METABOLIC RESPONSES TO SOCCER-SPECIFIC INTERMITTENT EXERCISE

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ABSTRACT

The intermittent exercise pattern associated with soccer makes analysis of the demands of the sport more complex than in many individual sports. The aim in this thesis was to determine the physiological and metabolic responses to soccer-specific exercise. The demands associated with elite level match-play were evaluated by techniques of motion-analysis. Laboratory based soccer-specific intermittent exercise protocols were then devised to determine the physiological strain associated with soccer and investigate the effects of increased ambient temperature and whole body pre-cooling on performance.

The work-rate profiles of elite South American soccer players and English Premier League players, performing in international and club level respectively, were determined. English Premier League players covered a greater total distance during a game than the South American players ($P < 0.05$). Differences were found for the total distance covered for playing positions with midfield players covering larger distances than forwards. Defenders covered a greater distance jogging backwards than forward players with forwards sprinting a greater distance than defenders. Work-rate was reduced in the second half of the game for all player. The total distance covered by the international players was done mainly at submaximal intensities. High intensity exercise was infrequent and bouts were of short duration. No significant correlations were observed between the work-rate profile and anthropometric charactersitics of individuals.

The use of the doubly-labelled water technique to indicate the energy expenditure during soccer match-play was investigated. The doubly-labelled water technique cannot determine energy expenditure during a soccer match as the rate of turnover of the isotopes is too small to allow the accurate estimation of energy expended.

Laboratory based soccer-specific intermittent protocols elicited physiological responses that were similar in magnitude and pattern to soccer match-play. Physiological demands fluctuated with exercise intensity during intermittent exercise. Oxygen consumption and heart rate were not significantly different during soccer-specific intermittent exercise and steady-rate exercise at the same average intensity. Rectal temperature did not differ significantly between the two protocols, although intermittent exercise performance resulted in a greater rise in rectal temperature as the protocol progressed ($P < 0.05$). Sweat production did not differ significantly between the two exercise sessions, though the rating of perceived exertion was significantly higher ($P < 0.05$), for the session as a whole, during intermittent exercise.

Intermittent exercise performance at 26 $^{\circ}$ C did not result in significant increases in the physiological, metabolic or thermoregulatory responses when compared to intermittent exercise at 20 $^{\circ}$ C. The physiological and metabolic responses were also similar when intermittent exercise was performed after a whole body pre-cooling manoeuvre. Rectal temperature was lowered by the pre-cooling strategy prior to exercise ($- 0.6 \pm 0.6\,^{\circ}$ C, $P < 0.05$). Rectal temperature during exercise was only significantly lower after pre-cooling than during exercise at 26 $^{\circ}$ C. No significant differences were observed in rectal temperature during exercise between the normal and pre-cooled condition The increase in rectal temperature during the second half of the protocol was significantly greater than the increase observed at 26 $^{\circ}$ C or under normal conditions. This may be a consequence of an altered thermoregulatory response due to the pre-cooling manouvre.

In conclusion, the work-rate demands of soccer seem to be predominantly aerobic in nature with anaerobic bouts and the performance of specific match activities increasing the demands placed on players. The demands of intermittent exercise are not significantly different from continuous work performed at the same average intensity though there is tentative evidence for a decrease in the efficiency of the thermoregulatory system during intermittent work. No adverse effects upon intermittent exercise performance were noted under conditions of moderate heat stress, while any thermoregulatory benefits of whole body pre-cooling during intermittent work are probably only transient.

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Soccer is a team game. Any investigations into the sport will then not only require an individual contribution but also the support from both advisors and team-mates.

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This thesis is dedicated to the memory of my mother. Your memory will live on with me forever.

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CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

Soccer is one of the most popular sports in the world in both terms of its participation and spectator levels. Participation in soccer is not restricted to the elite male performer as participants also include the old, young and females. Performance in soccer is determined by a number of interdependent factors. Physiological, psychological, tactical and technical elements are closely linked to performance. For example, a player may not fully utilise his physiological capacities during a game due to the tactical responsibilities placed upon him by the coach. During a game a player engages in a wide variety of activities ranging in intensity from light exercise to maximal sprints. The exercise pattern is intermittent with the changes in activity being frequent but irregular in duration. This intermittent activity pattern separates soccer from sports in which the exercise pattern is continuous and as a consequence makes the analysis of the physiological demands of the sport more complex than in many individual sports. Superimposed on this background of activity are the game skills performed. Specific match activities such as kicking, tackling, heading and dribbling are all required for successful performance at any level. These serve to further increase the physiological stresses placed and increase the complexity of evaluating the energy demands imposed on players during participation.

