.8	182.0 ± 17.0	199 ± 15	200.4 ± 45.3
Midfielders (N = 5)	13.0 ± 1.4	14.5 ± 1.7	4.42 ± 0.6	63.61 ± 4.7	181.2 ± 18.2	200 ± 10	228.2 ± 28.8
Forwards (N= 4)	12.3 ± 0.5	13.7 ± 0.8	4.36 ± 0.4	60.33 ± 2.9	177.1 ± 7.9	189 ± 8	149.8 ± 16.4†
Mean ± SD (N = 16)	12.8 ± 1.1	14.3 ± 1.1	4.36 ± 0.4	62.41 ± 4.8	179.0 ± 14	197 ± 11	199.5 ± 46.1

† = significant ($p<0.05$) to midfielders

There was no significant difference ($F_{3\ 40}$ = 1.385, p>0.05) in the HR_{peak} reached in the laboratory test (194 ± 11 beats.min^{-1}), the 20-m shuttle run (198 ± 7 beats.min^{-1}), the Yo-Yo intermittent recovery test (194 ± 9 beats.min^{-1}) or Part 2 of the 15-30 protocol (191 ± 8 beats.min^{-1}) (N = 11 for all tests). The results from the treadmill test in relation to playing positions are shown in Table 5.3.4.

There was no significant differences between playing positions reported for the running speed at T_{lac} ($F_{2\ 11}$ = 1.371, p>0.05) or V-4 mM ($F_{2\ 11}$ = 1.173, p>0.05), absolute $\dot{V}O_{2max}$ ($F_{2\ 11}$ = 0.075, p>0.05), relative $\dot{V}O_{2max}$ ($F_{2\ 11}$ = 0.408, p>0.05), scaled $\dot{V}O_{2max}$ ($F_{2\ 11}$ = 0.124, p>0.05) in relation to body mass or HR_{peak} ($F_{2\ 11}$ = 1.045, p>0.05) as shown in Table 5.3.4. A significant difference ($F_{2\ 11}$ = 6.165, p<0.05) was reported for the time to exhaustion with the time for forwards running for a significantly shorter time compared to midfielders.

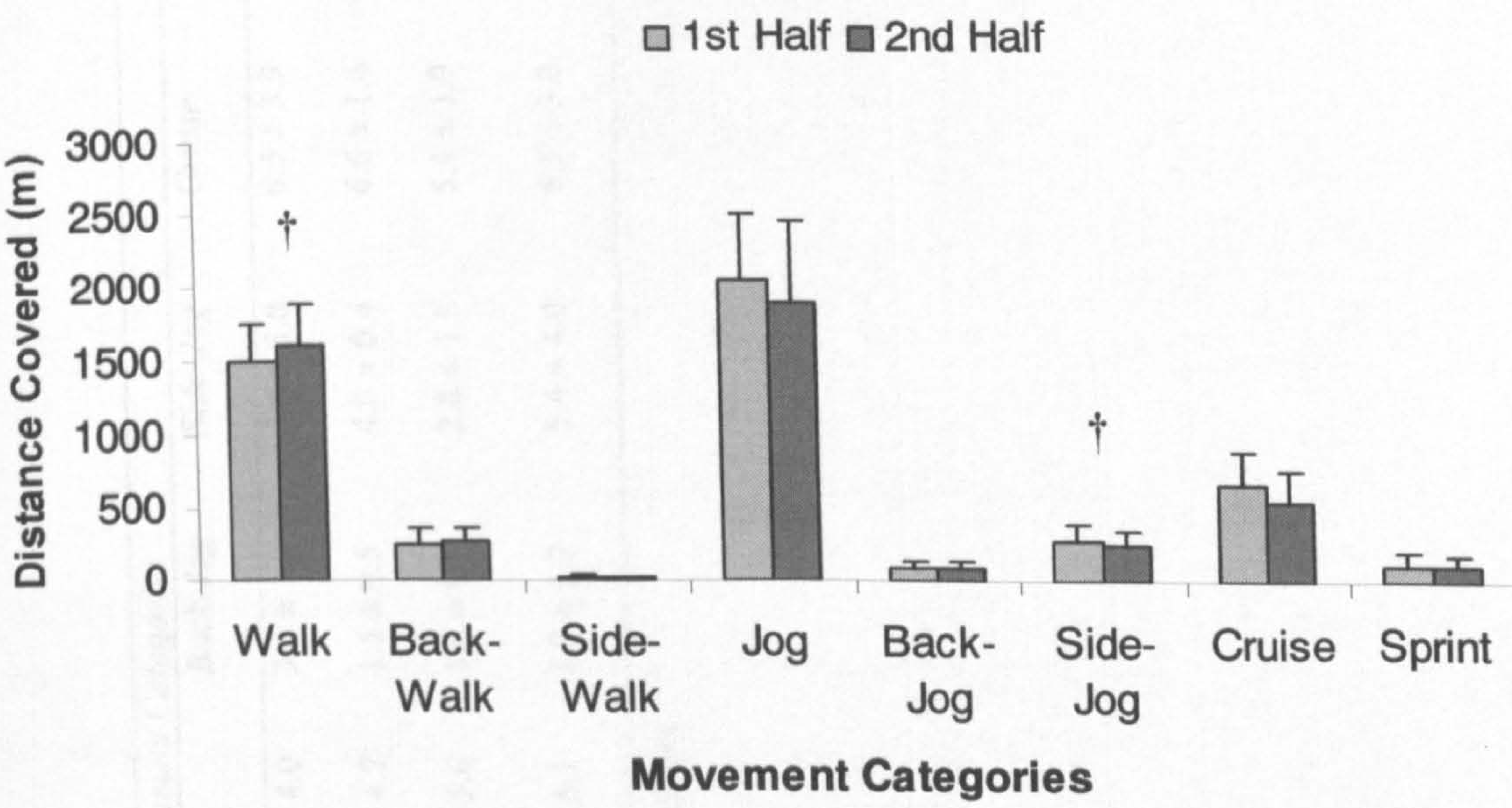
5.3.3. Motion Analysis

The mean distance covered for the professional youth scholars was 4950 ± 479 m in the first half and 4791 ± 577 m for the second half. There was a 3% decrease in distance covered from the first to second half. There was no significant difference (t (12) = 1.45, p>0.05) in the distance covered between the first and second half. The total distance covered was 9742 ± 984 m. The distance covered in high-intensity exercise defined as cruising and sprinting was 766 ± 254 m for the first half and 662 ± 245 m for the second half. The decrease in high-intensity running from the first half to the second half was 14%. No significant difference (t (12) = 1.59, p>0.05) was reported between the first and second half. The total distance covered in high-intensity exercise was 1428 ± 439 m.

Table 5.3.5. Total distance covered (m) during match-play in the professional youth scholars in relation to playing position.

	Playing Position		
	Defenders (N =5)	*Midfielders (N = 4)*	*Forwards (N = 4)*
Distance First Half (m)	4825 ± 201	5102 ± 354	4955 ± 826
Distance Second Half (m)	4502 ± 430	5133 ± 740	4812 ± 489
Total Distance (m)	9328 ± 541	10235 ± 1088	9768 ± 1299

There was no significant difference between playing positions in the distance covered for either the first ($F_{2\ 10} = 0.32$, $p>0.05$) or the second half ($F_{2\ 10} = 1.43$, $p>0.05$) as shown in Table 5.3.5. There was also no significant difference ($F_{2\ 10} = 0.94$, $p>0.05$) for the total match distance between the playing positions.



† = significant ($p<0.05$) to first half

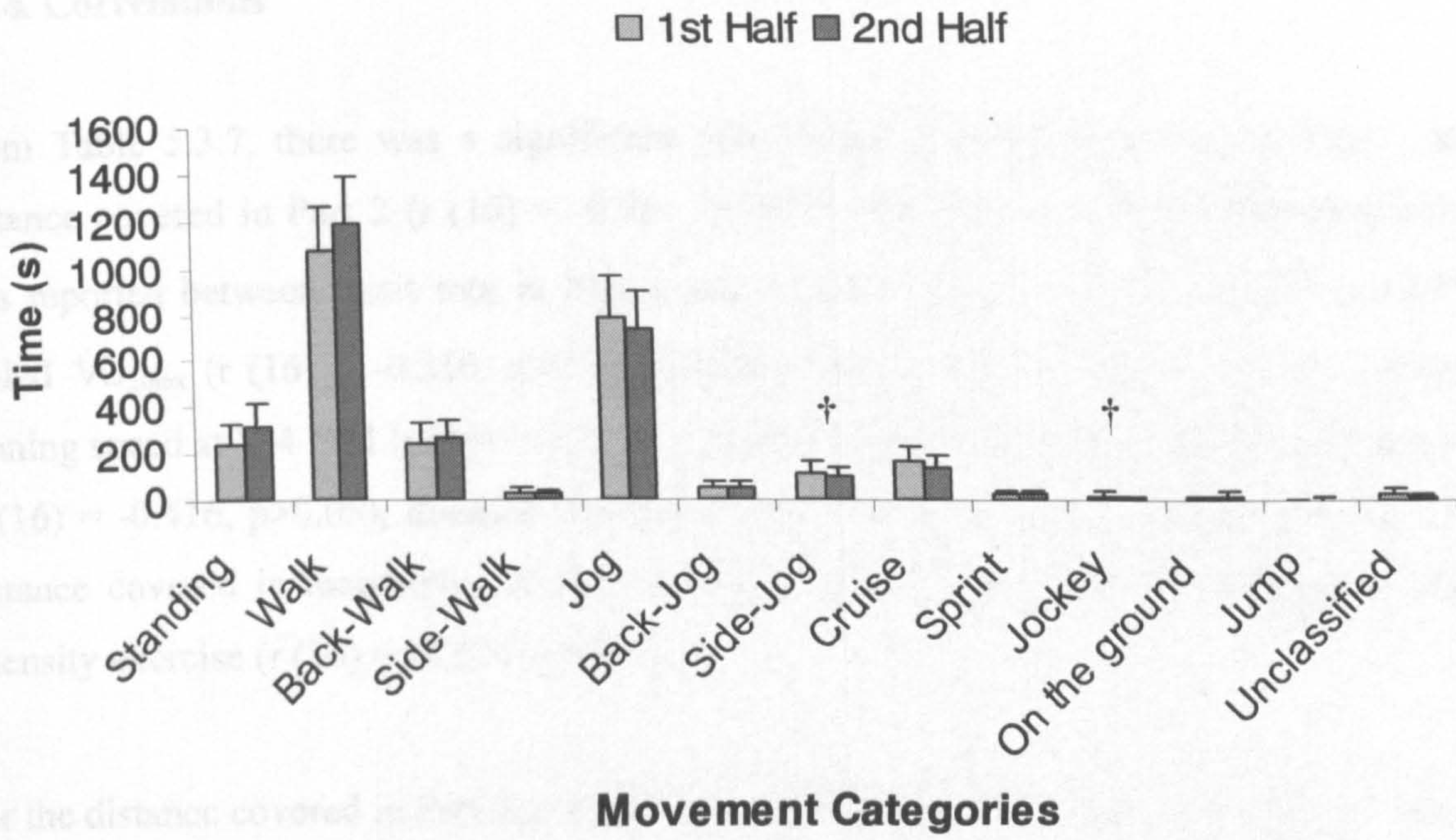
Figure 5.3.3. Distance covered (m) in the first and second half in each movement category in the professional youth scholars.

The greatest distance was spent in walking and jogging activities in both the first and second half as shown in Figure 5.3.3. There was a significant difference between the first and second half in the distance covered for the walk ($t\ (12) = -3.622$, $p<0.05$) and side-jog ($t\ (12 = 2.323$, $p<0.05$) categories.

Table 5.3.6. Proportion of the total match duration (% of total time) spent in each movement category in relation to playing position in the professional youth scholars.

	Movement Categories									
Playing Position	*Standing*	*Walk*	*Back-Walk*	*Side-Walk*	*Jog*	*Back-Jog*	*Side-Jog*	*Cruise*	*Sprint*	*Other*
Defenders (N = 5)	11.6 ± 2.0	33.8 ± 5.0	9.3 ± 1.4	1.6 ± 1.3	26.0 ± 4.0	3.0 ± 1.4	6.8 ± 5.0	6.5 ± 3.9	0.6 ± 0.4	0.3 ± 0.3
Midfielders (N = 4)	7.6 ± 2.8	35.8 ± 1.7	8.8 ± 3.8	1.3 ± 0.5	31.3 ± 4.7	1.6 ± 0.5	4.0 ± 0.4	6.6 ± 1.4	0.9 ± 0.4	0.5 ± 0.3
Forwards (N = 4)	9.7 ± 2.5	45.9 ± 6.0⋆†	8.7 ± 3.2	0.7 ± 0.3	23.5 ± 5.6	1.6 ± 0.8	2.8 ± 1.3	5.1 ± 1.9	0.8 ± 0.5	0.4 ± 0.3
Total (N = 13)	11.9 ± 7.6	39.0 ± 9.4	10.2 ± 4.3	1.2 ± 0.9	26.4 ± 5.1	3.3 ± 3.7	5.4 ± 4.0	5.5 ± 3.0	0.7 ± 0.5	0.4 ± 0.2

⋆ = significant different ($p<0.05$) to defenders, † = significant different ($p<0.05$) to midfielders



† = significant different ($p<0.05$) to first half

Figure 5.3.4. Time (s) spent in each of the movement categories in the first and second half in the professional youth scholars.

The mean duration of the first half was 2781 ± 63 s and 2889 ± 95 s for the second half with a significant difference (Z (12) = -2.760, $p<0.05$) between the halves. Significant differences in the time spent in an activity occurred between the first and second half for the side-jog (t (12) = 2.428, $p<0.05$) and jockey (Z (12) = -2.380, $p<0.05$) activities as shown in Figure 5.3.4.

From Table 5.3.6, the only significant difference ($F_{2\ 10}$ = 8.27, $p<0.05$) found in the proportion of total time spent in the different activities was for walking. Post-hoc analysis revealed that the forwards spent a significantly longer time walking compared to defenders and midfielders. Also, the majority of the time for all playing positions was spent walking (39 ± 9.4%) and jogging (26.4 ± 5.1%). The total time spent in high-intensity exercise was 6.2% of the total match duration with 5.5 ± 3.0% spent cruising and 0.7 ± 0.5% spent sprinting. Activities such as jumping, on the ground, jockeying and unclassified was grouped together in the category 'other', which made up 0.4 ± 0.2% of the total time.

5.3.4. Correlations

From Table 5.3.7, there was a significant relationship between heart rate in Part 1 and distance covered in Part 2 (r (16) = -0.561, $p<0.05$). However, no significant relationship was reported between heart rate in Part 1 and relative $\dot{V}O_{2max}$ (r (16) = -0.332, $p>0.05$), scaled $\dot{V}O_{2max}$ (r (16) = -0.310, $p>0.05$), running speed at T_{lac} (r (16) = -0.147, $p>0.05$), running speed at V-4 mM (r (16) = -0.124, $p>0.05$), distance covered in the 20-m shuttle run (r (16) = -0.416, $p>0.05$), distance covered in the YIRT-1 (r (16) = -0.096, $p>0.05$), total distance covered in match-play (r (16) = -0.139, $p>0.05$) and the total distance in high-intensity exercise (r (16) = -0.270, $p>0.05$).

For the distance covered in Part 2, a significant relationship was reported for relative $\dot{V}O_{2max}$ (r (16) = 0.831, $p<0.05$), scaled $\dot{V}O_{2max}$ (r (16) = 0.791, $p<0.05$), running speed at T_{lac} (r (16) = 0.642, $p<0.05$), running speed at V-4 mM (r (16) = 0.600, $p<0.05$), distance covered in the 20-m shuttle run (r (16) = 0.745, $p<0.05$). No significant relationship was reported between distance covered in Part 2 and the distance covered in the YIRT-1 (r (16) = 0.448, $p>0.05$), total distance covered in match-play (r (16) = 0.331, $p>0.05$) or the total high-intensity distance during match-play (r (16) = 0.414, $p>0.05$).

Table 5.3.7. Pearson's correlation coefficient between various performance parameters.

	% of HR_{peak} during Part 1	Distance covered (m) in Part 2	$\dot{V}O_{2max}$ ($ml.kg^{-1}.min^{-1}$)	$\dot{V}O_{2max}$ ($ml.kg^{-0.75}.min^{-1}$)	Running speed ($km.h^{-1}$) at T_{lac}	Running speed ($km.h^{-1}$) at V-4 mM	Distance covered (m) in the Yo-Yo test	Distance covered (m) in the 20-m shuttle run	Time spent in high-intensity running during match-play	Total distance covered (m) during match-play
% of HR_{peak} during Part 1	x	x	x	x	x	x	x	x	x	x
Distance covered (m) in Part 2	-0.561†	x	x	x	x	x	x	x	x	x
$\dot{V}O_{2max}$ ($ml.kg^{-1}.min^{-1}$)	-0.332	0.831†	x	x	x	x	x	x	x	x
$\dot{V}O_{2max}$ ($ml.kg^{-0.75}.min^{-1}$)	-0.310	0.781†	0.936†	x	x	x	x	x	x	x
Running speed ($km.h^{-1}$) at T_{lac}	-0.147	0.642†	0.733†	0.635†	x	x	x	x	x	x
Running speed ($km.h^{-1}$) at V-4 mM	-0.124	0.600†	0.660†	0.634†	0.780†	x	x	x	x	x
Distance covered (m) in the Yo-Yo test‡	-0.096	0.448	0.731†	0.581†	0.694†	0.464	x	x	x	x
Distance covered (m) in the 20-m shuttle run	-0.416	0.745†	0.614†	0.468	0.607†	0.546†	0.646†	x	x	x

Time spent in high-intensity running during match-play*	-0.270	0.414	0.065	0.051	0.205	0.094	0.073	0.344	x	x
Total distance covered (m) during match-play*	-0.139	0.331	0.100	0.153	-0.291	0.043	-0.130	0.133	0.140	x

† = significant ($p<0.05$) correlation, ‡N = 12, *N = 13

5.4 Discussion

The aim of this study was to compare performance on the 15-30 protocol to aerobic fitness measures, various field tests used in soccer and physical performance during match-play. The main finding of the study was that there was a significant relationship between aerobic fitness measures and Part 2 of the 15-30 protocol. No significant relationship was observed between any of the performance variables and Part 1 of the 15-30 protocol. There was also no significant relationship between the subjects work-rate indices in match-play and any of the laboratory or field tests including the 15-30 protocol. The total distance and the time spent high-intensity exercise was lower in the present study compared to that reported in the literature.