The methodolgical approaches that can be used in competitive situations to determine the physiological stresses associated with match-play are limited. This invites opportunities for research studies of the demands of the game. The physiological demands of soccer have been examined by making relevant observations during game play, obtaining physiological measures (e.g. heart rate, blood lactate) during real and simulated games and determining the physiological capacities of elite players on performance tests (Bangsbo, 1994). Few researchers have attempted to devise soccer-specific laboratory protocols that seek to replicate the exercise patterns observed during match-play. Laboratory based protocols present an opportunity to utilise apparatus that increases both the depth and accuracy of the data provided as well as the controlled conditions that are associated with experimental work. It is hoped that through this investigation a greater insight will be gained into the physiological and metabolic responses to intermittent exercise patterns representative of soccer. Such information will have implications for the design of training programmes and fitness evaluation.

1.2. INTRODUCTION TO RESEARCH STUDIES

The analysis of the demands of soccer will be achieved by the use of field based and laboratory research. Field based research provides crucial information about the specific demands of the sport and hence the relative importance of the different aspects of fitness to intermittent exercise performance. It is, therefore, pertinent to investigate the physiological demands of elite soccer match-play as this will provide information regarding the physiological consequences of the game in general. Methodological problems restrict the information that can be collected in competitive match situations so the emphasis has to be placed on laboratory simulations for specific investigations. Laboratory simulations of the activity patterns observed in soccer match-play will then supplement this information. This information is a useful addition to field based research as it permits accurate physiological and respiratory measurement techniques to be used in the assessment of energy expenditure. Such procedures therefore enhance the accuracy of the data relating to the physiological demands of soccer-specific intermittent exercise. Little information is also available regarding the comparison with continuous exercise and factors that may affect intermittent exercise performance e.g. heat and the recovery procedures involved.

It is the purpose of this thesis not only to quantify the demands of match-play but also to enable comparisons to be made between continuous and intermittent exercise patterns. The impact of environmental variables on the demands associated with soccer-specific intermittent exercise performance will also be examined. The thesis is structured so that the studies in which the demands of match-play are quantified are described in Chapter 4 while the physiological and metabolic responses to laboratory based soccer-specific intermittent protocols are reported in Chapter 5.

1.3. AIMS AND OBJECTIVES

A two-way approach has been adopted to investigate the metabolic responses to soccer-specific intermittent exercise. Both the demands associated with match-play and the physiological responses to laboratory based soccer-specific intermittent protocols will be delineated separately through the fulfillment of the following aims :-

QUANTIFICATION OF THE DEMANDS OF MATCH-PLAY

1. To establish the work-rate profiles of soccer players during match-play.

2. To evaluate techniques to estimate the energy cost of soccer match-play under competitive match situations.

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3. To develop laboratory based soccer-specific intermittent exercise protocols.

4. To evaluate the physiological and metabolic demands associated with laboratory based simulations of match-play work-rates.

5. To examine the effects of thermal strain on soccer-specific intermittent exercise performance.

The successful realisation of the following aims will enable an overview of the physiological responses to soccer-specific intermittent exercise and the factors that affect it to be constructed. This will be accomplished by the following objectives :-

1. The work-rate profiles of players will be evaluated using techniques of motion-analysis performed on video recordings of performances of players in competitive matches.

2. The usefulness of the doubly-labelled water technique will be assessed as an indicator of energy expenditure during competitive match-play.

3. Both motorised and non-motorised treadmills will be used in order to develop laboratory based intermittent protocols that attempt to replicate match-play work-rates.

4. Evaluation of the metabolic and physiological responses to steady-rate exercise and soccer-specific intermittent protocols.

5. (a) Quantification of the effects of high ambient temperature (26 ^{o} C) on the physiological responses to soccer-specific intermittent exercise.
   (b) The effects of a whole body pre-cooling manoeuvre on the physiological responses to soccer-specific intermittent exercise performance will also be evaluated.

CHAPTER 2

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The aim of this review of literature is to provide the reader with information on the physiological demands of intermittent exercise with specific reference to soccer match-play. The research available on players' work-rate profiles from motion-analysis studies is reviewed as well as the physiological and metabolic responses to playing the game. Reference is also made, in terms of background and related research, to soccer-specific performance tests as these may also provide an indication of the demands of the game. The final sections of the review of literature relates to the complications that high ambient temperatures impose on exercise performance of a continuous and intermittent nature.