5.4.1 Aerobic Endurance

A strong significant relationship (r = 0.831) was established between Part 2 of the 15-30 protocol and $\dot{V}O_{2max}$ as shown in Table 5.3.2. No significant relationship (r = -0.331) was reported between Part 1 and $\dot{V}O_{2max}$. These observations would suggest that the players' performance in Part 2 was strongly influenced by their aerobic power. In fact, 83% of their performance in Part 2 can be explained by their $\dot{V}O_{2max}$ levels. This relationship was also the strongest relationship reported between any of the performance variables and Part 2 from Table 5.3.2. The lack of a relationship between Part 1 and $\dot{V}O_{2max}$ is surprising. The sub-maximal nature of Part 1 would suggest that players with a higher $\dot{V}O_{2max}$, T_{lac} and V-4 mM would have exercised at a lower percentage of HR_{peak} during Part 1. One possible explanation may be the different criteria used to evaluate performance in Part 1 and Part 2.

Performance in Part 1 was evaluated via heart rate measurements expressed as a percentage of players HR_{peak} whereas performance in Part 2 was based on the number of completed runs. It may be that performance in Part 1 is influenced by other factors than aerobic fitness *per se*. The exercise pattern in Part 2 is slightly different from Part 1 where the subjects perform as many runs as they can as opposed to exercising for a set time with 90-s rest periods interspersed between blocks. In Part 2, it would seem that the players taxed the aerobic system maximally as shown by the high average heart rates (94.3 ± 2.6% of HR_{peak}). There was also no significant difference in peak heart rate compared to the YIRT-1 or the 20-m shuttle run. Peak heart rate was also lower in all the field tests compared to the laboratory tests. This has been reported previously (Ingjer, 1991). These findings suggest that Part 2 of the 15-30 protocol can be used to determine peak heart rate. Peak heart rate was also significantly lower in Part 1 compared to Part 2, in accordance with the sub-maximal nature of Part 1. The supposedly greater anaerobic contribution to performance in Part 2 has to also be taken into consideration.

The average relative and individual (scaled to body mass) $\dot{V}O_{2max}$ values found in this study were compatible with $\dot{V}O_{2max}$ values reported in Norwegian (Helgerud *et al.*, 2001), Scottish (McMillan *et al.*, 2005b) and Tunisian (Chamari *et al.*, 2004) elite U-19 soccer players. It has been suggested that $\dot{V}O_{2max}$ should be scaled in relation to body mass raised to the power of 0.67 or 0.75 (Bergh *et al.*, 1991). Using this method will allow for more accurate inter-individual comparisons and account for differences in body mass. There are several possible explanations why a high $\dot{V}O_{2max}$ would be advantageous for performance in Part 2. It has been shown that the oxidative potential of the muscle is directly related to the aerobic fitness of the individual (Jansson *et al.*, 1990). During high-intensity intermittent exercise such as Part 2 of the 15-30 protocol, an enhanced oxidative potential would result in an improved oxygen delivery to the muscles (Tomlin and Wenger, 2001), a higher PCr resynthesis (Harris *et al.*, 1976), improved H^+ removal (Sahlin and Henriksson, 1984) and a delayed onset of anaerobic energy production (Hamilton *et al.*, 1991; Balsom *et al.*, 1994a and b) in order to sustain ATP production. It has also been shown that during high-intensity intermittent exercise, the substrate utilisation can fluctuate from aerobic to anaerobic during work and rest periods (Essèn *et al.*, 1977). The rate of anaerobic energy production would have also influenced the rate of lactate production in the muscle (Hermansen and Stensvold, 1972).

There was a moderate relationship between distance covered in Part 2 and T_{lac} ($r = 0.642$) as well as V-4 mM ($r = 0.600$). These correlations were moderate rather than strong compared with the significant correlations observed for relative $\dot{V}O_{2peak}$, suggesting that aerobic power had a greater influence on performance than T_{lac} and

V-4 mM. In the players where the T_{lac} occurs at a higher running speed meant that they could exercise at a higher intensity without the accumulation of lactate compared to individuals with a lower T_{lac} (Hoff, 2005). In terms of the 15-30 protocol, these findings suggest that in Part 2, players with a better T_{lac} and V-4 mM could theoretically tolerate the running speed and the short rest periods and therefore perform more runs without the accumulation of lactate. The 15-30 protocol is based on a fixed running speed, which is different from the interval shuttle run (Lemmink and Visscher, 2003) and the Yo-Yo tests (Bangsbo, 1993b) where the running speed is incremental. Therefore, it is likely that players with a higher T_{lac} and V-4 mM were able to tolerate the running speed in Part 2 without any increase in blood lactate. Another alternative explanation may have been that T_{lac} made it possible for players to tolerate the required running speed whereas $\dot{V}O_{2max}$ influenced lactate clearance in the short rest periods. It has also been shown that lactate clearance is related to aerobic fitness levels (Hamilton *et al.*, 1991).

5.4.2 Work Rate during Match-Play

Work-rate during match-play in the professional youth scholars was determined via distance covered measurement and time spent in the respective movement category. No significant or strong relationships were reported between match distance and responses in the 15-30 protocol. Nor was there any significant relationships reported between match distance and any of the other performance variables as shown in Table 5.3.7. Previous authors have reported significant relationships between match performance and various fitness tests (Castagna *et al.*, 2002b; Krustrup *et al.*, 2003) whereas others have found no relationships (Bangsbo and Lindqvist, 1992). These inconsistent findings may be due to the specific make-up of the fitness tests. Moreover, it is well known that there is a strong relationship between aerobic power and work-rate during a match (Apor, 1988; van Gool *et al.*, 1988; Castagna and D'Ottavio, 2001; Helgerud *et al.*, 2001). The findings of this study may be attributed to the complexity of soccer itself as opposed to a poor external validity of the 15-30 protocol. If the analysis system is considered, there was no variation in the within-observer technique. The repeatability and objectivity of the analysis system used in this study were deemed suitable and the same methodology has also been used in other studies (Rienzi *et al.*, 2000; Thatcher and Batterham, 2004).

One has then to consider that soccer consists of a complex activity pattern where the work-rate of players is influenced by a whole host of factors. Some of these factors may include the tactical role of the player, score of the match and environmental conditions (Reilly, 2005; Carling *et al.*, 2005). It is possible that these factors can lead to large within-player variability in performance between matches. As a consequence, in some matches players may not fully utilise their aerobic capacity but employ a 'pacing strategy' where the players save high-intensity activities for when necessary. A reason for this may be an increased certainty of the result as a means to an end. This inherent variability in work-rate during soccer match-play itself may then explain the lack of relationship to time spent in high-intensity running seen in this study. Tracking the same player in several matches is a solution but the problem of within-player variability would still exist. These issues are something that soccer researchers have to consider when comparing physical performance of individual players in a match to other measures of soccer-specific performance. It may be that the complexity of work-rate in soccer match-play may limit the applicability of comparisons to fitness tests.

Compared with data from the only other studies in which distances covered has been determined in elite professional youth players the total distance covered was slightly lower in this study (9742 m) *vs.* 10335 m (Helgerud *et al.*, 2001) and 10274 m (Thatcher and Batterham, 2004). When compared to senior professional players the total distance covered was slightly lower than total distance covered reported for English Premier League players (Rienzi *et al.*, 2000), Danish elite players (Bangsbo *et al.*, 1991; Mohr *et al.*, 2003a) and Australian elite players (Withers *et al.*, 1982). The total distance covered in the second half was 3% lower compared to the first half and 14% lower in high-intensity distance. The reduced work-rate in the second half may be explained by a manifestation of fatigue, as evidenced by the reduced high-intensity running distance in the second half (Mohr *et al.*, 2003). Fatigue in the second half may have been caused by a host of different factors including muscle glycogen depletion (Saltin, 1973; Balsom *et al.*, 1999b). The trend was that the midfield players covered a greater distance compared to defenders or midfielders although this difference was not significant as shown in Table 5.3.5. It is well known that midfielders cover the greatest distance in a match compared to other players due to the physical demands of that position, linking defence and attack (Reilly and Thomas, 1976; Bangsbo *et al.*, 1991). However, it is difficult to make any meaningful conclusions based on the small sample size for each position in the present study.

The majority of the time was spent walking (39 ± 9.4%) and jogging (26.4 ± 5.1%) with only 6% of the time spent in high-intensity activities as shown in Table 5.3.6. The greatest distance was also covered walking and jogging in both the first and second half as shown in Figure 5.3.2. In Table 5.3.6, forwards also spent a significantly longer time walking compared to midfielders and defenders. The positional requirements for forwards used in a 4-4-2 formation in this study are different from the other positions with less defensive responsibilities, which may explain these findings. However, the tactical role of the forwards may change between matches. The total time spent in high-intensity exercise was also lower compared to other studies although the total distance covered in high-intensity exercise was compatible (Bangsbo *et al.*, 1991; Rienzi *et al.*, 2000). A possible explanation for the reduced time spent in high-intensity exercise may be due to within-player variability in work-rate between matches, which is further discussed below. Another limitation may have been that each player was only filmed in one match. A better indication of the players' ability to perform high-intensity exercise in a match may have been obtained if they were filmed in several matches.

5.4.3 Field Tests

Distance covered in the YIRT for the professional youth scholars in this study was slightly lower than that reported for senior elite Italian (Mohr *et al.*, 2003a), elite Danish (Krustrup *et al.*, 2003) and elite Portuguese youth players (Malina *et al.*, 2004). There was no relationship between YIRT and either Part 1 or Part 2 of the 15-30 protocol as shown in Table 5.3.2. However, a significant moderate relationship (r = 0.731) was reported between the YIRT and the relative $\dot{V}O_{2max}$, which has also been shown elsewhere (Krustrup *et al.*, 2003). The HR_{peak} reached in the YIRT (194

± 9 beats.min^{-1}) was also higher compared to Part 2 of the 15-30 protocol (191 ± 8 beats.min^{-1}) although this difference was not significant. These findings may be explained by the differences in running speed between the two protocols: there is a progressive increase in velocity in the YIRT *vs.* a fixed running speed in the 15-30 protocol. However, the soccer-specific activity pattern was similar in both tests with acceleration, deceleration and directional changes. Every other run in the 15-30 protocol was performed without directional changes, which makes it distinct from the YIRT. It is possible that the progressive acceleration in the running speed in the YIRT may have lead to a higher anaerobic load towards the end of the test compared to the 15-30 protocol. Krustrup *et al.* (2003) reported high blood lactate values as well as a 51% and a 23% decrease in creatine phosphate and muscle glycogen respectively towards the end of the YIRT. These findings provide evidence for anaerobic involvement of the YIRT. The aim of both tests is to evaluate the ability to recover from high-intensity exercise but the 15-30 protocol may be considered as more aerobic fitness related test than the YIRT level 1 which is more aerobic-anaerobic in nature (Castagna *et al.*, 2006a). Further research is warranted to establish the exact level of anaerobic energy production during Part 2 of the 15-30 protocol.

There was also a moderate significant relationship (r = 0.614) between Part 2 and the distance covered in the 20-m shuttle run. This finding is surprising considering the continuous activity pattern of the 20-m shuttle run is different from the intermittent profile in both the 15-30 protocol and the YIRT-1. There was also a moderate significant relationship (r = 0.646) between the distance covered in the 20-m shuttle run and the YIRT-1. The players estimated $\dot{V}O_{2max}$ from the 20-m shuttle run was also 15.9% lower or equivalent to 8 ml.kg^{-1}.min^{-1} compared to the direct $\dot{V}O_{2max}$ obtained in the laboratory test raising questions about the predictive power of the 20-m shuttle run for soccer players. However, indirect measurements of $\dot{V}O_{2max}$ should be viewed with caution (Åstrand *et al.*, 2003). Because of these discrepancies between real and estimated $\dot{V}O_{2max}$, it has been suggested that test result on the 20-m shuttle run should be expressed as distance covered instead (Stølen *et al.*, 2005). Both the 15-30 protocol, the YIRT-1 and the 20-m shuttle run consists of acceleration, deceleration and directional changes so the players may have been used to this type of running requirements. As a consequence of these factors described, the anaerobic energy contribution to the 20-m shuttle run may also be higher, which has been suggested by previous authors (O'Gorman *et al.*, 2000). The suggested anaerobic contribution on the 20-m shuttle run may explain the positive relationship to the high-intensity intermittent nature of the YIRT-1 and the 15-30 protocol.

5.4.4 Conclusion

Soccer is a complex activity where there may be a large within-variability in players' physical performance between matches. Such variability in performance may be as a result of several external and internal factors. Comparing work-rate profile during match-play to soccer-specific fitness may therefore be problematic. These issues have been highlighted in this study where there was no relationship between work-rate during match-play and any of the laboratory or field tests. These findings highlight the complexity of the activity pattern in soccer as opposed to poor external validity of the 15-30 protocol. Physical performance during the sub-maximal Part 1 may be governed by other variables than aerobic power or capacity. Performance in Part 2 was greatly influenced by the players' aerobic power. Compared to the YIRT, Part 2 may be a more aerobic test with some anaerobic contributions towards the end of the test. Further research may be warranted to examine the physiological mechanisms which govern performance in the 15-30 protocol.

Chapter 6

The Sensitivity of the 15-30 Protocol to Detect Changes in Soccer-Specific Endurance Following Training

6.1.1 Introduction

In sport, the typical training year is periodised into a competitive phase, a transitional off-season phase, where typically no formal training is conducted, and a preparatory phase between the transitional and competitive periods (Bompa, 1999). In soccer, the length of a specific training phase may be governed by the stage of the season and the players level of physical fitness. An example of a specific training phase in soccer is the preparatory phase before the beginning of the competitive season. The aim of the pre-season phase is to physically prepare the players for the competitive period by ensuring that they reach an acceptable level of physical fitness usually following a period of inactivity. During the pre-season training period, the training load is normally higher than in the competitive period with special priority given to soccer-specific aerobic endurance training (Reilly, 2005). The preparatory period or pre-season period in many top leagues in Europe is usually brief, performed during the summer and lasts between 5-7 weeks.

Coaches and practitioners can easily monitor the endurance performance of soccer players during the season through specific field tests. Results from field tests can reveal inter-player variability in training status. Various field tests have been used to detect changes in training status following pre-season. Improvements in both continuous tests such as the 20-m shuttle run (Polman *et al.*, 2004) and tests with a more soccer-specific activity pattern such as the interval test (Rebelo and Soares, 1997) and the Ekblom test (Ekblom, 1989) have been reported in soccer players following pre-season training. Aerobic power seems to either increase slightly (Bangsbo, 1993a) or remain unchanged (Rico *et al.*, 1992; Heller *et al.*, 1992) following pre-season training. Since the subsequent off-season period in soccer has been associated with a reduction in aerobic fitness (McMillan *et al.*, 2005a) and a reduction of key metabolic enzymes in muscle (Amigo *et al.*, 1998), monitoring the effectiveness of a pre-season training programme is very important.

In recent years; the Yo-Yo tests have become the most widely used test to evaluate soccer-specific endurance performance (Erith, 2004). Krustrup *et al.* (2003 and 2006a) reported that YIRT-1 and YIRT-2 performance varied throughout the season in players from the Danish premier league. After a period of pre-season training, performance on the YIRT-1 and YIRT-2 increased by 25% and 42% respectively. The authors also reported a decline in YIRT-1 and YIRT-2 test performance towards the end of the season. Moreover, performance on the YIRT-2 was improved by 15% in Danish elite players following a 12 week in-season high-intensity training programme (Majgaard Jensen *et al.*, 2007). These results show that physical performance can easily be monitored during the season using soccer-specific field tests.

During periods of hard training in soccer, it is advantageous for coaches to be able to assess endurance both through sub-maximal and maximal components. Recently, a new test has been developed where soccer-specific endurance performance is assessed sub-maximally from heart rate measurements and maximally from number of completed high-speed runs. The structure, activity pattern, distances covered and duration of the 15-30 protocol is unique and different to the Yo-Yo tests. Coaches also have the option of using the sub-maximal stage as a conditioning drill. The reliability, internal validity and external validity of the 15-30 protocol has already been explored. In addition to being reliable and valid, the sensitivity of new fitness tests to sport-specific training interventions must also be examined (Hopkins *et al.*, 1999). If tests are not sensitive to detect changes in training status, they cannot be confidently used by coaches and practitioners. Therefore, the aims of this study were to:

1) investigate the sensitivity of the 15-30 protocol to a period of pre-season training in both senior and young professional soccer players;
2) examine the sensitivity of the Yo-Yo Intermittent Recovery Test Level 1 to a period of de-training and re-training in young professional soccer players.

6.1.1.1 Limitations

- All field tests had to be performed outdoors on a grass turf due to a lack of an indoor artificial grass turf. As a result, the physiological responses during the field tests may have been affected.
- The 15-30 protocol could not be performed at the end of season in the professional youth scholars due to poor weather conditions.

- The Yo-Yo Intermittent Recovery Test could not be performed end of season in the senior professional players due to involvement in the Coca-Cola Championship play-off semi-final.
- There was a change in the coaching staff at the end of season. The new coaching staff did not prioritise heart rate monitoring. As a result, heart rate was not measured during training in the youth scholars and both training and the 15-30 protocol in the senior professionals.
- Both the youth scholars and the senior professionals were asked to refrain from any vigorous physical activity the day before the field tests. However, the subjects have performed a heavy training session the day prior to the tests, which could not be controlled by the researcher. As a result, the physiological responses during the tests could have been affected.
- Some players had to be removed from the study due to illness or injury on some of the test occasions.
- Some heart rate data files were lost due to technical errors with the Polar Team System belts.

6.1.1.2 Delimitations

- The subjects performed one experimental tests (the 15-30 protocol) and one criterion test (the Yo-Yo Intermittent Recovery Test- Level 1).
- The subject groups chosen were delimited to male professional youth scholars and senior professional players from a Coca-Cola Championship team in England.
- The physiological measurements were delimited to heart rate during the field tests.
- The psychological measurement was delimited to ratings of perceived exertion during the field tests.
- The test occasions were delimited to end of season, start of pre-season and end of pre-season.

6.1.2 Methods

6.1.2.1 Subjects

Twenty male senior professional soccer players (Group 1) and twelve male professional youth scholars (Group 2) from a club participating in the Coca-Cola Championship in England were recruited as subjects for this study. Five players from Group 1 and two players from Group 2 did not perform the re-test at the end of pre-season due to injury. The final subject numbers were therefore fifteen players for Group 1 and ten players for Group 2. The physical characteristics of both subject groups are shown in Table 6.1.2.1

Table 6.1.2.1. Physical characteristics of Group 1 and Group 2.

Subject Group	*Age*	*Stature (m)*	*Body Mass (kg)*
Group 1 (N = 15)	25.6 ± 4.1	1.83 ± 0.05	75.8 ± 4
Group 2 (N = 10)	16.3 ± 0.7	1.79 ± 0.6	72.9 ± 7.9

6.1.2.2 Test Location

All the field tests for both Group 1 and Group 2 were carried out outdoors on a natural grass turf at Springfields Training Complex, Preston North End Football Club, Lea, Preston.

6.1.2.3 Training

Group 1 performed pre-season training over a five-week period at the start of the 2006-2007 season. For Group 2, the pre-season training period lasted for six weeks. An example of the activities performed during a week of pre-season training is shown in Table 6.1.2.2.

During the pre-season period, there were 35 days (Group 1) and 42 days (Group 2) in total available for training. Group 2 performed 27 training days (46 training sessions), played 4 friendly matches and had 11 recovery days. A summary of the experimental set-up for Group 1 and Group 2 is shown in Figure 6.1.2.1. Due to bad weather the

15-30 protocol was not performed for Group 2 at the end of the season 2005/06. Group 1 only performed the 15-30 protocol and not the YIRT-1. Group 1 did not perform a test at the end of 2005-2006 season due to participation in the Coca-Cola Championship play-off semi-finals. Due to circumstances beyond the investigators' control heart rate was not measured during the training sessions in pre-season in either Group 1 or Group 2. No structural strength training was conducted in either Group 1 or Group 2 during the pre-season period. Heart rate was also not measured in Group 1 during any of the two test occasions.

6.1.2.4. Field Tests

6.1.2.4.1. The Yo-Yo Intermittent Recovery Test

Details of the Yo-Yo Intermittent Recovery Test (YIRT) have been described in section 3.1.2.

6.1.2.4.2. The 15-30 Protocol

Details of the 15-30 protocol have been described in section 3.1.4.

6.1.2.5. Physiological Measurements

During all the field tests for Group 2, heart rate was measured every 5-s using short-range telemetry via the Polar Team System (Polar Electro Oy, Kempele, Finland). The exact details of the procedure are described in section 3.4. Due to unforeseen circumstances, heart rate was not measured during the 15-30 protocol in Group 1. Four player heart rate files were lost from the YIRT-1 performed at the end of season 2005/2006. As a result, peak heart rate from the YIRT-1 was only analysed for six players.

Table 6.1.2.2. An example of a weekly training load for Group 2 during the pre-season training period with the main activity of the session described excluding warm-up and cool-down.

Day	*Number of sessions*	*Training component (aerobic/anaerobic)*	*Description of session*
Monday	2	Aerobic Aerobic/Anaerobic	AM: 4 min dribbling track 3 min recovery x 4 PM: Track running: pyramid (400 m, 800 m, 1200 m, 800 m, 400 m) x 1
Tuesday	2	Anaerobic Aerobic/Anaerobic	AM: Hill speed work x 12 PM: Track running: 400 m 70 s lap/70 s recovery x 10
Wednesday	2	Aerobic/Anaerobic Aerobic	AM: Track running: pyramid (400 m, 800 m, 1200 m, 800 m, 400 m) x 1 PM: 7 v 7 with GK 15 min/3 min recovery x 3
Thursday	2	Aerobic Aerobic	AM: 3-2-1 run 2 min/90 s/30 s recovery x 3 PM: 3 v 3 w/o GK 3 min/3 min recovery x 6
Friday	2	Aerobic Aerobic	AM: 3-2-1 football w/o GK 2 min/90 s/30 s recovery x 3 PM: 7 v 7 with GK 15 min/3 min recovery x 3
Saturday	0		Off/Recovery
Sunday	0		Off/Recovery

End of season*	Off-season	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Field tests (2†)	6 Weeks	Beginning of pre-season training Field tests (1,2†)				End of pre-season training* Field test (1)	End of pre-season training† Field tests (1,2)

Key: 1 = 15-30 protocol, 2 = YIRT-1, * = Group 1 only, † = Group 2 only

Figure 6.1.2.1. The schematic illustrates the experimental procedures during the pre-season training period for Group 1 and Group 2.

Figure 6.1.2.2. Group 1 performing the 15-30 protocol at the end of pre-season.

Figure 6.1.2.3. Group 2 performing the 15-30 protocol at the end of pre-season.

6.1.2.6. Psychological Measurements

The players were asked to rate their perceived exertion from the Borg scale described in section 3.5.1 of this thesis. The perceived exertion was not recorded during the YIRT-1 but only after each exercise block in the 15-30 protocol.

6.1.2.7. Statistical Analysis

All data were expressed as means ± SD unless otherwise stated. The data was tested for normality using the Shapiro-Wilk normaility test. Comparison of performance in Part 2 of the 15-30 protocol at the beginning and end of pre-season training period in Group 1 was examined using a Wilcoxon Signed Ranks Test. Comparisons of distance covered and peak heart rate in YIRT-1 between the different stages of the season in Group 2 were made using a one-way analysis of variance (ANOVA). A two-way analysis of variance (ANOVA) was used to test for differences in the mean heart rate during the different test stages in Part 1 at the beginning and end of pre-season training period. Any differences in distance covered in Part 2 for Group 2 were tested using a Wilcoxon signed ranks test. A Student's T-test was used to test for differences following pre-season training in the mean heart rate during Part 2 in Group 2. Statistical significance was set at $p<0.05$.

6.1.3 Results

6.1.3.1 Group 1

6.1.3.1.1. The 15-30 Protocol

At the start of pre-season training, all players in Group 2 completed Part 1 of the 15-30 protocol. In Part 2, the average number of runs completed was 20 ± 11 runs which was equivalent to 1176 ± 625 m. The total distance covered for both Part 1 and Part 2 was 3207 ± 623 m. Following 5 weeks of pre-season training, all players completed Part 1 and the number of runs in Part 2 increased significantly ($Z_{(15)} = -3.408$, $p<0.05$) by 246% to 71 runs equivalent to 4130 ± 1249 m. The total distance covered in the 15-30 protocol (Part 1 and Part 2) at the end of pre-season training was 6160 ± 1249 m.

6.1.3.2 Group 2

6.1.3.2.1 Yo-Yo Intermittent Recovery Test

There were no significant improvements in distance covered in the YIRT-1 from the end of season 2005/06 to the beginning of pre-season 2006/07. Moreover, a significant ($F_{2\ 27} = 9.86$, $p<0.05$) 38.4% increase in distance covered was reported from the end of season 2005/06 to the end of pre-season 2006/07. There was no significant change ($F_{2\ 15} = 0.15$, $p>0.05$) in peak heart rate between the three test occasions, as shown in Table 6.1.3.1.

Table 6.1.3.1. Performance in the Yo-Yo Intermittent Recovery Test (Level 1) at the end of season 2005/06, start of pre-season 2006/07 and end of pre-season 2006/07 for Group 2.

Stage of season	*Distance covered (m)*	*HR_{peak} (beats.min^{-1})*
End of season 2005/06 (N = 10)	1656 ± 344	197 ± 6‡
Start of pre-season 2006/07 (N = 10)	1972 ± 299	198 ± 8‡
End of pre-season 2006/07 (N = 10)	2292 ± 316†	195 ± 8‡

† = significant ($p<0.05$) to end of season 2005/06, ‡ = N = 6

6.1.3.2.2 The 15-30 Protocol

Due to bad weather, the 15-30 protocol was not performed at the end of the season 2005-2006. At the beginning of pre-season, the overall mean heart rate during Part 1 (23 min 30 s) was 176 ± 9 beats.min^{-1} (88.1 ± 4.5% of HR_{peak}) which was significantly ($p<0.05$) higher compared to at the end of pre-season (163 ± 12 beats.min^{-1} equivalent to 81.7 ± 5.6% of HR_{peak}). There was no significant ($t (9) = -0.168$, $p>0.05$) change in peak heart rate at the beginning (194 ± 10 beats.min^{-1}) compared to the end (194 ± 7 beats.min^{-1}) of the pre-season training period.

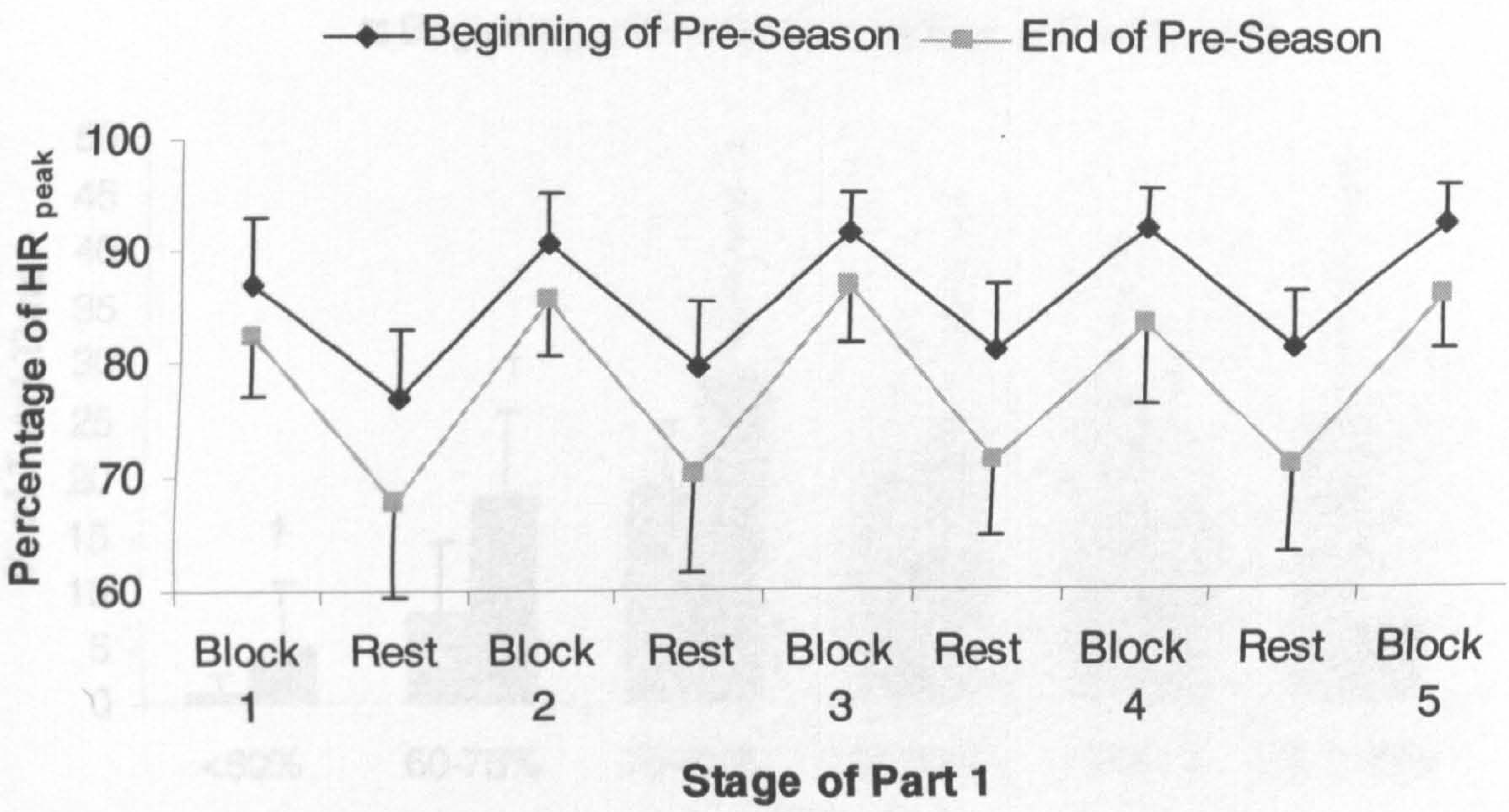
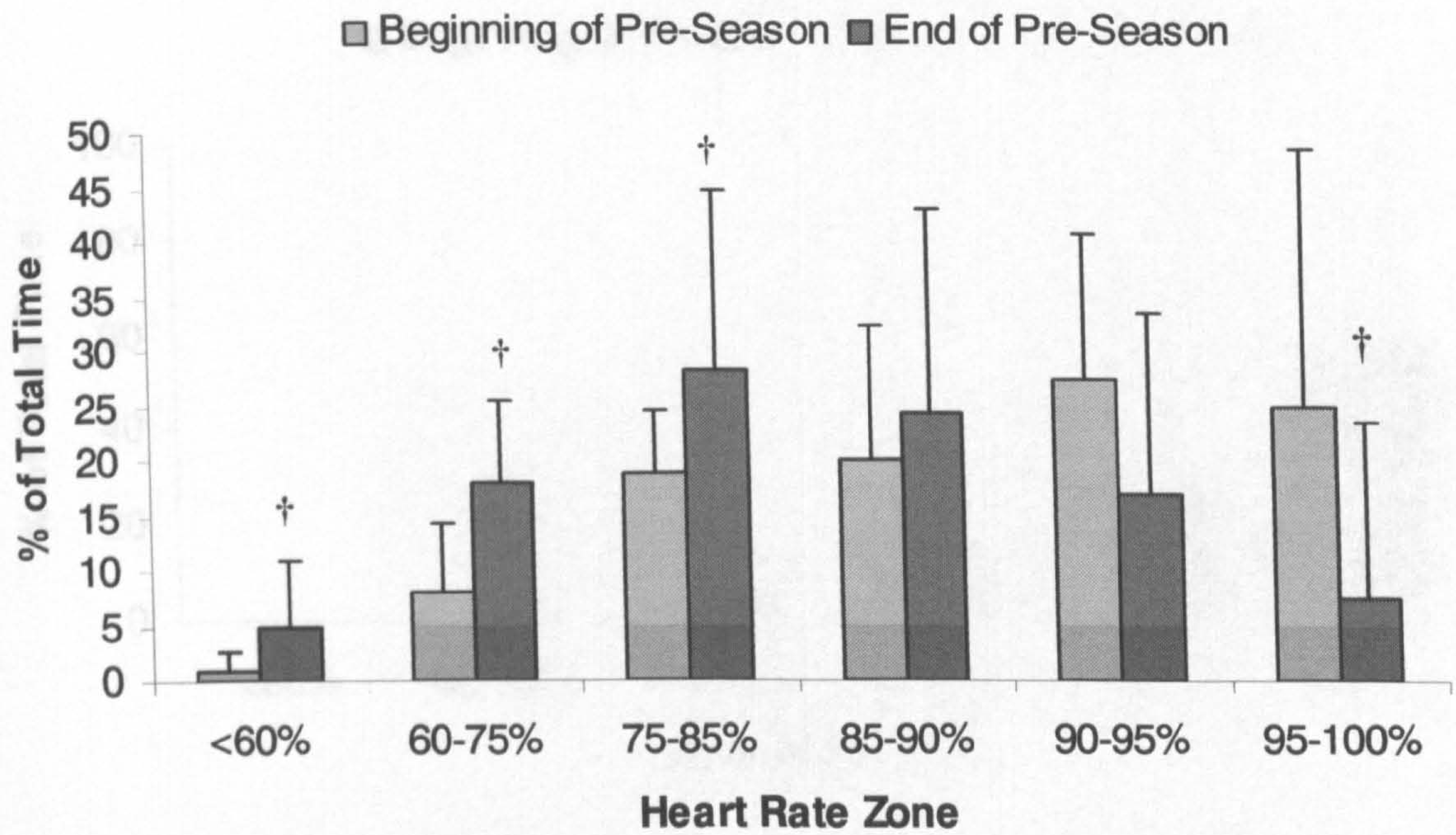


Figure 6.1.3.1. Heart rate profile of Group 2 during Part 1 at the beginning and at the end of the six week pre-season training period.

Heart rate was significantly lower ($F_{1\,9} = 34.28$, $p<0.05$) in the different stages in Part 1 at the end of the pre-season training period compared to beginning of pre-season, as shown in Figure 6.1.3.1. When comparing the different test stages in Part 1, there was a significant difference ($F_{8\,72} = 133.11$, $p<0.05$) in heart rate between most test stages. There was also a significant interaction ($F_{8\,72} = 8.81$, $p<0.05$) between time and test stage.



† = significant (p<0.05) to beginning of pre-season

Figure 6.1.3.2. Percentage of total time spent in each heart rate zone during Part 1 in Group 2 at the beginning and at the end of the six week pre-season period.

At the end of pre-season, the players spent a significantly (Z (9) = -2.52, $p<0.05$) shorter time in the 95-100% zone, as shown in Figure 6.1.3.2. They also spent significantly longer in the <60% zone (t (9) = -2.641, $p<0.05$), 60-75% (t (9) = -4.555, $p<0.05$) and the 75-85% zone (Z (9) = -2.191, $p<0.05$) at the end of the pre-season training period. No significant change was reported for the 85-90% zone (t (9) = 1.604, $p>0.05$) and the 90-95% zone (t (9) = -0.968, $p>0.05$).