2.1. THE DEMANDS OF MATCH-PLAY

2.1.1. Motion-Analysis

Motion-analysis entails determining work-rate profiles of players within a team and classifying activities in terms of intensity, duration and frequency (Reilly, 1994). The primary purpose of such techniques is to provide technical and tactical evaluations of players and the analysis of movement patterns produced during match-play.

An individual's energy expenditure can be directly related to mechanical work output (Reilly and Thomas, 1976). As a result the total distance covered during game play has been employed as an index of work-rate. This is a global measure of work-rate that can be broken down into a number of discrete actions (Reilly, 1994a). Classifications can be made with regard to type, intensity (quality), duration (distance) and frequency of activity.

2.1.2. Distance covered

Several methods have been employed in an attempt to determine the distance covered during a soccer match, although there are large discrepancies within the published data (Reilly, 1994). Winterbottom (1952) tracked players' movements on a scale plan of the pitch and estimated the total distance covered to be in the region of 3361 m while Wade (1962) reported a range of 1600-5486 m. No methodological details were provided, and so as a result the data must be treated with caution. Brooke and Knowles (1974) used a hand notation system, reporting values for the distance covered in 4 games to be in the region of those observed by Wade (1962). The mean value over the four games observed was 4834 m. Distance covered was based on the observer's subjective estimates of 5 yard (4.6 m) units. Twenty observers were allocated one player each per game so the reported distance was probably affected by a lack of objectivity as well as the insensitivity of the units used.

The majority of the remaining research has produced values in excess of those already mentioned. Vinnai (1973) cited Russian reports of players covering around 17 km during match-play. Such estimates are the largest observed for players, though no methodological details were reported. Total distances covered have been reported for Belgian (Van Gool et al., 1988), Australian (Withers et al., 1982), Danish (Bangsbo and Lindquist, 1992), Swedish (Saltin, 1973), English (Reilly and Thomas, 1976) and Japanese (Ohashi et al., 1988) players. Despite the use of a wide variety of methodological approaches, mean distances of around 10 km have typically been reported.

Saltin (1973) extrapolated the distance covered during a friendly game from 3-minute films of each player taken during each half. A sample of 5 players produced a mean total distance of 12000 m. The estimation of the total distance covered during game play, based upon such limited analysis, will be problematic and probably represent an overestimation of the game's demands. No consideration is given to changes in the total distance covered during the remaining period of the game as a conseqence of factors such as fatigue or match outcome which may reduce the work-rate in the later stages of the match. Whitehead (1975) registered players' movements on paper for 10-minute periods per half and found a similar range of 11472-13827 m for English "First Division" midfield players and full-backs. This is in close agreement with the 11527 ± 1796 m reported by Withers et al. (1982) upon linking video analysis of the movements during an entire competitive Australian match with individual stride characteristics obtained at different intensities of motion.

Reilly and Thomas (1976) estimated the mean distance covered in a game to be 8680 m with a range of 7069 to 10921 m for 40 players in the English "First Division". Observations were made from a seat in the stand overlooking the half-way line with a coded commentary of events being registered on a tape recorder. Distance was estimated in 1 m units by utilising cues on the pitch and on its boundaries. Games were also filmed for concomitant analysis to establish validity, stride characteristics at different running speeds being employed in an attempt to determine the reliability of the data. The difference of 2487 m between the mean distances of Reilly and Thomas's (1976) work and the data of Withers et al. (1982) is possibly related to variations in ground conditions or the longer stride lengths of the Australian players (Reilly, 1994).

Ekblom (1986) used a hand notation system in recording the action of an individual player on a paper representation of the field for alternate minutes of the game. Four Swedish and one German team were reported to cover around 10 km during match-play. This figure is in agreement with the results for 20 Danish players (10.98 km) obtained by Bangsbo and Lindquist (1992) who observed players' activity patterns for the full 90 minutes of play using video analysis techniques.

Ohashi et al. (1988) reported distances of 9303 m and 10387 m for two players in the Japanese Football league using a trigonometric approach. Two video cameras were mounted on tripods linked to potentiometers 20 m from the corner flags in a position overlooking each half. Each camera tracked the same player throughout the entire match. Co-ordinates were calculated using the angular data provided by the potentiometers. These were monitored every 0.5 s with the distance between two consecutive co-ordinates calculated continuously to obtain the total distance covered for the individual.