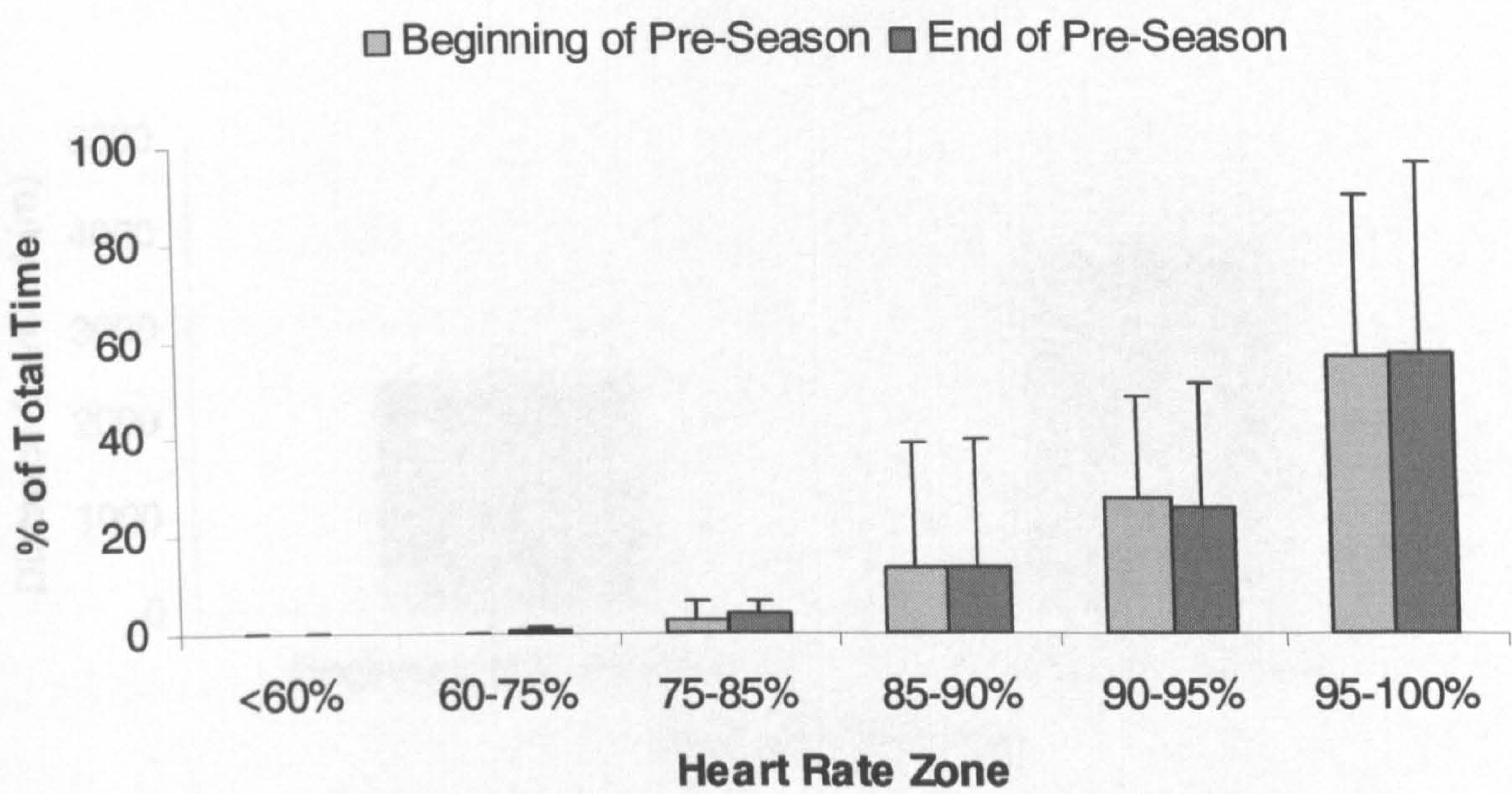
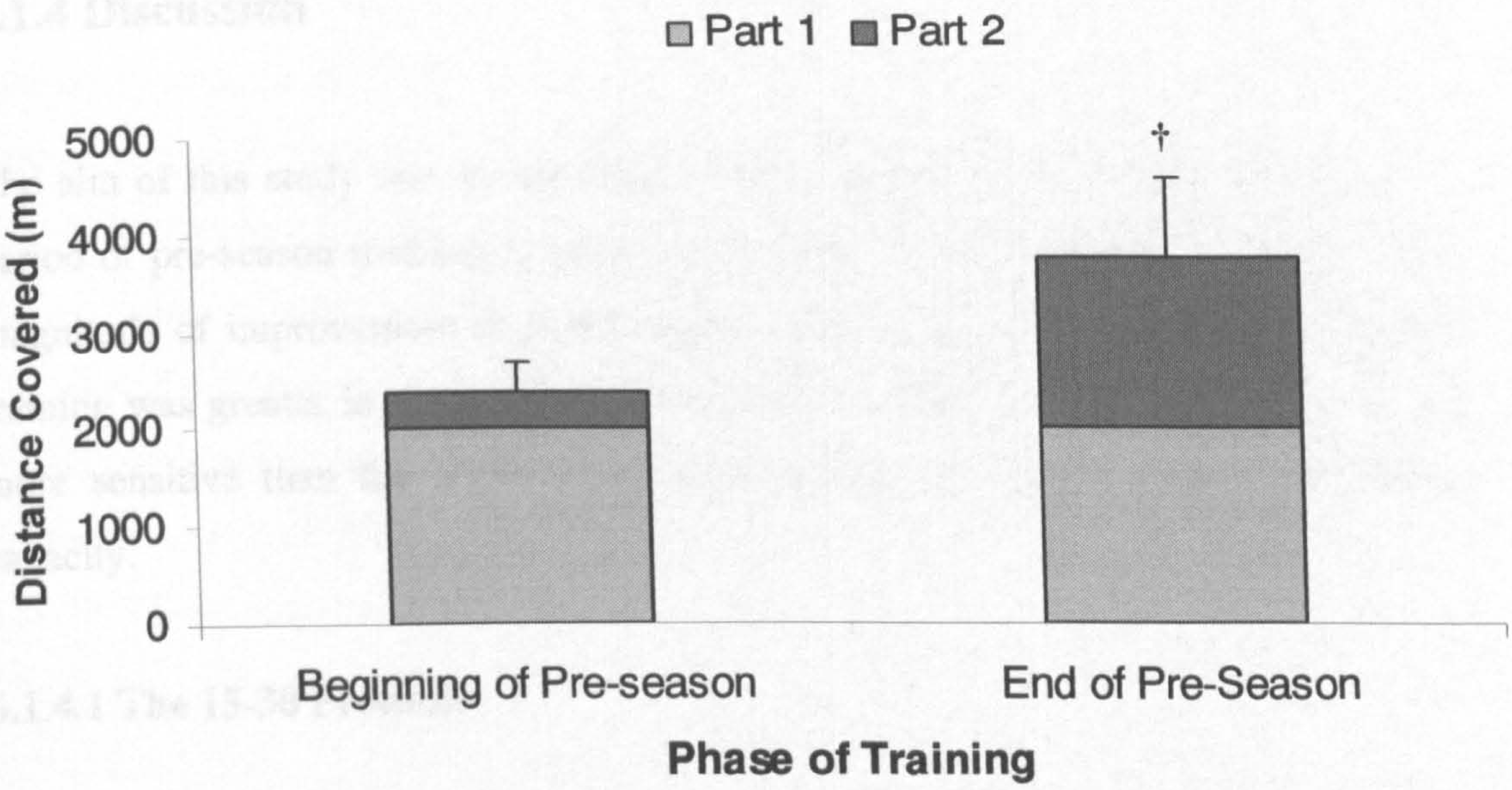


Figure 6.1.3.3. Percentage of total time spent in each heart rate zone during Part 2 in Group 2 at the beginning and at the end of the 6 week pre-season training period.

No significant change in the time spent in heart rate zones were reported for any of the zones including the 60-75% zone (Z (9) = -1.826, p>0.05), 75-85% zone (Z (9) = -1.352, p>0.05), 85-90% zone (Z (9) = -0.140, p>0.05), 90-95% zone (Z (9) = -0.140, p>0.05) or the 95-100% zone (Z (9) = -0.280, p>0.05). The players spent no time in the <60% zone in the test at the beginning or at the end of pre-season so no statistical analysis was performed on this heart rate zone.



† = significant ($p<0.05$) to beginning of pre-season

Figure 6.1.3.4. Distance covered during Part 1 and Part 2 of the 15-30 protocol for Group 2 at the beginning and at the end of the six week pre-season training period.

There was no significant difference in the mean heart rate during Part 2 at the beginning (188 ± 10 beats.min^{-1} equivalent to 94.3 ± 3.2% of HR_{peak}) or end (188 ± 8 beats.min^{-1} equivalent to 94.2 ± 2.5% of HR_{peak}) of the six week pre-season training period. At the start of pre-season, the players performed 6 ± 5 runs which corresponded to 343 ± 303 m. The total distance covered (Part 1 and Part 2) was 2373 ± 303 m. Following six weeks of pre-season training, the players performed significantly ($Z(12) = -3.063$, $p<0.05$) more runs (30 ± 13.4, equivalent to 1740 ± 778 m), which was an improvement of 395% compared to the start of pre-season as shown in Figure 6.1.3.4. The total distance covered in Part 1 and Part 2 at the end of pre-season was 3770 ± 778 m.

6.1.4 Discussion

The aim of this study was to investigate the sensitivity of the 15-30 protocol to a period of pre-season training in senior and young professional soccer players. The magnitude of improvement in performance on the 15-30 protocol after pre-season training was greater in comparison to the YIRT-1. The 15-30 protocol seems to be more sensitive than the YIRT-1 to detect changes in soccer-specific endurance capacity.

6.1.4.1 The 15-30 Protocol

It seemed that there was a physiological adaptation in the players from both Group 1 and Group 2 as a result of the pre-season training programme. Both the overall global heart rate in Part 1 and the heart rate during the different stages in Part 1 were significantly lower in Group 2 following the pre-season training period as shown in Figure 6.1.3.1. Heart rate was not measured during the 15-30 protocol in Group 1 but it is likely that a similar adaptation would have occurred. In addition, the players in Group 2 spent significantly more time in sub-maximal heart rate zones <85% of HR_{peak} after the pre-season training period, as shown in Figure 6.1.3.2. Less time was also spent in the maximal (95-100% of HR_{peak}) heart rate zone. Moreover, the distance covered in Part 2 for Group 1 and Group 2 was increased by 246% and 395% (Figure 6.1.3.4) respectively. It is difficult to establish if these changes were due to factors associated with an improved $\dot{V}O_{2max}$, a peripheral adaptation at muscle level or genetic endowment. Maximal oxygen consumption was not measured in this study but the YIRT-1 was introduced as an alternative "reference test" in addition to the 15-30 protocol.

As a result of the training stimulus from the pre-season period, it is likely that a chronic physiological and/or metabolic adaptation occurred following the training period. It has been established that an increase in stroke volume may be one of the most significant adaptations to endurance training (Richardson, 2000). A reduced stroke volume associated with de-training has been responsible for a reduction in $\dot{V}O_{2peak}$ (Mujika and Padilla, 2000). During high-intensity training, an increase in stroke volume will lead to more blood being pumped from the heart and thus enhancing oxygen delivery to the muscles (Vanfraechem and Tomas, 1993). As stroke volume increases in proportion to work load, during periods of heavy work, all of the oxygen transport system chain is highly stimulated (Ekblom, 1986b). These central factors can lead to significant improvements in $\dot{V}O_{2max}$ (Hoff, 2005). The specific nature of the training programme could have resulted in peripheral adaptations such as an increased mitochondrial density (Holloszy and Coyle, 1984; Lindstedt *et al.*, 1988), capillary density (Richardson, 1998), mitochondrial enzyme activity (Svedenhag *et al.*, 1983) and intra-musclular myoglobin stores (Hickson, 1981).

It is difficult to determine which of these variables may have led to training induced improvements in an high-intensity intermittent exercise test such as the 15-30 protocol. Since there was a moderate relationship between $\dot{V}O_{2max}$ and Part 2 of the 15-30 protocol established in Study 3, it is likely that improvements in $\dot{V}O_{2max}$ also influenced performance in Part 2. For example, it has been shown that one of the major adaptations to endurance training is an improved lactate clearance ability (Donovan and Brooks, 1983; Hamilton *et al.*, 1991; Juel *et al.*, 2003). However, others have shown that endurance training reduces lactate production (Favier *et al.*, 1986). If the players in Group 1 and Group 2 were more efficient in clearing the lactate or H^+ ions accumulated in Part 2, theoretically they could then perform more high-speed runs. It is important to consider that performance may be governed by several factors, including availability of PCr (Bergström and Hultman, 1991), muscle glycogen (Balsom *et al.*, 1999a) as well as accumulation of other metabolites such inorganic phosphates (Dahlstedt and Westerblad, 2001).

It is likely that not one but a combination of some of these factors may have caused fatigue during high-intensity intermittent activity such as the 15-30 protocol (Glaister, 2005). Thus, $\dot{V}O_{2max}$ may explain some of the improvements in performance but it is difficult to determine the physiological consequences of what limits performance especially in Part 2. By examining the physiological mechanisms of the 15-30 protocol, a better insight into how aerobic and anaerobic energy production is utilised before and after a period of training will be given.

Such information would also help understand the physiological adaptations to training.

The improvements in endurance performance based on the 15-30 protocol and YIRT-1 results are usually what should be expected following pre-season training in soccer (Bangsbo, 1993a). The magnitude of the improvements will depend on the duration of the training programme and the type of training conducted (Bompa, 1999). In this study, the training load was high during pre-season with the majority of the training consisting of interval training in the form of small-sided games, dribbling tracks or formal interval running, as shown from the example training week for Group 2 in Table 6.1.2.3. The reminder of the time was spent in technical/tactical training.

6.1.4.2 The Yo-Yo Intermittent Recovery Test

The endurance performance on the YIRT-1 for the players in Group 1 increased from the end of season 2005/06 to the start of pre-season 2006/07 as shown in Table 6.1.3.1. This improvement in YIRT-1 performance is surprising. During the six week off-season period, the players had been given training programmes by the club with the aim of maintaining aerobic endurance levels. These programmes were performed to avoid the likelihood of the players starting pre-season training in a de-trained state thus requiring extra conditioning to improve aerobic fitness. De-training can cause a significant reduction of key glycolytic enzymes leading to an impaired ability to perform high-intensity exercise (Bangsbo and Mizuno, 1988). Another likely explanation for the increase in YIRT-1 performance from end of season 2005/06 to start of pre-season 2006/07 may be that the players fitness levels at 2005/06 was low. Krustrup *et al.* (2003) reported a reduced YIRT-1 performance in professional players at the end of season compared to mid- and start of the season. A reduced fitness levels may be due to the number of matches played in the competitive season and as a consequence a lack of basic aerobic maintenance training. Due to poor weather, the 15-30 protocol could not be performed at the end of the 2005-06 season. However, it is likely that performance in the 15-30 protocol would also have improved as improvements following pre-season training was mirrored for the YIRT-1 and 15-30 protocol in Group 2.

The large improvements for both Group 1 (246%) and Group 2 (395%) in distance covered in Part 2 compared to the YIRT-1 (16.2%) may be attributed to the difference in running speed between the two tests. The running speed in the 15-30 protocol is constant in both Part 1 and Part 2 whereas in the YIRT-1, there is a progressive increase in running speed. Due to the incremental running speed in the YIRT-1, the players will be primarily limited by inability to tolerate increases in running speed. In Part 2, the players may have been limited by the brief rest period (6-s) after each high-speed run, which was shorter compared to the 10-s rest period used in the YIRT-1. It must be stated that the players had performed two familiarisation trials on the 15-30 protocol to avoid any learning bias. It may be difficult to speculate how much any learning bias influenced the test result. Taken together, it seems that due to the differences in the performance criteria of the two tests, the physiological mechanisms that govern test performance may be markedly different. This difference warrants further investigation.

Another possible explanation for the large improvements in 15-30 protocol compared to the lower adaptations in the YIRT-1 may be the nature of the training stimulus. The aim of the majority of the pre-season training period was to conduct aerobic high-intensity training. It is possible that there is a greater aerobic component to the 15-30 protocol compared to the YIRT-1. Therefore, the anaerobic demands may be greater in the YIRT-1 resulting in a lower training adaptation following a predominant aerobic-based training period.

The findings in this study correspond well with other studies that have examined changes in endurance performance following a period of pre-season training. The 16.2% increase in distance covered on the YIRT-1 was slightly lower than the 25% increase in distance covered reported by Krustrup *et al.* (2003) following pre-season. Mohr *et al.* (2003b) also reported a lower heart rate on a sub-maximal YIRT-1 in Danish national team players after 8 weeks of high-intensity training before the World Cup. This finding mirrors the lower heart rate in Part 1 and for different stages in Part 1, as shown in Figure 6.1.3.1. Improvements in performance on other field tests following pre-season training has also been reported by other authors (Ekblom, 1989; Rebelo and Soares, 1997; Polman *et al.*, 2004).

6.1.4.3 Conclusion

In conclusion, heart rate was significantly lower in Part 1 and distance covered in Part 2 was significantly improved following pre-season training. There was also an improvement on the YIRT-1 after the pre-season training period, although this improvement was not significant. This study also demonstrated the difficulty in monitoring endurance performance in professional soccer players due to the inherent lack of control over testing conditions. The results from this study have shown that the 15-30 protocol is sensitive to detect changes in soccer-specific endurance performance in both senior and young professional soccer players following a period of pre-season training. For future research, the effect of a period of training on 15-30 protocol performance and $\dot{V}O_{2max}$ should be examined. This investigation would help to establish to what extent $\dot{V}O_{2max}$ governs performance on the 15-30 protocol.

Chapter 6

The Effects of a Period of In-Season Aerobic Interval Training on Performance on the 15-30 Protocol and Maximal Aerobic Power

6.2.1 Introduction

It is important for soccer players to have a high level of physical capacity to be able to recover from high-intensity exercise bouts during match-play (Reilly, 1997). The endurance performance of soccer players seems to decline midway and towards the end of the competitive season (Krustrup *et al.*, 2003). The reason for the decline may be due to the number of competitive matches played leading to a reduction in aerobic maintenance sessions. Coaches should therefore try to implement strategies to maintain aerobic capacity and soccer-specific endurance performance throughout the season. One of the more effective strategies to maintain and elicit further increases in endurance performance is high-intensity aerobic interval training (Laursen and Jenkins, 2001). Moreover, it has been suggested that one session of high-intensity aerobic interval training per week is sufficient to maintain aerobic capacity (Stolen *et al.*, 2005).