Van Gool et al. (1988) studied 7 outfield players in a friendly game between a Belgian and British university team. A 16 mm camera was positioned on a 57 m high apartment block overlooking the playing field. The film was projected repeatedly with each player being studied in turn thus allowing data from 7 players to be collected. Projection on an x-y co-ordinated system allowed distances, velocities and acceleration to be derived. The position of the players was notated each second with the distance between two successive points being calculated. Mean total distance for the players was 10225 ± 580 m.

Various methodological approaches have been utilised to determine the total distance covered during soccer match-play. These methodologies have been applied to a wide range of levels of ability, although the number of subjects examined has been small in most research projects. Mean distances of around 10 km have been reported in the majority of cases. It is, however, difficult to make firm conclusions regarding the overall energy demands of all soccer playing populations as the data available are not comprehensive.

2.1.3. Time based analysis

An alternative strategy to examining the total distance covered is to set the results against a time base to which the activity patterns produced by the player during the game can be related. Mayhew and Wenger (1985) analysed video recordings of 3 midfield players from the North American Soccer league over a 4-game period. Two players were followed per game for alternate 7 min periods. The data collected were analysed for the time spent in each activity and the frequency of each classifications occurrence was recorded. Walking and jogging accounted for a combined 1706.1 s. This was determined to be 84.8 % of the total time; 11.3 % of the time was spent running (striding and sprinting combined). Based on the data collected, it was claimed that 88 % of match-play primarily stresses the aerobic energy system as this predominates during the performance of sub-maximal activities with the remaining 12 % being anaerobic in nature. This anaerobic contribution was believed to be alactic in nature, i.e. engages high energy intra-muscular phosphates without concomitant lactate production.

Bangsbo et al. (1991) monitored the work-rate profiles of 14 top class Danish players. Players were videotaped for the duration of an entire match with more than one player being followed per game. Upon completion of the match each player observed was filmed moving along the short side of the penalty area performing specific activities from walking to sprinting. This enabled five separate movement categories to be devised with mean velocities ascribed to each. All 15 min periods of the observed games produced similar estimated distances with the exception of the first 15 min of the match in the first half and the final 15 min of play in the second. Such discrepancies could be attributable to motivational effects at the onset of the match and fatigue during the closing stages, respectively. Such findings are in contrast to the observations of Ekblom (1986) who noted only slight differences in the distance covered for each 15 min of game play. This could be a result of methodological differences between the studies as Ekblom's procedure of recording observations every second minute may have been too crude to allow accurate assessments to be made over small durations of time. Bangsbo et al. (1991) also quoted a mean total distance of 10.8 (range 9.49-12.93) km.

The major component of the total distance covered during games is performed at a sub-maximal intensity. The demands are aerobic in nature with only a small contribution coming from anaerobic sources. The demands of the game are relatively constant irrespective of the period of the match with the possible exeception of the final stages of the second half. This would neccessitate a high aerobic capacity in players to enable them to endure the entire 90 minutes of play without large reductions in work-rate.

2.1.4. Limitations to methodologies

There are large discrepancies in the total distance covered by players in match-play as recorded in the literature. Reilly (1994) stated :-

"Methodologies for measurement of distance must be reliable, objective and valid."

p.32

Most studies in the area (e.g. Mayhew and Wenger, 1985; Reilly and Thomas, 1976; Bangsbo et al. 1991) have controlled their experimental investigations in an attempt to ensure reliable data collection techniques. These have ranged from assigning two observers to the same player (Brooke and Knowles, 1974) to the application of an alternative technique to enable comparisons to be drawn regarding the same data (Reilly and Thomas, 1976). This involved filming the same game as was being observed and then using mean stride lengths for each activity category, calculated during training, to estimate the total distance covered during game play.

High correlation coefficients have been observed with the use of such techniques. Mayhew and Wenger (1985) reported r values using Pearson's product moment method for reliability and objectivity of 0.97 and 0.95 respectively while Reilly and Thomas (1976) found a value of 0.97 when correlating distance covered using their devised methodology with that estimated from the stride lengths for each movement activity. Compliance with the criteria stipulated by Reilly (1994) had thus been achieved. Such conclusions cannot, however, be made on the basis of the statistical techniques employed. The correlation coefficient is highly influenced by the heterogeneity of the sample, and is a measure of relationship rather than agreement (Bland and Altman, 1986).

Differences in the methodologies applied to obtain the data on the activity of the player and then to convert these recordings subsequently to an estimation of the distance covered during a match probably explain some of the discrepancies when different studies are compared. Bangsbo (1994) highlighted the influence of such observation procedures by comparing the data of Whitehead (1975) with those of Reilly and Thomas (1976). Mean distance differed by approximately 3 km between the studies. This figure is unlikely to represent any developments in the game but rather reflects methodological discrepancies between the studies. Such problems are compounded by the relatively small number of observations in most studies. As will be discussed later, work-rate profiles are affected by positional role, tactical conditions, importance of game and quality of the opponents, among other things. This results in match-to-match variations which may not be observed unless analysis is performed over a number of games. Ekblom (1986) stated that differences in the distance covered will also be found between teams. Generalisation of results will thus be improved if different teams in the same league are observed.

2.1.5. Activity profile

During a soccer match individuals perform a wide variety of activities ranging from light exercise to maximal sprints. The exercise pattern can therefore be described as intermittent with maximal efforts superimposed on a background of endurance exercise. Reilly and Thomas (1976) observed that a English "First Division" soccer match incorporated approximately 900 discrete bouts of activity. This figure represents a change every 5-6 s during the 90 minutes of play.

It seems the vast majority of such activities are aerobic in nature and submaximal in intensity. Critical match events, however, call for anaerobic efforts, both with and without the ball. Such efforts, though of minor quantitative importance, can determine the outcome of the match as they refer to actions such as quick moves into space to receive a pass or act as a decoy, movements to win the ball and movements with agility to go past defending players.

Whitehead (1975) reported that the largest part of the total match distance for the majority of his sample was performed while walking with jogging, striding and sprinting following numerically. This breakdown was limited as activities were arbitrarily assigned to categories with no attempts being made to identify them objectively. The data were also based on extrapolations from 10-minute sampling periods. Reilly and Thomas (1976) employing a more complex methodological technique in an attempt to ensure the objectivity of their data produced broadly similar proportions with jogging and walking being the dominant exercise activities. Video recordings were made of the player during the game in conjunction with the experimental method. Activities were analysed from the recordings post-game according to the classifications utilised during the live analysis. Jogging and walking explained 36.8 % and 24.8 % of the total distance covered with cruising and sprinting accounting for 20.5 % and 11.2 %, respectively. Data from Yamanaka et al. (1988) showed similar levels with regard to the lower intensity classes (walking/jogging 83-88%) for Japanese players but smaller figures for the high intensity work (run/sprint 7-10 %). Reilly and Thomas (1976) also included the backing and sideways movements of players in their analysis. Such activities accounted for 6.7 % of the total distance. Mean cumulative time standing still was 143 s (range 19-455 s) for the players notated with the mean duration of each rest pause being 3.2 s.

Withers et al. (1982) found that Australian professional players remained static for up to 60 s less than the players studied by Reilly and Thomas (1976) who displayed a mean value of 85 s. Players covered a similar percentage of the total distance walking (31.4 %) and jogging (47.1 %) as the English players. These figures become even closer when allowance is made for the addition of backing movements to both classes for the data relating to the Australian players. The high intensity efforts (striding and sprinting) accounted for 18.8 % of the total distance covered. This is a substantially smaller figure than that observed in English professionals (Reilly and Thomas, 1976) and may reflect environmental and tactical differences between the two samples.

Bangsbo and Lindquist (1992) defined high intensity distance as being a combination of moderate speed running (15 $km.h^{-1}$), high speed running (18 $km.h^{-1}$) and sprinting (30 $km.h^{-1}$). A mean figure of 2.1 km (0.6-3.8 km) was covered by the players in this cumulative category, a value which is almost identical to that reported by Withers et al. (1982) yet still smaller than the 2.8 km for English players (Reilly and Thomas, 1976). Bangsbo et al. (1991) found no intra-individual differences between games in the high intensity distance, concluding that the observation of one match could provide an accurate assessment of the high intensity activity of an individual player. This then may act as a better comparison between players than the total distance covered during a match. Comparisons with other studies may still suffer from problems relating to the classification of actions and method of analysis employed (Bangsbo et al., 1991). The Danish players studied by Bangsbo et al. (1991) were examined in relation to the time spent in each activity rather than the distance covered in various activities. Players changed activity approximately 1179 times, though this figure is partly a reflection of the larger number of exercise categories employed in the analysis. Players were again found to spend the majority of the game walking (mean and S.E., 40.4 ± 1.6 %) and performing low intensity running (35.1 %), a category made up of jogging (16.7 ± 2.3 %), low speed running (17.1 ± 2.5 %) and backing (1.3 ± 0.3 %). High intensity activities accounted for 8.1 % of the total time and was composed of moderate speed running, high speed running and sprinting in the percentages of 5.3 ± 0.4 %, 2.1 ± 0.2 % and 0.7 ± 0.1 %. Players were found to stand still for 17.1 ± 1.5 % of the game. In terms of time, the mean ratio between high speed running, low speed running and standing /walking for the Danish players was 1:4.3:7.1. These figures are comparable to the 1:7 high intensity to low intensity ratio (low intensity = all other activities) observed by Mayhew and Wenger (1985) and the 1:5:3 sprint:jog:walk ratio stated by Brooke and Knowles (1974).