Evidence for improvements on cardio-respiratory endurance ($\dot{V}O_{2max}$) in soccer players following a period of intense aerobic endurance training has been presented by several authors (Nowacki and Preuhs, 1993; Krustrup *et al.*, 2003). Recently, a number of studies have utilised a high-intensity interval training programme consisting of 4 sets of 4 min running at 90-95% of HR_{peak} interspersed with a 3-min active recovery period at 60-65% of HR_{peak}. It was reported that $\dot{V}O_{2max}$ was improved by 10.8% in a Norwegian elite U-19 team (Helgerud *et al.*, 2001), 9% in elite youth Scottish players (McMillan *et al.*, 2005b) and 7% in elite Italian youth players (Impellizzeri *et al.*, 2006) using this interval training protocol. Moreover, Helgerud *et al.* (2001) also reported a 100% increase in the number of sprints, a 20% increase in distance covered and a 24% increase in the number of involvements with the ball at the end of an 8-week aerobic interval training programme using 4 x 4 min principle. It seems that this particular aerobic interval training protocol seems to be very effective in improving endurance performance in soccer.

The general principle of this 4 x 4 min training programme can be incorporated into soccer training such as small-sided games as well as formal interval running without the ball (Reilly and White, 2005; Sassi *et al.*, 2005; Little and Williams, 2006; Impellizzerri *et al.*, 2006). The advantage of small-sided games such as 3 v 3 is that the players will be challenged to make technical and tactical decisions as well as a eliciting a suitable physiological training stimulus (Platt *et al.*, 2001). It is important to make sure that the players work at a sufficiently high intensity during the small-sided games. Therefore, a good level of organisation is needed from the coaches and constant verbal encouragement. The volume of training can be adapted to suit the experience level and the calibre of players. The protocol can be modified to be able to be better applied to soccer training. For example, a 1:1 exercise:rest ratio may be more practical to use for coaches during small-sided games if a whole squad is involved where teams can alternate exercise and rest periods (Reilly and White, 2005). This type of training using small-sided games may be an effective method of maintaining endurance performance during the competitive season. It is also more motivational for the players to perform training with the ball. In order to evaluate the effectiveness of such training interventions, it would be useful to assess both soccer-specific endurance performance and laboratory testing of $\dot{V}O_{2max}$. These tests would also offer some insight into the possible physiological adaptations to high-intensity aerobic interval training.

In-season monitoring of physical fitness can be done using both laboratory and soccer-specific field tests. One such field test, the 15-30 protocol has been designed to monitor the intermittent endurance performance of soccer players during the season. The reliability, validity and sensitivity to a pre-season training period of the 15-30 protocol have already been established. Gross changes in soccer-specific endurance performance are expected when players' transitions from a period of low activity to a period of heavy training such as pre-season. Therefore, there is a need to explore the sensitivity of the 15-30 protocol to in-season training periods when the players are in an already trained condition. This study was designed to investigate the effects of an in-season aerobic interval endurance programme on soccer-specific endurance performance and maximal oxygen consumption. The aims of the experiment were to implement a high-intensity aerobic interval training programme to a group of professional youth scholars to:

1) establish the sensitivity of a soccer-specific endurance test the 15-30 protocol to the in-season training period;
2) investigate the sensitivity of an aerobic fitness measure such as $\dot{V}O_{2max}$ to the in-season training period.

6.2.1 Limitations

- The 15-30 protocol had to be performed outdoors on an artificial grass turf due to a lack of an indoor artificial grass turf. As a result, the physiological responses during the 15-30 protocol may have been affected.
- Some of the training days for the aerobic interval training programme had to be re-scheduled or cancelled at the coach's discretion. As a result, the days of the intervention occurred on consecutive days in some weeks.
- The players were asked to refrain from any vigorous physical activity the day before the field and laboratory tests. However, the subjects have performed a heavy training session the day prior to the tests, which could not be controlled by the researcher. As a result, the physiological responses during the tests could have been affected.
- Some players had to be removed from the study due to illness or injury on some of the test occasions.
- Some heart rate data files were lost due to technical errors with the Polar Team System belts.

6.2.2 Delimitations

- The subjects performed one experimental test (the 15-30 protocol) and one criterion test (laboratory test).
- The subject groups chosen were delimited to male professional youth scholars from a Coca-Cola League 2 team in England.
- The physiological measurements were delimited to heart rate during the field tests and oxygen uptake, heart rate and blood lactate during the laboratory test.
- The psychological measurement was delimited to ratings of perceived exertion during the field and laboratory tests.
- The duration of the in-season aerobic interval training intervention was delimited to six weeks with two sessions performed every week.

6.2.2 Methods

6.2.2.1 Subjects

Fifteen young male professional soccer players from a club participating in the Coca-Cola Championship League Two in England were recruited as subjects for this study. Two players could not perform the re-tests at the end of the training intervention so 13 male youth scholars (age: 16.5 ± 0.5; stature: 1.79 ± 0.05 m; body mass: 71.6 ± 9.3 kg) performed all the field and laboratory tests at the beginning and at the end of the training intervention.

6.2.2.2 Test Location

All the field tests for the first part of the study were carried out outdoors on a third generation artificial grass turf at St Marys School, Middleton, Rochdale. All the laboratory tests were performed in the physiology laboratories at the Research Institute for Sport and Exercise Sciences, Liverpool John Moores University. The training intervention was conducted outdoors on a natural grass turf at Bow Lee playing fields, Middleton, Manchester.

6.2.2.3 Field Test

The 15-30 protocol was performed at the beginning and at the end of the six-week training intervention. The details of this test have been described in section 3.1.4.

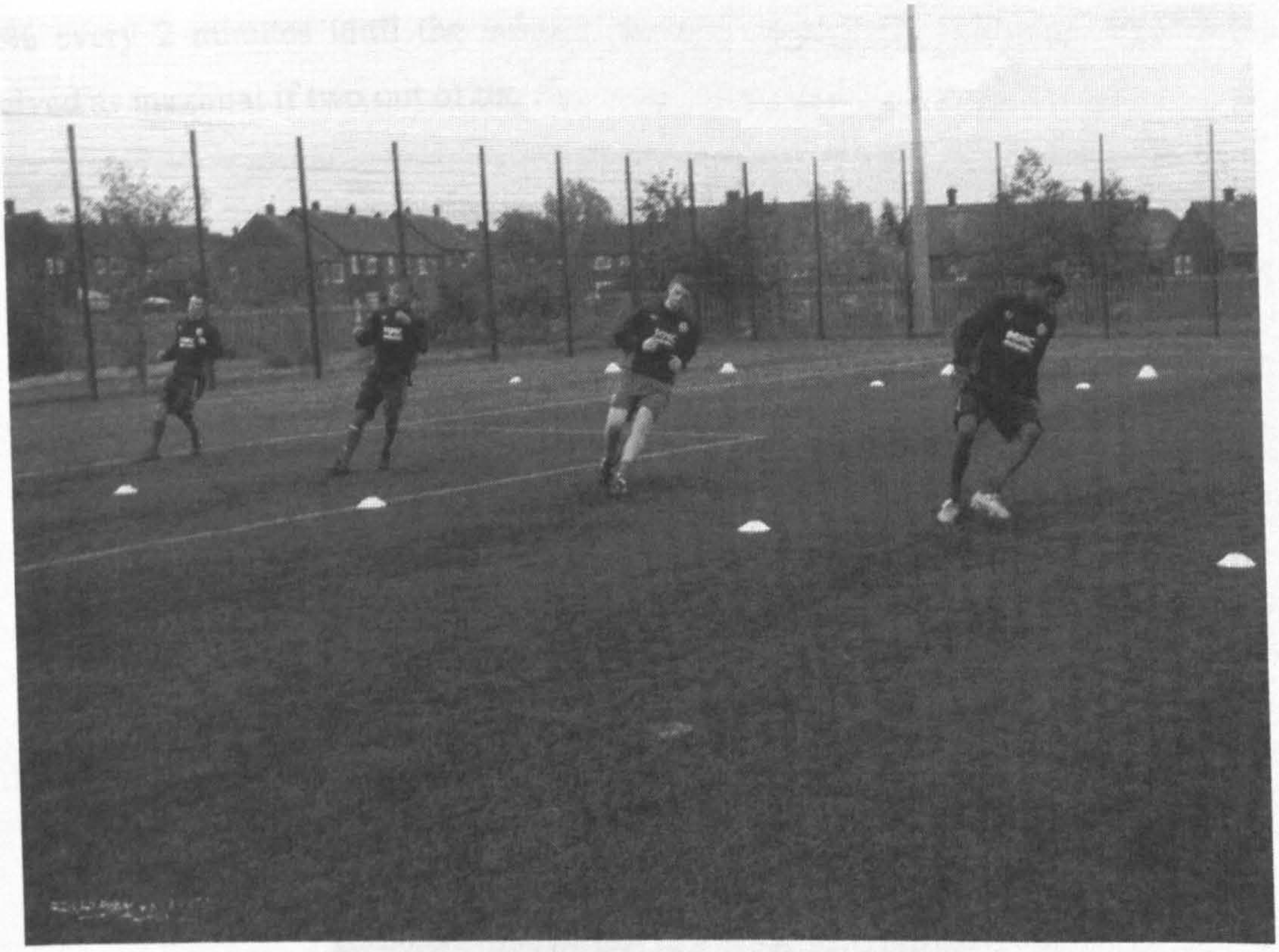


Figure 6.2.2.1. The professional youth scholars performing the 15-30 protocol at the end of the six-week aerobic interval training intervention.

6.2.2.4 Laboratory Test

6.2.2.4.1 Pre-Test Procedures

The subjects height and body mass was recorded using the procedures described in section 3.1. The tests were carried out with a dry bulb temperature of 20°C and a relative humidity of 15%.

6.2.2.4.2 Treadmill Test

The treadmill test was performed to determine peak oxygen uptake ($\dot{V}O_{2max}$) and performed at the beginning and at the end of the training intervention. The test was performed on a motorised treadmill (h/p Cosmos Pulsar, Nüssdorf-Traunstein, Germany). Prior to the start of the test, the subjects performed a 5 minute warm-up at 10 $km.h^{-1}$ and 5 minutes at 12 $km.h^{-1}$ followed by stretching exercises. The initial running velocity of the test was 14 $km.h^{-1}$ for 2 minutes, followed by 2 minutes at 16 $km.h^{-1}$. The running velocity then stayed constant at 16 $km.h^{-1}$ after which the treadmill inclination increased by 2% every 2 minutes until the subject reached volitional exhaustion. The test was perceived as maximal if two out of the five criteria described in section 3.3.2.

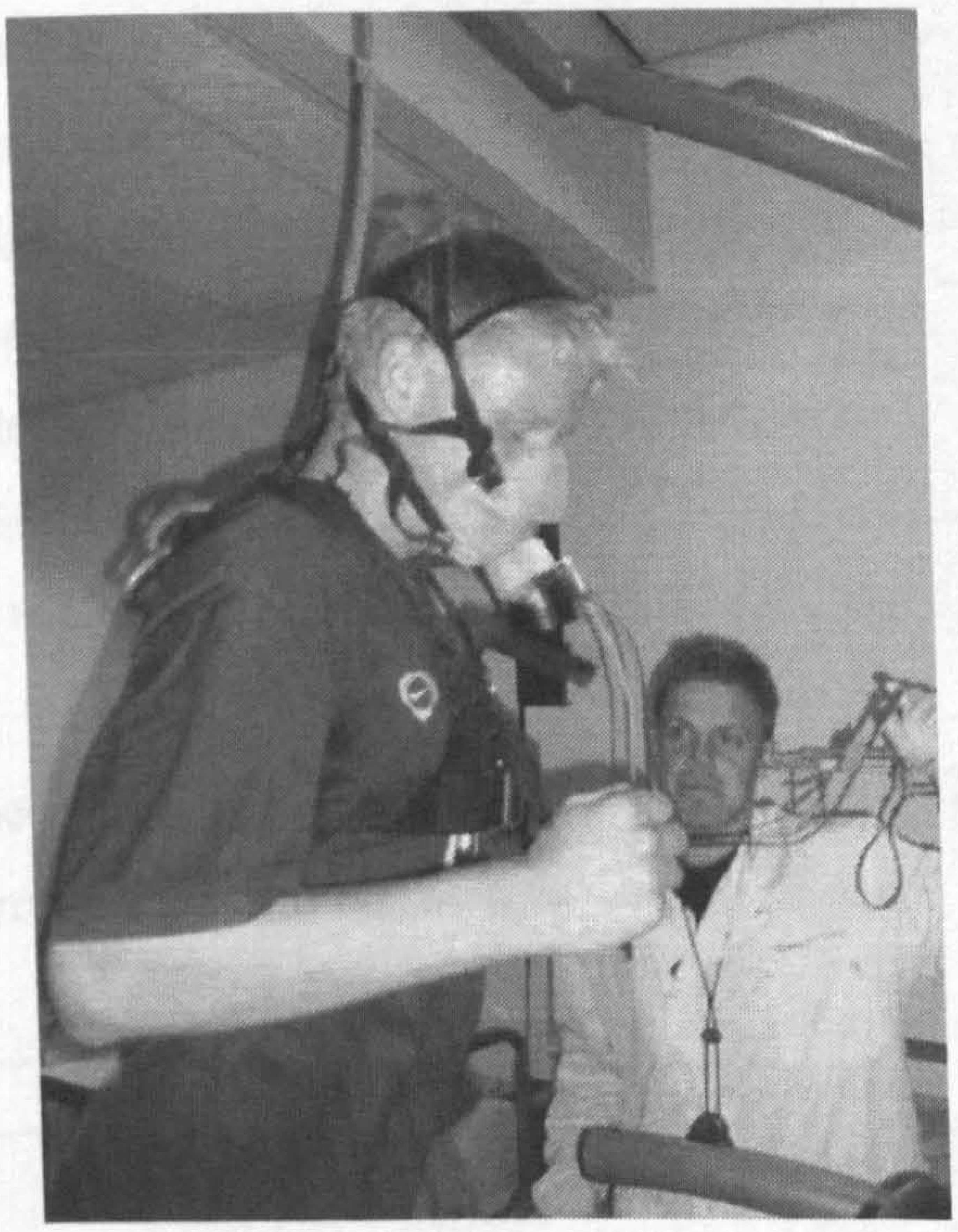


Figure 6.2.2.3. One subject performing the laboratory treadmill test to establish $\dot{V}O_{2max}$.

6.2.2.5. Interval Training Programme

The high-intensity aerobic interval training intervention took place 4 weeks after the end of the pre-season period during the 2006-2007 season. An example of the structure of a normal training week for the youth team is shown in Table 6.2.2.1. The duration of each football training session was approximately 90-120 min. Two sessions per week were allocated for the aerobic high-intensity interval training programme. The interval training was conducted on the morning training sessions on a Monday and Wednesday where possible. The aim was to perform twelve sessions in total over a period of six weeks. Two training sessions were cancelled at the coach's discretion, as shown in Figure 6.2.2.4. In total, ten interval training sessions were performed during the six-week training intervention.

An overview of the experimental set-up of the six-week training intervention is shown in Figure 6.2.2.1. The training consisted of soccer-specific activities. Most of the soccer-specific training consisted of small-sided games. The small-sided games consisted of 3 v 3 in an area of 30 x 30 m. In addition, for weeks 1 and 4 of the training intervention, the interval training sessions were performed on two consecutive days. Each training session consisted of 3 min of high-intensity exercise with a target heart rate of 85-90% of HR_{peak} interspersed with a 3-min active recovery period at 50-60% of HR_{peak}. The active recovery period consisted of light jogging to collect footballs. During weeks 1-3, three sets of the 3-min exercise periods were performed. The sets were then increased to 4 and 5 for sessions 7-9 and 10-12 respectively to maintain the physiological training stimulus.

Table 6.2.2.1. Example of the typical training week for the professional youth scholars during the six week aerobic interval training intervention.

Weekday	*Activity*
Monday	AM: Football Training PM: Strength Training
Tuesday	AM: Football Training PM: College
Wednesday	AM: Training PM: Rest or reserve team fixture (Pontins League West)
Thursday	Rest day (College all day)
Friday	AM: Training PM: Learning Education Authority Work
Saturday	Puma Youth Alliance League Match
Sunday	Rest Day

Pre-Test Week	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Post-Test Week
Field (1) and laboratory (2) tests	Monday (1): 3 x 3 min Tuesday (2): 3 x 3 min	Tuesday (3): 3 x 3 min Friday (4): 3 x 3 min	Tuesday (5): 3 x 3 min Wednesday (6): 3 x 3 min	Monday (7): Session cancelled Wednesday (8): 4 x 3 min	Monday (9): 4 x 3 min Wednesday (10): 5 x 3 min	Monday (11): 5 x 3 min Wednesday (12): Session cancelled	Field (1) and laboratory (2) tests

Key: 1 = 15-30 protocol, 2 = $\dot{V}O_{2max}$ test, (1 = session 1 of the interval training programme)

Figure 6.2.2.4. The experimental set-up for the study during the six week training intervention with a description of the number of sets and the exercise duration of the interval training for each week.

6.2.2.6. Physiological Measurements

6.2.2.6.1. Gas Analysis

Oxygen uptake was measured continuously during the test. The same procedure was used as described in section 3.4.1.

6.2.2.6.2. Heart Rate

Heart rate was measured every 5 s via short-range telemetry during all of the training sessions and during the 15-30 protocol using the Polar Team System (Polar Electro Oy, Kempele, Finland). During the treadmill test heart rate was measured every 5-s using the Polar S810 heart rate monitor (Polar Electro Oy, Kempele, Finland). The heart rate was analysed using the procedure described in section 3.4.3.

6.2.2.6.3. Blood Sampling

Blood samples were taken at rest and immediately at the end of the treadmill test. The procedures described in section 3.4.2 were employed.

6.2.2.7. Psychological Measurements

The subjects were asked to rate their perceived exertion according to the Borg scale as described in section 3.5.1. This procedure was performed at the end of each exercise block in Part 1 and immediately at the end of Part 2 in the 15-30 protocol and at the end of the treadmill test.

6.2.2.8. Statistical Analysis

All the data were expressed as means ± SD unless otherwise stated. Comparisons in mean heart rate during Part 2, HR_{peak} in Part 2, HR_{peak},, perceived exertion, time to exhaustion, absolute, relative and individual $\dot{V}O_{2max}$ in the laboratory test at the beginning and at the end of the treadmill test was made using a Student's T-test. A non-parametric Wilcoxon Signed Ranks test was used to test for significance in distance covered in Part 2 of the 15-30 protocol. A two-way repeated measures analysis of variance (ANOVA) was used to test for differences between the test stages in heart rate, time spent in heart rate zones and perceived exertion between exercise blocks in Part 1 in the 15-30 protocol. Statistical significance was set at $p<0.05$.