Reilly and Thomas (1976) showed English professional players sprinted on average once every 90 s. This was reduced to a figure of one sprint every 4-5 minutes for Danish players (Bangsbo et al., 1991). This difference may be the result of discrepancies in tactics and styles of play between the samples of players analysed in the two studies. Such bouts are short in duration both in terms of distance and time (e.g. mean distance 22.4 m, mean duration 3.7 s; Withers et al., 1982). Brooke and Knowles (1974) undertook a more detailed analysis of sprinting by examining the frequency and distance of high intensity bouts. The average sprint distance was found to be 10.4 ± 3.1 m with the mean longest sprint being 24.2 ± 8.5 m. These figures are less than those for the Australian players observed by Withers et al. (1982) though the notation system used by Brooke and Knowles (1974) probably did not produce highly accurate results due to the insensitivity of the methods. Reilly and Thomas (1976) and Bangsbo et al. (1991) found average sprint distances were between 15-17 m. Such small discrepancies probably reflect slight methodological differences between the studies.

Imposed on an individual's activity profile are the games skill elements. These elements reflect the players' direct involvement in play (Reilly, 1994). Such skills incorporate a wide variety of actions ranging from throw-ins and corner kicks to tackles, passes, shots and headers. Reilly and Thomas (1976) found that outfield players were in possession of the ball for 1.73 % of the total distance covered (range 0.26-4.0 %). Such figures may represent an underestimation of the players' direct involvement in the game as they represent the distance covered with the ball as opposed to an indication of the engagement in simple contacts. Frequency counts have been employed in an attempt to analyse the occurrence of specific match actions (e.g. controlling the ball, heading, passing). Based on such analysis the mean numbers of headers and tackles can be seen to be 8.9 and 10.9 for

Danish players (Bangsbo et al., 1991), 9.9 and 13.1 for Australian players (Withers et al. 1982) and 9.0 and 14.0 for Swedish players (Ekblom, 1986). Withers et al. (1982) provided a more comprehensive analysis of the games skill elements, stating that only half of the total of the 51.4 ± 11.4 ball contacts are with the foot (26.1 ± 12). This leads to an estimation of around 2.3 contacts being made with the thigh and chest. Frequency counts were also made for both turns (49.9 ± 13) and jumps (9.4 ± 6.5).

Such data become more meaningful when examined in relation to the success rates of different skills in game contexts. Reilly and Holmes (1983) studied one non-professional team over six games on their home pitch to analyse the execution of game skills. The pitch was divided into three zones - attack, defence and midfield, with cues used on and alongside the pitch to estimate distance. The greatest requirement placed on players was in terms of passing and controlling the ball with heading, tackling and dribbling following in order of frequency. Success rates were lowest for heading and shooting with passing and controlling being the most successful. The most passes were made in the midfield area of the field with tackling being most frequently observed in the defending third and dribbling being seen to be an attacking function. For all the skills recorded it was observed that the success rate diminished as play moved from the field's defensive to attacking third. This is a reflection of the increasing pressure placed on players by opponents as play moves to the field's "danger areas". Space available to players decreases with increasing distance from their own goal line, thus necessitating quick responses and execution of skills. These factors contribute to the increased incidence of errors.

In summary, soccer can be categorised as an intermittent sport in which brief high intensity exercise bouts are superimposed on a background of endurance running. This pattern is replicated irrespective of the population examined. Research indicates that the high to low exercise intensity ratio, based upon the time spent in high and low intensity activities, is around 1:7. This would emphasise the dominance of the aerobic system for energy provision. The anaerobic contribution to the energy demands of match-play should not be under-emphasised as it is primarilly concentrated around critical match events. Analysis of the skill elements in the game reflect an individual's direct involvement in play. Only about 2 % of the total distance covered is performed in possession of the ball with the greatest demands relating to both controlling and passing it. This indicates that the majority of the work-rate demands in soccer are associated with work "off the ball" to create space, win possession or support team-mates.