6.2.3 Results

6.2.3.1 Aerobic Interval Training Programme

The mean heart rate data for the two aerobic interval training sessions for each week of the six-week training intervention are shown in Table 6.2.3.1. A few players did not complete all training sessions during the six-week intervention due to either injury, called up to train with the first team squad or selection for the reserve team. Ten sessions were performed in total with two sessions cancelled at the coach's discretion.

6.2.3.2. Physical Characteristics

There was no significant change in the players stature ($t(12) = -1.169$, $p>0.05$) (pre-training: 1.79 ± 0.05 cm, post-training: 1.79 ± 0.06 m) or body mass ($t(12) = -2.026$, $p>0.05$) pre-training: 71.6 ± 9.3 kg, post-training: 72.2 ± 9.0 kg following the six week training programme.

6.2.3.3 The 15-30 Protocol

The overall global heart rate in Part 1 (23 min 30 s) for the professional youth scholars was significantly ($t(12) = 5.118$, $p<0.05$) lower at the end (158 ± 11 beats.min^{-1} equivalent to 82.1 ± 4.3% of HR_{peak}) compared to the beginning (165 ± 12 beats.min^{-1} equivalent to 86.2 ± 4.2% of HR_{peak}) of the six-week training intervention. The mean heart rate in Part 2 was unchanged ($t(11) = -0.792$, $p>0.05$) from the beginning (181 ± 9 beats.min^{-1} equivalent to 94.3 ± 3.0% of HR_{peak}) compared to the end (183 ± 10 beats.min^{-1} equivalent to 94.2 ± 1.9% of HR_{peak}) of the six-week training intervention. There was also no change ($t(11) = -0.322$, $p>0.05$) in peak heart rate in Part 2 from the beginning (188 ± 9 beats.min^{-1} or 98.0 ± 2.9% of HR_{peak}) to the end (189 ± 10 beats.min^{-1} or 98.2 ± 2.2% of HR_{peak}) of the training intervention.

Table 6.2.3.1. Mean heart rate data for the professional youth scholars from the two aerobic interval training sessions for each week of the six-week training intervention.

	Training Week					
	Week 1	*Week 2*	*Week 3*	*Week 4*	*Week 5*	*Week 6*
Heart rate (beats.min^{-1})	172 ± 6*	170 ± 10†‡	171 ± 7*‡	171 ± 8₣	169 ± 8¥	171 ± 8#
Heart rate (% of HR_{peak})	88.3 ± 2.2	87.0 ± 3.3	89.8 ± 5.7	89.0 ± 2.5	87.8 ± 2.6	89.0 ± 8.8

₣ = 1 player missed both training sessions, ‡ = 2 players missed for both training sessions, * = 3 players missed both training sessions,

= 1 player missed one training session, ¥ = 2 players missed one training session, † = 3 players missed one training session

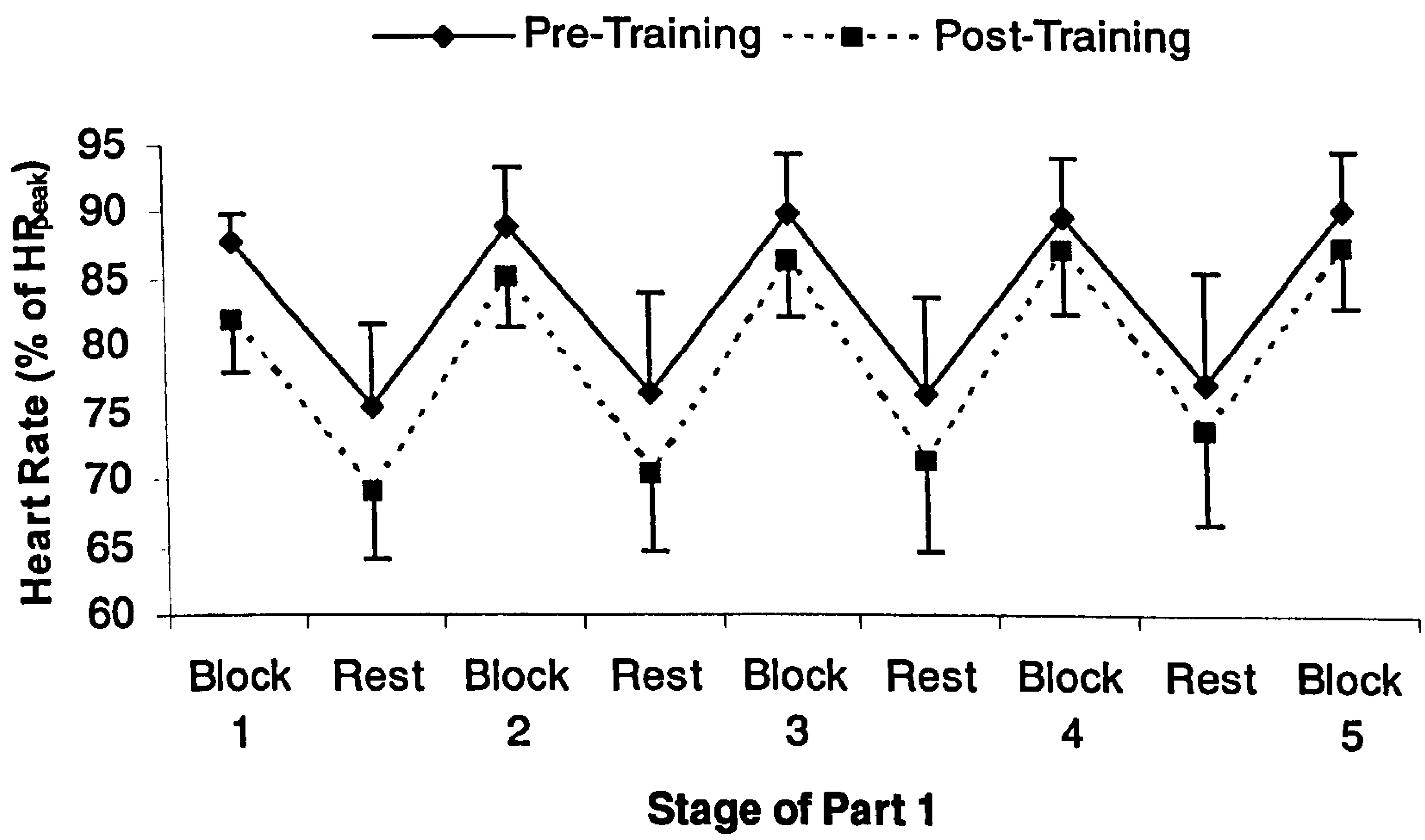
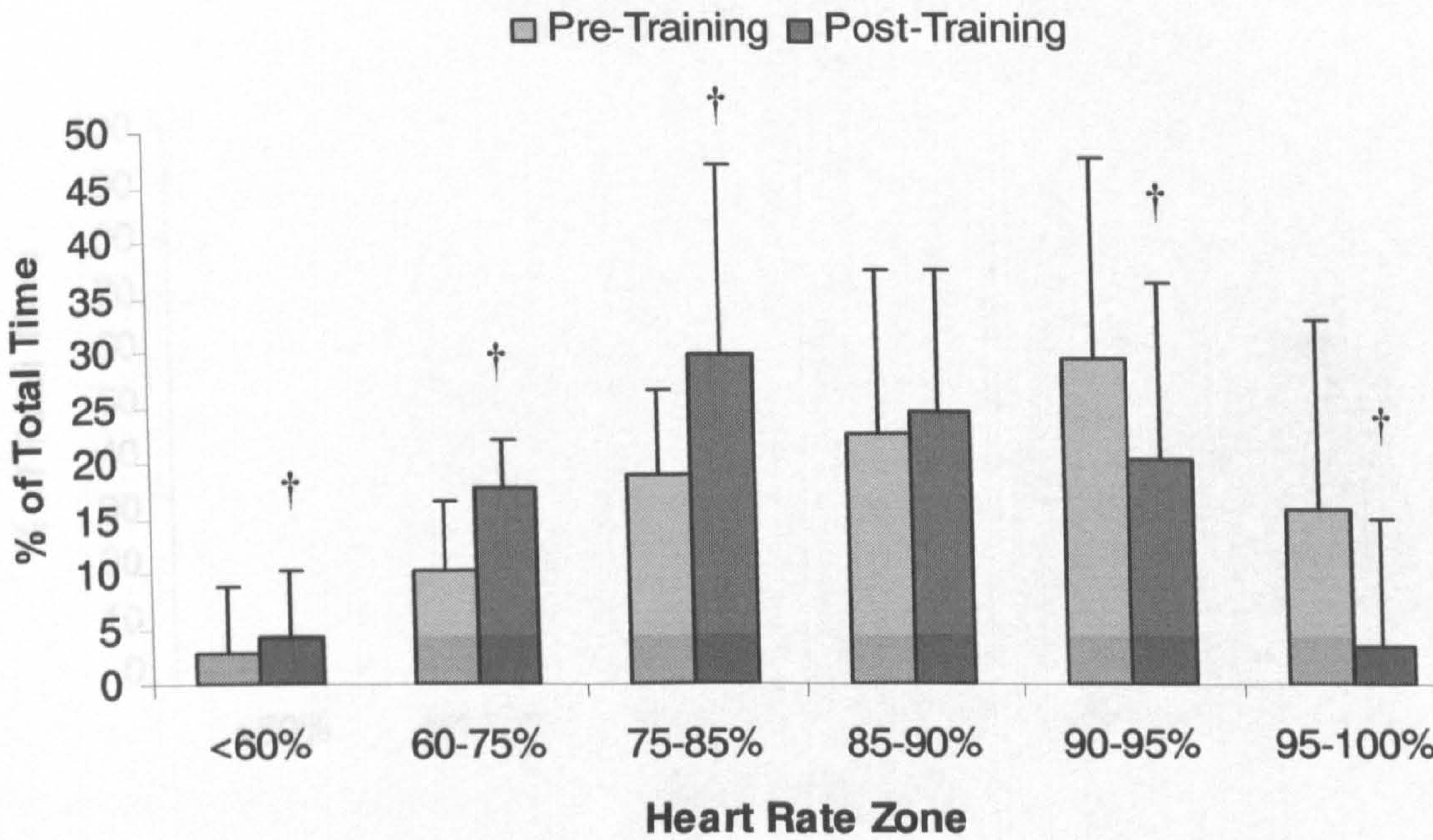


Figure 6.2.3.1. Heart rate profile of the professional youth scholars during Part 1 of the 15-30 protocol at the beginning and at the end of the six weeks aerobic interval training programme.

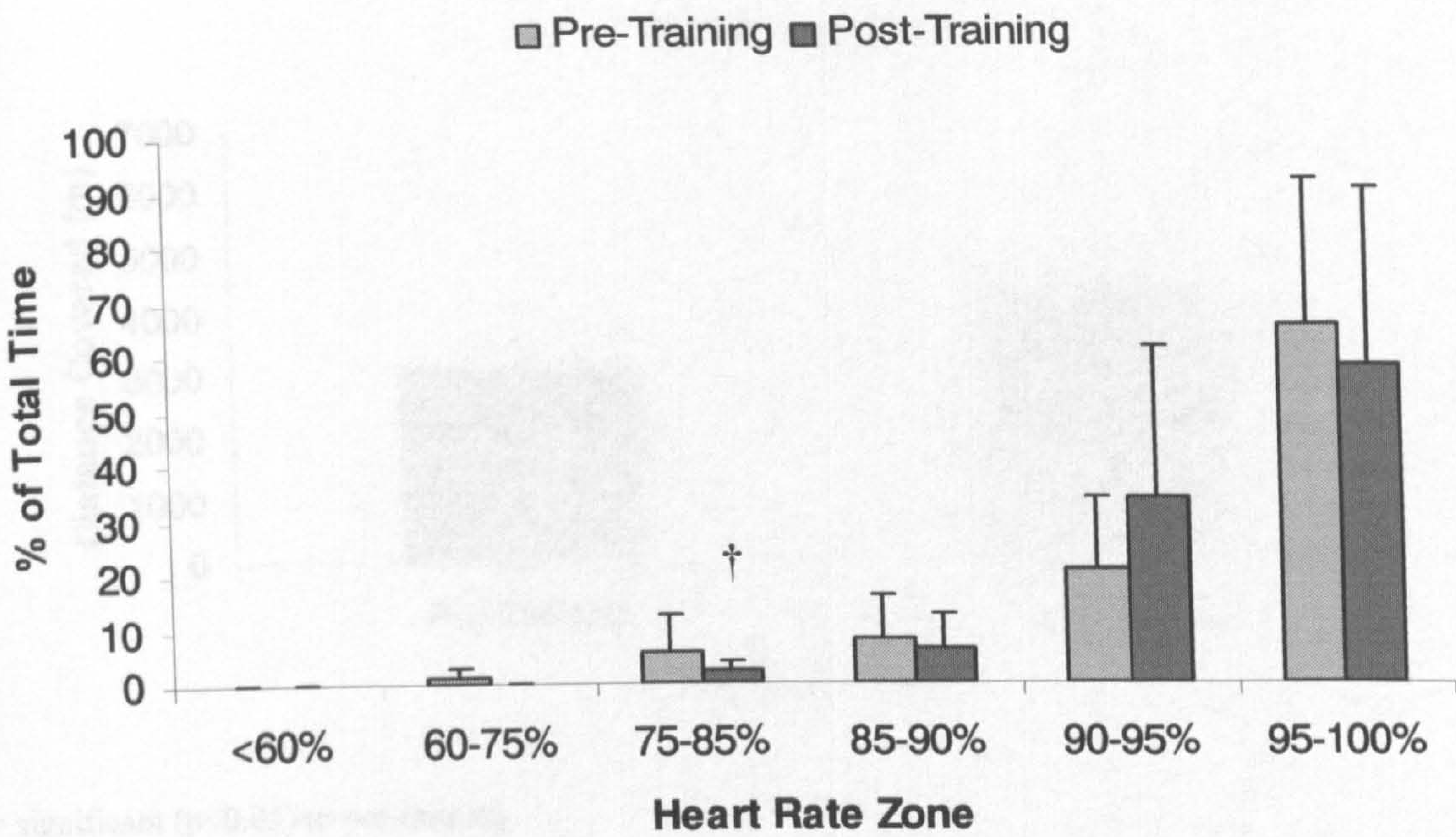
Heart rate in the different test stages in Part 1 was significantly ($F_{1\ 11} = 35.88$, $p<0.05$) lower at the end of the six week aerobic interval training. There was also a significant difference ($F_{8\ 88} = 83.71$, $p<0.05$) between most of the different test stages (i.e. exercise blocks to rest periods) in Part 1. A significant interaction ($F_{8\ 88} = 4.46$, $p<0.05$) was also reported over time between time and test stage.



† = significant (p<0.05) to pre-training

Figure 6.2.3.2. Percentage of total time in Part 1 spent in the respective heart rate zones at the beginning and at the end of the six-week aerobic interval training intervention.

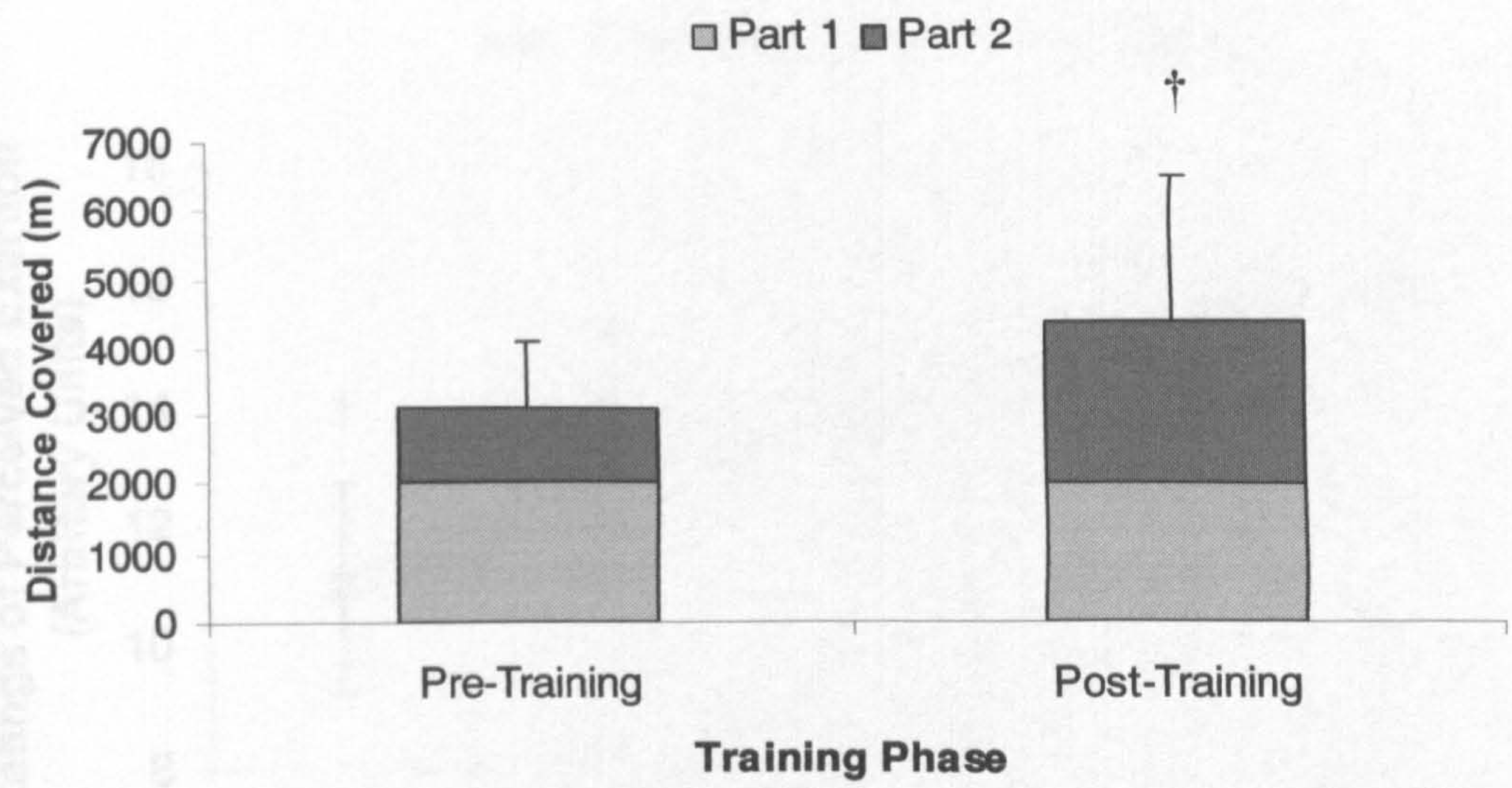
The players spent significantly longer time in the <60% zone (Z (12) = -2.077, $p<0.05$), 60-75% zone (t (11) = -4.471, $p<0.05$) and 75-85% zone (Z (12) = -2.312, $p<0.05$) in Part 1 after the six week training intervention, as shown in Figure 6.2.3.2. The professional youth scholars also spent a significantly shorter time in the 90-95% zone (t (11) = 2.595, $p<0.05$) and 95-100% (Z (12) = -2.201, $p<0.05$) following the training intervention as shown in Figure 6.3.2.2. No significant change was reported for the time spent in the 85-90% zone (Z (12) = -0.455, $p>0.05$).



† = significant (p<0.05) to pre-training

Figure 6.2.3.3. Percentage of total time spent in the respective heart rate zones during Part 2 at the beginning and at the end of the six-week aerobic interval training intervention.

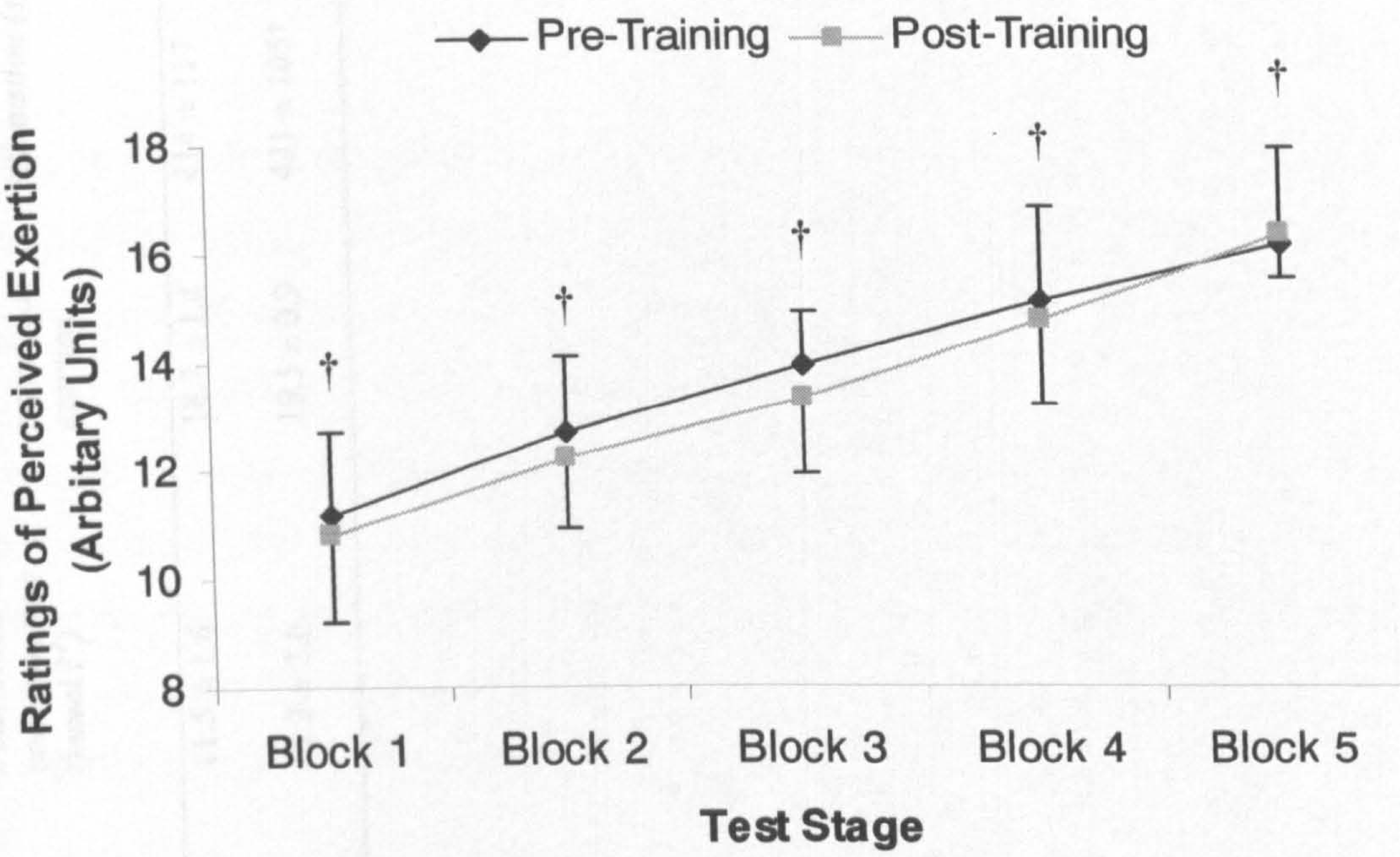
The professional youth scholars spent a significantly shorter time (Z (12) = -2.824, p<0.05) in the 75-85% zone in Part 2 after the training intervention. There was no significant difference in the time spent in the 60-75% zone (Z (12) = -1.461, p>0.05), 85-90% zone (Z (12) = -1.334, p>0.05), 90-95% zone (Z (12) = -1.334, p>0.05) and the 95-100% zone (Z (12) = -0.392, p>0.05) after the six week training intervention as shown in Figure 6.2.3.3. No statistical analysis was performed on the recovery heart rate zone as no player spent any time in that zone either before or after the training intervention.



† = significant (p<0.05) to pre-training

Figure 6.2.3.4. Distance covered in Part 1 and Part 2 of the 15-30 protocol at the beginning and at the end of the six-week aerobic interval training intervention.

The players covered a significantly (Z (13) = -3.110, $p<0.05$) longer distance in Part 2 of the 15-30 protocol at the end (2360 ± 2059 m) compared to at the beginning (1057 ± 1021 m) of the six week aerobic interval training intervention, as shown in Figure 6.2.3.4. The improvement from beginning to the end of the training intervention corresponded to a 123% increase in distance covered. The distance covered was equivalent to 18 ± 18 runs at the beginning and 41 ± 36 runs at the end of the training intervention.



† = significant (p<0.05) to all blocks

Figure 6.2.3.5. Ratings of perceived exertion in Part 1 at the beginning and at the end of the six week aerobic interval training intervention.

There was no significant difference ($F_{1\ 11} = 1.04$, $p>0.05$) in the perceived exertion before compared with after the training intervention. A significant difference ($F_{4\ 44} = 133.176$, $p>0.05$) was reported between all the blocks in the perceived exertion, as shown in Figure 6.2.3.5. The players rated their perceived exertion higher after each subsequent block at the end of the training intervention. No significant interaction ($F_{4\ 44} = 0.636$, $p>0.05$) was reported between the test and block.

Table 6.2.3.2. Results from the treadmill test for the professional youth scholars at the beginning and at the end of the training intervention.

Training stage	*Absolute* $\dot{V}O_{2max}$ *($l.min^{-1}$)*	*Relative* $\dot{V}O_{2max}$ *($ml.kg^{-1}.min^{-1}$)*	*Relative* $\dot{V}O_{2max}$ *($ml.kg^{-1}.min^{-0.75}$)*	HR_{peak} *($beats.min^{-1}$)*	*Resting blood lactate concentration ($mmol.l^{-1}$)*	*Peak blood lactate concentration ($mmol.l^{-1}$)*	*Ratings of perceived exertion*	*Time to exhaustion (s)*
Pre-training (N = 13)	4.53± 0.40	64.06± 5.66	184.8± 13.4	192 ± 9*	1.9 ± 0.4	11.5 ± 1.6	18.7 ± 1.4	414 ± 117
Post-training (N = 13)	4.81 ± 0.56†	66.83 ± 4.65	192.5 ± 13.2	191 ± 9*	1.7 ± 0.6	11.3 ± 2.0	19.5 ± 0.9	431 ± 105†

*N = 12, † = significant ($p<0.05$) to pre-training

6.2.3.4 Laboratory Tests

The results from the laboratory tests are shown in Table 6.2.3.2. Absolute ($t(12) = -2.234$, $p<0.05$) $\dot{V}O_{2max}$ was significantly higher (6.1%) after the training intervention. There was a 4.3% and 4.2% increase in relative ($t(12) = -1.826$, $p>0.05$) and scaled ($t(12) = -1.988$, $p>0.05$) $\dot{V}O_{2max}$ respectively at the end of the six week training intervention. Neither of these increases were significant. The players time to exhaustion on the treadmill test was 4.1% longer ($t(12) = -2.261$, $p<0.05$) after the training intervention. No significant change after training was reported in perceived exertion ($t(11) = -1.682$, $p>0.05$), resting blood lactate ($t(12) = 1.617$, $p>0.05$), peak blood lactate ($t(12) = 0.293$, $p>0.05$) or HR_{peak} ($t(11) = 0.484$, $p>0.05$) at the end of the treadmill test.

6.2.4 Discussion

The aim of this study was to examine the sensitivity of the 15-30 protocol and $\dot{V}O_{2max}$ to a six-week in-season aerobic interval training programme in young professional soccer players. The main finding of this study was that performance in both Part 1 and Part 2 of the 15-30 protocol improved significantly following the aerobic interval training programme. No significant change in relative or scaled $\dot{V}O_{2max}$ was reported.

6.2.4.1 The 15-30 Protocol

The overall heart rate for Part 1 was significantly lower at the end of the six-week training programme. In addition, heart rate for each test stage in Part 1 was also significantly lower following the aerobic interval training as shown in Figure 6.2.3.1. These results suggest that there was a marked improvement in the players' running economy after the training intervention. At most of the test stages, heart rate was lower which may indicate a sub-maximal training adaptation that lead to a faster recovery from the exercise blocks (Hagberg *et al.*, 1980). There was also evidence for an improved running economy (as reflected from the reduction in heart rate) during the exercise blocks. The improved running economy may be the result of the sparing of muscle glycogen during each of the exercise blocks (Henriksson and Hickner, 1993). The importance of muscle glycogen to high-intensity intermittent exercise performance has been reported previously (Bangsbo *et al.*, 1992). In addition, the players perceived exertion at the end of each exercise block was also significantly lower after the training intervention, as shown in Figure 6.2.3.5. It seems that the performance measures in the 15-30 protocol indicated that there was a physiological adaptation after the training programme.

The reduced heart rate during Part 1 may also indicate a better efficiency of the aerobic energy system. It is likely that oxygen consumption was also reduced at the same relative work rate. It has been reported that sub-maximal tests of soccer-specific endurance and aerobic endurance may be more sensitive to detect changes in performance than $\dot{V}O_{2max}$ alone (Bangsbo, 1993a; Edwards *et al.*, 2003; McMillan *et al.*, 2005a). Hardman *et al.* (1986) also found that sub-maximal changes in endurance performance were independent of $\dot{V}O_{2max}$. In this study only a small 4.3% increase in $\dot{V}O_{2max}$ was reported, as shown in Table 6.2.3.2, whereas the overall mean heart rate in Part 1 was 7 beats.min^{-1} lower at the end of the training intervention. Based on these findings it seems that a sub-maximal test of soccer-specific endurance such as Part 1 of the 15-30 protocol is not influenced by $\dot{V}O_{2max}$. It is important to consider that the physiology of intermittent exercise is complex and physical performance may be influenced by many other factors other than $\dot{V}O_{2max}$. It is also difficult to establish how much influence (if any) a learning effect had on the improved performance in the 15-30 protocol. The players had performed familiarisation trails to habituate themselves fully to the protocol. It has been previously shown in study 2 that two familiarisation sessions are needed for professional youth scholars of the same calibre as in this study.

Distance covered in Part 2 was improved by 123% at the end of the six-week training intervention as shown in Figure 6.2.3.4. The performance improvement in Part 2 was similar to the lower heart rate reported in Part 1. However, the structure of Part 2 is different to Part 1 with no set exercise blocks but the completion of as many high-speed runs as possible until exhaustion. Since there were no significant improvements in relative and scaled $\dot{V}O_{2max}$, it is plausible to suggest that the improved distance covered in Part 2 may be attributed to more peripheral soccer-specific adaptations following the training programme.

Peripheral adaptations may include an increase in muscle oxidative enzymes (Gollnick *et al.*, 1973), capillary density (Laursen and Jenkins, 2002) and mitochondrial content (Henriksson and Hickner, 1993). Muscle oxidative enzymes also seem to be more responsive to periods of de-training as opposed to central factors such as $\dot{V}O_{2max}$ (Bangsbo and Mizuno, 1988). A 100% increase in muscle oxidative enzyme activities have also been reported following a short 5-week high-intensity intermittent training programme (Roberts *et al.*, 1982). The increase in distance covered may also be explained by an improved muscle buffering capacity especially towards the latter stages of Part 2 (Cheetham *et al.*, 1986a and b; Sharp *et al.*, 1986). In addition, the muscle cation pumps (Na^+-K^+) may also have been enhanced following the high-intensity training programme (Laursen and Jenkins, 2002). An improved buffering capacity may have lead to the players being able to delay the onset of fatigue and perform more high-speed runs.

6.2.4.2 Maximal Oxygen Consumption

Absolute $\dot{V}O_{2max}$ was significantly higher at the end of the training intervention, as shown in Table 6.2.3.2. However, it seems that the most appropriate method of expressing $\dot{V}O_{2max}$ is independent of absolute body mass (Bergh *et al.*, 1991). Therefore, when $\dot{V}O_{2max}$ was expressed in relation to relative body mass and scaled to body mass $\dot{V}O_{2max}$ increased by 4.1% and 4.2% respectively. The reasons for the small increases in $\dot{V}O_{2max}$ may be that the players initial $\dot{V}O_{2max}$ was high. Since the training intervention started four weeks into the competitive season, it is plausible that the players training status was improved following pre-season training. Hence, the players $\dot{V}O_{2max}$ were relative homogenous at the start of the training intervention, as shown in Table 6.2.3.2. In order to improve $\dot{V}O_{2max}$ further, the volume of training and the duration of the intervention could have been increased. However, soccer-specific endurance performance in Part 1 and Part 2 of the 15-30 protocol was significantly improved, which may reflect more peripheral adaptations to training. Another plausible explanation may be that $\dot{V}O_{2max}$ is insensitive to detect changes in soccer-specific endurance performance.

This is also the first study which has tested professional youth scholars from the lowest professional division in England. Both the pre-training and post-training $\dot{V}O_{2max}$ values (64.06 $ml.kg^{-1}.min^{-1}$ and 66.83 $ml.kg^{-1}.min^{-1}$ respectively) were similar or slightly higher than $\dot{V}O_{2max}$ values reported in senior professional players (Bangsbo, 1993a; Puga *et al.*, 1993: Wisløff *et al.*, 1998; Casajus, 2001; Chamari *et al.*, 2004; Dupont *et al.*, 2004; McMillan *et al.*, 2005b). These findings show that the physical fitness levels in lower standards of play can equal to that of top class players. The high values may be explained by an improvement in the level of physical conditioning at the lower leagues. It is important to consider that the pre-training values were measured 4 weeks into the competitive season. The players aerobic endurance levels should therefore be at a reasonable high level compared to pre-season.

Several authors have also reported little or no improvements in $\dot{V}O_{2max}$ following 5-8 weeks of high-intensity intermittent training in-season (Bangsbo, 1993a; Impellizzeri *et al.*, 2006), similar to observations in this study. Others (Helgerud *et al.*, 2001; McMillan *et al.*, 2005b) found a 10.8% and a 9% significant increase in $\dot{V}O_{2max}$ utilising a similar training principle to the one used in this study. A plausible explanation for the very small improvement may be that the athletes are close to their 'ceiling'. Therefore, the pre-training $\dot{V}O_{2max}$ levels reported in this study for the professional youth scholars may have been close to their aerobic capacity 'ceiling'. For this group of highly trained professional youth soccer players, the improvements from the training programme may be so small that changes cannot be detected by statistical significance tests (Hopkins *et al.*, 1999). However, this may have been a plausible explanation for central factors such as $\dot{V}O_{2max}$ associated with the training programme. It is possible that soccer-specific endurance performance was more sensitive to the training programme, which can reflect a peripheral training adaptation. This view is supported by the lower heart rate in Part 1 and the increased distance covered in Part 2 of the 15-30 protocol found in this study.

6.2.4.3. The Interval Training Programme

The aerobic interval training programme did significantly improve performance in both Part 1 and Part 2 of the 15-30 protocol. However, the duration and intensity of the aerobic interval training programme may not have been sufficient to significantly improve $\dot{V}O_{2max}$ significantly. Tabata *et al.* (1996) reported that high-intensity intermittent training of a sufficient intensity can improve both the aerobic and anaerobic energy systems leading to a greater improvement in $\dot{V}O_{2max}$ compared to moderate-intensity endurance training. The 3-min exercise period was chosen because of its practicality for coaches where players can alternate exercise and rest periods (Reilly and White, 2005). Due to two sessions being cancelled, the effective exercise time per week from the interval training varied from 18 min for week 1-3, 12 min for week 4, 27 min for week 5 and 15 min for week 6. However, it has been shown that 20 min of effective interval training per week can significantly increase both glycolytic and oxidative enzyme activities (Billat, 2001).

As shown in Table 6.2.3.1, the average training intensity during the 3 min exercise periods in the sessions varied between 87-89.8% of HR_{peak}. Exercise intensity within this range has been shown to stimulate the cardiorespiratory system sufficiently (Bangsbo, 1994a). However, to elicit improvements in $\dot{V}O_{2max}$ in already well-trained players, the exercise intensity should be >90% of HR_{peak} (Hoff, 2005; Stølen *et al.*, 2005). A plausible explanation why the players did not attain heart rates >90% of HR_{peak} may be a lack of motivation. In order for small-sided games to be effective and elicit the appropriate training stimuli, players are encouraged to perform runs which they would not necessarily perform in match-play. The coach could also manipulate the number of touches per player, size of the playing area and introduce man-marking (Bangsbo, 1994a). Even though the investigator together with the coaching staff provided strong verbal encouragement during each training session, the players may not have exercised hard enough.