2.1.6. Factors affecting work-rate

2.1.6.1. Positional role

According to Ekblom (1986) a players' work-rate is determined by the individual's physiological and psychological profile with differences being observed between individuals within a team, for players between games and finally between teams. Reilly and Thomas (1976) and Bangsbo et al. (1991) have demonstrated the effect that positional role can have on the total distance covered and the work-rate profile of professional players. The midfield players in the work of Reilly and Thomas (1976) covered a significantly greater distance (9805 ± 787 m) than players in any of the other positional roles. Bangsbo et al. (1991) showed that the highest value for midfield players was a direct result of an increased amount of low intensity activity as no positional differences were found for high intensity work. The increased amount of low intensity acitivity can be attributed to the "link" function of midfield players as they serve both an offensive and defensive role in the team. Fewer tactical limitations may be placed upon them than on the other playing positions giving them a more flexible role than forwards or defenders and therefore an increased chance to utilise their physical capacities. Central defenders were shown by Reilly and Thomas (1976) to cover the least distance of any of the outfield positions though these players exhibited the greatest jump frequency per game, suggesting that for them anaerobic power may be more important than endurance capacity. Bangsbo et al. (1991) found strikers performed more headers than defenders, suggesting a high anaerobic power output is also important for forward players. Central defenders have also been shown to cover a relatively higher percentage of their activities in backward and sideways movements than players in other positions (Reilly, 1994). Full backs displayed the largest variance among positions in the total distance covered (Reilly and Thomas, 1976). This was believed to be a consequence of the tactical flexibility applied to full backs in each game with lower values being recorded when the individual was directly confronted by an attacking opponent and higher values being seen in a player who had been converted from a midfield role.

The goalkeeper's profile includes voluntary movements in addition to those involved directly in game demands. Such activity according to Reilly (1994) serves not only to maintain concentration and arousal but also to support body temperature within the thermal comfort zone in winter conditions. Despite this, goalkeepers are directly involved in play more than any other player receiving the ball on average 24 times from defenders and distributing it into play 67 times when combining kick outs and throws (Reilly and Thomas, 1976). Sprints were infrequent, occurring approximately 7 times in the mean total distance value of 3972 m. A far greater proportion of the activity profile was spent backing (25.6 %). Time spent stationary was greatly increased in goalkeepers. This amounted to 776 s made up of 252 separate pauses. It should be noted, however, that these figures were produced before the 1992 rule changes prohibiting the pick-up of the back pass. Small alterations in data under the present conditions may be expected. Rico and Bangsbo (1993) looked at the involvement of goalkeepers before and after the rule changes. Goalkeepers were found to receive 28 passes and be in possession of the ball a total of 6.1 minutes before the rule changes compared to receiving 8 passes and being in possession 1.5 minutes after. More changes in the games regulations regarding the goalkeeper's contact with the ball are schedulded in the next few years, most notably a time limit of 6 s in possession of the ball. These changes by the world's governing body (FIFA) will probably further affect the goalkeepers involvement in play.

Ekblom (1986) has found that the ratios of rest to high intensity periods varied with playing position on the field. The main difference between players was the total distance covered at maximum speed as opposed to the total distance covered during the game. Reilly and Thomas (1976) found that the overall distance covered sprinting was significantly more for strikers and midfielders than for both full backs and central defenders. Ekblom (1986) also investigated the effects of level of play on the work-rate profiles of players by looking at four Swedish teams from different leagues and a group of recreational players. Players all covered similar distances of around 10 km with no difference been observed between any of the positions. Recreational players also covered the same distance per unit time as the professionals. Differences were observed between levels of play with longer and more frequent high intensity bouts being observed in the higher divisions. Lower level players therefore seem to cover a larger proportion of the total distance at lower intensities than players from higher divisions. Bangsbo (1992) supported these findings in Danish First Division players who performed more moderate speed, high speed and sprinting bouts than Danish Second Division players. Reilly (1994) claimed that players at lower levels of play are much more reluctant to make runs to support a colleague in possession of the ball. This also results in rest breaks being more frequent and of a longer duration. Differences in work-rate profiles also reflect the superior conditioning of players as aerobic fitness tends to improve with competitive level thus enabling the requirements of working "off the ball" to be fulfilled. Yamanaka et al. (1988) have shown a lower frequency of sprinting in players in the European-South American cup match than Japanese professional and college players. These results were interpreted by the researchers to indicate how efficiently these top class players move and manoeuvre with the ball. This would help prevent excess high intensity bouts in order to regain possession of the ball if it is lost. The data of Ekblom (1986) probably did not reflect this trend as all the players included in the study were of a sufficiently high skill level to prevent consistent errors in ball control.