One of the biggest problems when studying professional soccer players is the lack of control. It is shown in Table 6.2.3.1 that all players did not perform all of the aerobic interval training sessions. Some of the players missed the sessions due to injury, called up to train with the first team or playing in the reserve team. Hence, the first team manager could draft in players from the youth team to train with the first team at a very short notice. These players would then miss the subsequent training session and the aerobic interval training. The training programme was scheduled to be performed on a Monday and a Wednesday where possible. However, in two of the training weeks, the interval training was performed on consecutive days (Tuesday and Wednesday). It is difficult to establish how much influence the disruption of the training schedule for the aerobic interval training had on the test results in this study.

This study would also have benefited from the use of a control group. However, it is very difficult to implement control groups within professional soccer especially during the competitive season. Helgerud *et al.* (2001) reported one of the few studies which used a control group. They found that the control group did not significantly improve physical performance during match-play, T_{lac} or $\dot{V}O_{2max}$ after 8 weeks of normal soccer training. The training group performed high-intensity interval training twice per week. It is plausible that similar results would have been found in this study with the inclusion of a control group although this is very difficult to estimate.

6.2.4.4 Practical Applications

Maintaining soccer-specific endurance fitness levels throughout the competitive season is always a challenge for coaches. Incorporating an aerobic interval training protocol used in this study seems to be of sufficient intensity to significantly improve soccer-specific endurance performance but only a small improvement in $\dot{V}O_{2max}$. In order to improve $\dot{V}O_{2max}$ significantly coaches should either increase training volume or intensity. It seems that coaches can use soccer-specific endurance tests such as the 15-30 protocol to monitor changes in training status in-season.

6.2.4.5. Conclusion

A six-week aerobic interval training programme did significantly improve soccer-specific endurance performance whereas $\dot{V}O_{2max}$ improved but not significant. These findings would suggest that changes in soccer-specific endurance performance may be due to peripheral adaptations at muscle level as opposed to central adaptations. Players with an enhanced aerobic capacity may have needed additional training stimulus in order to elicit any further improvements. It may be difficult for well-trained athletes to further improve $\dot{V}O_{2max}$ in-season unless training volume and intensity is appropriate. It has also been shown in this study the difficulty in controlling test conditions when testing professional soccer players especially during the competitive season.

Chapter 7

Synthesis of Findings

7.0 Synthesis of Findings

The studies in this thesis were conducted to investigate the development of a soccer-specific high-intensity intermittent exercise protocol. These protocols were developed to assess soccer-specific endurance performance in players. The first study was an extended pilot work where the reliability of the first high-intensity intermittent exercise protocol- the 15-50 protocol was examined. This study formed the background for study 2, where the original protocol was refined and the reliability of the new high-intensity intermittent exercise protocol 15-30 protocol was investigated. Completion of these studies fulfilled the aims described as described in page 4.

In study 3, the relationship between 15-30 protocol performance and performance in soccer-specific field tests, sub-maximal and maximal laboratory tests of aerobic endurance and physical performance during competitive match-play was examined. The sensitivity of the 15-30 protocol and the Yo-Yo Intermittent Recovery test to a period of pre-season training was investigated in study 4. The effect of an in-season aerobic interval training programme on 15-30 protocol performance and maximal aerobic power were investigated in the final study.

7.1 A New Soccer-Specific Test Protocol

The aim of the first set of studies was to develop a high-intensity intermittent protocol to assess soccer-specific endurance performance through sub-maximal and maximal components. The original protocol, the 15-50 protocol, was developed through pilot work leading to the development of the 15-30 protocol. Although the reliability of the 15-50 protocol was thoroughly assessed, the structure of the protocol was not representative of the activity pattern and physical demand during match play. The modified 15-30 protocol was better suited for the assessment of soccer-specific endurance. In addition, both the initial pilot work on the 15-50 protocol and the 15-30 protocol underwent extensive reliability analysis using the appropriate statistics (Atkinson and Nevill, 1998; Hopkins, 2000). No other field test in soccer has been as thoroughly assessed for reliability.

It is important to consider that several familiarisation sessions are needed for the 15-30 protocol to habituate the players fully to the running pattern. As the players are more familiar with the test, their running economy improves. Coaches and practitioners must consider this issue to be certain that changes in the test protocol are due to training adaptations as opposed to measurement error. The number of familiarisation sessions seems to be more of a problem with non-professional players where the physical fitness and motivation may be more varied. For example, in study 4 and study 5, the young professional players were fully habituated with only 2 familiarisation trials which increases the probability of that improvements on the 15-30 protocol occurred as a result of training. At least two familiarisation sessions should be performed for all standards of play. The coach or practitioner can then judge whether further familiarisation tests are needed.

7.2. Physical Performance in Part 1 and Part 2

The physiological challenge in Part 1 and Part 2 of the 15-30 protocol was distinctly different. It seems that Part 1 fulfilled the criterion for sub-maximal exercise with the majority of the time spent in heart rate zones <90% of HR_{peak} as shown in Study 2. It is obvious that the physical demand during Part 2 was higher than Part 1 where the players performed repeated high-speed runs with 6-s rest periods until exhaustion. Additionally, sub-maximal and maximal markers of aerobic endurance such as T_{lac}, V-4 mM and $\dot{V}O_{2max}$ were significantly correlated to performance in Part 2 but not to responses in Part 1. Part 2 was open-ended and maximal where the players performed as many high-speed runs as possible. It is plausible that players with a higher $\dot{V}O_{2max}$ would have been better able to recover from each high-speed run and maintain homeostasis especially at the muscle periphery (Hermansen and Stensvold, 1972; Hamilton *et al.*, 1991; Balsom *et al.*, 1992a). The lack of relationship between any of the aerobic endurance markers and Part 1 may be explained by the structure of Part 1 which is separated in defined exercise blocks and rest periods. It appears that sub-maximal heart rate measurements in this particular activity pattern may not be related to standardised measures of aerobic endurance.

Although Part 1 was not related to any sub-maximal markers of aerobic endurance, it was sensitive to detect changes in training status following pre-season and in-season training as shown in study 4 and study 5. It may be that it is difficult to relate heart rate responses during soccer-specific endurance tests to other standardised tests due to the complexity of the activity itself as explained above. Although it seems that coaches can use Part 1 to assess players' training status during the season. However, the application of Part 1 needs to be explored further with special reference to the physiological mechanisms governing test performance.

Moreover, there was no relationship between either heart rate measurements in Part 1 or distance covered in Part 2 and time spent in high-intensity exercise or the total distance covered during match-play. No relationship was also reported between physical performance in match-play and YIRT-1 or performance in the 20-m shuttle run. This finding was surprising considering that significant relationships between high-intensity distance in match-play and distance covered in YIRT-1 have been reported elsewhere (Krustrup *et al.*, 2003). A plausible explanation may be that physical performance during a soccer match can be highly variable including the development of pacing strategies (Reilly, 2005). Soccer-specific endurance performance is very complex and it may not be possible to find a test protocol which fully represents the ecological validity of physical performance in match-play. Therefore, as shown in Figure 7.4.1, soccer-specific endurance performance is difficult to predict, as discussed below.

There was no relationship reported between the two soccer-specific endurance test protocols:- the 15-30 protocol and the YIRT-1 in study 3. This finding also highlights the complexity of evaluation of soccer-specific endurance. Moreover, following pre-season training in study 4, performance improvements on the 15-30 protocol were not compatible to YIRT-1 improvements. These results seem to suggest that 15-30 protocol and the YIRT-1 assesses different components of soccer-specific endurance. The difference in the physiological responses may be attributed to a different running speed stimulating a different pattern of energy production (Krustrup *et al.*, 2003; Castagna *et al.*, 2006a). It is likely that the running speed in the 15-30 protocol will be slightly lower than the majority of the subjects' maximal aerobic speed (Lčger *et al.*, 1980; Berthoin *et al.*, 1996).

Furthermore, the complexity of the physiological responses to a period of soccer-specific training was highlighted from both the pre-season and in-season training studies. It is plausible that the training adaptations were mainly attributed to peripheral factors such as an increase in muscle enzyme activity and mitochondrial content as opposed to central factors such as $\dot{V}O_{2max}$ (Hermansen and Stensvold, 1972; Gollnick *et al.*, 1973; Bangbso, 1993a; Laursen and Jenkins, 2002). The small increases in $\dot{V}O_{2max}$ together with the large improvements in the 15-30 protocol suggest that soccer-specific protocols may be more sensitive to detect changes in-season compared to $\dot{V}O_{2max}$. However, it is important to consider that the magnitude of the response to a training programme is dependent on volume, intensity, duration and the progressive overload of training as well as the initial physical fitness of the persons tested (Brooks *et al.*, 1993; Bompa, 1999; Billat, 2001). Although improvements in soccer-specific endurance were shown in these studies, the exact mechanisms responsible for the adaptations are still inconclusive.

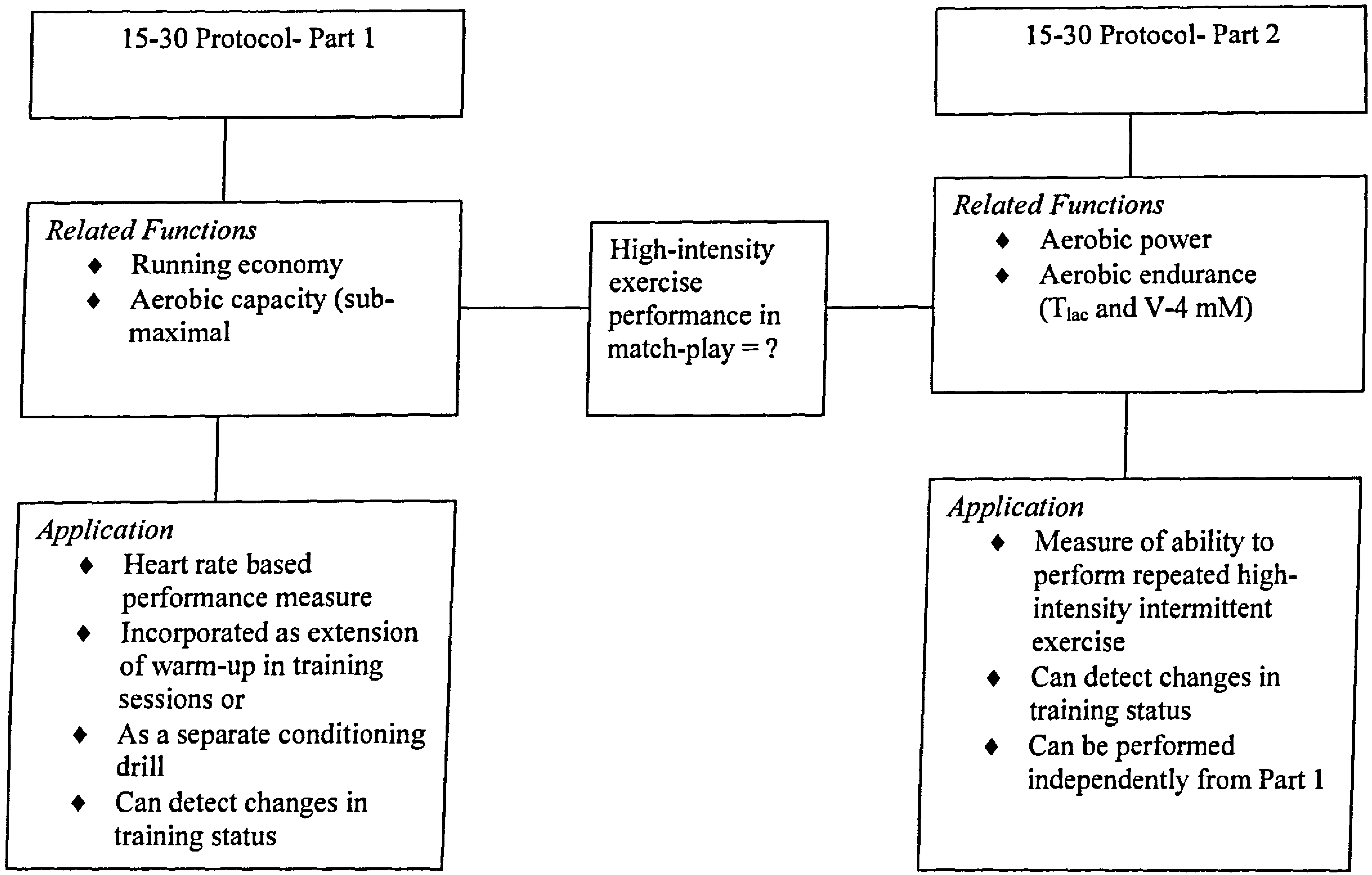


Figure 7.4.1. Schematic illustration of the related physiological functions and the applications of Part 1 and Part 2 of the 15-30 protocol in soccer.

Both the pre-season training study and the in-season training study were performed without a control group. The inclusion of a control group was not possible because the coach wanted all the players to perform the same training during the interventions. It is obvious that the effectiveness of the two training programmes would have been better highlighted with a control group. However, this issue summarises the difficulty of performing applied research at a professional soccer club.

7.3. Conclusions

The aim of this thesis was to develop a high-intensity intermittent running protocol to assess soccer-specific endurance. This aim has been fulfilled through the objectives expressed by means of the series of studies in this thesis. After initial pilot work with the 15-50 protocol, it was shown that the 15-30 protocol offered a more practical assessment of soccer-specific endurance. The series of studies in this thesis has also highlighted the difficulties in finding a test protocol which accurately reflects soccer-specific endurance. The development of the 15-30 protocol has provided a test which offers a different and unique activity pattern compared to existing field tests. The main conclusions from this thesis can be summarised as follows:

- Several familiarisation tests are needed on the 15-30 protocol both for professional and recreational players. The high learning effect associated with performance on the test is something that needs to be taken into consideration. Any learning bias has to be dissipated so that performance changes on the test are due to changes in training status.
- Physical performance in Part 1 and Part 2 of the 15-30 protocol seemed to be governed by different physiological mechanisms. Factors such as aerobic endurance seemed to be a limiting factor for maximal performance during Part 2. Sub-maximal assessment of soccer-specific endurance in Part 1 is complex and is dictated by other factors which need to be explored further.
- Physical performance during match-play is not related to soccer-specific endurance tests or aerobic endurance measures from the laboratory. The lack of relationships may be further evidence of the inherent characteristics of soccer with the variability of physical performance in match-play.

- Pre-seasonal and in-season training interventions with the associated training adaptations can be detected from the 15-30 protocol.
- Assessment of soccer-specific endurance performance is very difficult. This thesis has highlighted the complexity that is associated with predicting and evaluating soccer-specific endurance. The 15-30 protocol may assess a different component of soccer-specific endurance compared to other standardised field tests. These difficulties are related to the complex physiological variables that governs high-intensity intermittent sports such as soccer.

7.4 Future Recommendations

The series of studies performed in this thesis has shown the foundational applications of the 15-30 protocol in soccer. The studies have also highlighted some issues regarding the complexity of soccer-specific endurance assessment and the physiological mechanisms governing physical performance in soccer. In order to further develop the 15-30 protocol some suggestions for future research are given.

7.5.1. Longitudinal Evaluation of Physical Performance in Match-Play and 15-30 Protocol Performance

In study 3, the players were filmed only in one match. It would therefore be of interest to film the players during several consecutive matches in the same season. Sophisticated match analysis systems such as ProZone could be used to assess the physical performance in match-play accurately. Data on high-intensity exercise performance can then be accessed for all outfield players. The average time spent in high-intensity exercise in match-play can then be related to 15-30 protocol performance. By filming the players in several matches, any variability in high-intensity exercise performance of players can also be highlighted. The 15-30 protocol can then be performed for example once every two weeks so changes in soccer-specific endurance during the test can be related to work-rate in match play.

7.5.2. Physiological Responses during the 15-30 Protocol

In this thesis only limited information was obtained on the physiological responses during the 15-30 protocol, specifically heart rate and blood lactate measurements. By measuring several physiological variables, the exact physiological mechanisms which govern test performance could be examined. Measurement would include on-line gas analysis during both Part 1 and Part 2 through a portable device such as the Cosmed K-4. Blood samples could also be taken after each exercise block in Part 1 and immediately after Part 2 to measure blood metabolites and blood borne substrates. Muscle biopsies would provide information on the substrate utilisation and energy production during the test. Taken together, these measurements would aid in providing a better understanding of the physiological mechanisms which govern Part 1 and Part 2.

Moreover, it would be of interest to compare the physiological responses in Part 2 when this stage is performed independently from Part 1. The physical load in Part 1 would then be examined and how this influences the physiological responses and performance in Part 2.

7.5.3. The Discriminative Power of the 15-30 Protocol for Standards of Play

Although recreational and professional soccer players were used in the studies in this thesis no cross-sectional comparison was made. It would be beneficial to compare different standards of play to evaluate the discriminative power of the 15-30 protocol. Assessment could be made on players from clubs in every professional division of the country. In England for example, this assessment would incorporate the Barclays Premiership, Coca-Cola Championship, Coca-Cola League 1 and Coca-Cola League 2. Moreover, players from semi-professional divisions and finally recreational players would also be assessed. This study would provide valuable data in how soccer-specific endurance performance may differ across standards of play.

7.5.4. Development of the 15-30 Protocol for Female and Adolescent Players

The distances for each high-speed run in the 15-30 protocol were developed for male players and adapted for elite female players. In order to assess female and adolescent players of various standards of play, a revised standardised version of the 15-30 protocol should be developed. To be able to complete each high-speed run in the allocated time, the distances may need to be modified for the specific population being assessed. For example, recreational female players may not be able to complete 28 m in 6 s for the short high-speed run due to the different physical status of female players. A progression chart would also have to be developed for when to increase the distance of the short and long high-speed runs. The concept is to use the same audio CD but have different test courses at the same time thus individualising the test to suit the particular individual and standard of play.

7.5.5 Development of Other Soccer-Specific Endurance Protocols

The series of studies in this study has highlighted the complexity in assessing soccer-specific endurance. Coaches and practitioners should also be exploring different test protocols in view to identify the best means to assess endurance performance. Several different test protocols can be compared together with the physiological responses during the protocols. By developing different test protocols, a better understanding of the physiological mechanisms which governs test performance may be given. At some point it will be necessary to evaluate the tests collectively in view to identify those worthy of retention and those that can be discarded. Information from these test protocols may also dictate how conditioning training should be performed in soccer.

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