2.1.6.2. Style of play

It has already been noted that individual work-rate profiles of players may partly reflect the tactical restrictions placed upon them by the coach. Similarly the style or the system of play adopted by the team may determine both the overall work-rate and the details of its component parts (Reilly, 1994). For example the "direct method" of play utilised by the Republic of Ireland team under its manager Jack Charlton and the "total" football style such as that adopted by the Dutch national team of the seventies may serve to equal out the work-rate profiles among outfield players : the reason is because forward and defensive players are required to maintain a high work-rate when not directly involved in play in order to dispossess opponents, create space and receive passes and to cover team-mates. Increased demands are thus placed on an individual's aerobic fitness, irrespective of the positional role in this style of play (Reilly, 1996).

2.1.6.3. Fatigue

Towards the end of the game general muscle fatigue may occur as a result of the activities previously performed in the match. Players may be able to exercise at low intensities but have a reduced ability to perform maximally. Such performance decrements are often related to a reduction in muscle glycogen levels (Bangsbo, 1994b). Nutritional status may also play a role as low muscle glycogen levels affect an individual's capacity to maintain work-rate over the 90 min period. Saltin (1973) found a 25 % reduction in the distances covered during the second half in players who started the game with low muscle glycogen levels. These differences became more marked when examined in relation to the running speeds involved. Players with the low muscle glycogen covered half the total distance walking and 15 % at maximum speed compared to 27 % walking and 24 % sprinting for the players with initial normal concentrations.

Significantly smaller distances were covered by 32 of the 44 English players in the second half compared to the first in the work of Reilly and Thomas (1976). These findings were supported by Van Gool et al.(1988) who observed a 444 m decrement for university players in the second half. This reduction is in the order of 5 % decrease observed for elite Danish players (Bangsbo et al. 1991). The decline was due largely to a reduction in low intensity activity.

Reilly and Thomas (1976) found a link between the fall in work-rate and aerobic fitness, in terms of maximal oxygen consumption ($\dot{V}O_2$ max), for individual players. Central defenders and forward players covered significantly reduced distances in each half compared with the midfield players and fullbacks. Midfielders and fullbacks did not show such a drop in performance and possessed higher $\dot{V}O_2$ max values than the other positions.

By far the best performance indicator in soccer is the match result. Reilly (1994) used figures from the Scottish league to demonstrate that the vast majority of goals are scored during the final 10 minute period of games. This phenomenon may be due in part to the decline in work-rate observed during the second half of match-play as more space may be available to attacking players to capitalise on defensive errors or inadequate marking.

Differences in the work-rate profiles of players exist between the first and second halves of match-play. The evidence for such a reduction is not conclusive. This indicates the need for experimental investigations into the effects of repeated intermittent exercise on subsequent performance.

2.1.6.4. Environment

Ekblom (1986) stated that the reductions in performance associated with prolonged match-play are further compounded by environmental factors. Hot conditions (air temperature > 30 °C) when combined with high humidity can result in the maximum speed distance of players being reduced by approximately 50 % (900 m to 500 m) when compared to performance at a temperature of 20 °C. Reilly (1994a) believed such performance decrements to be the result of factors such as increases in core temperature, dehydration and ineffective sweat production. A full discussion of the physiological responses to exercise in high ambient temperatures, and the factors that affect performance are provided in section 3.4 of the review of literature. Such considerations are particularly relevant when the number of major competitions (e.g. the World Cups in 1990, 1994) that are played in hot conditions are noted.

Exercise in the cold does not have the same effects. The major problems posed by this climatic variations are associated with pitch conditions (Reilly, 1996). Hard surfaces may promote work-rate yet impair sport specific skills such as accelerating, tackling and dribbling. Safety implications of playing in the cold are also an important consideration as the risk of injury may be increased due to low muscle temperature or slipping due to unsuitable footwear or a wet surface.

Impairments in VO_2 max as a result of playing at altitude also lead to changes in work-rate profiles. Bangsbo and Mizuno (1988) tested Danish national players in a pressure chamber under conditions corresponding to an altitude of 2550 m above sea level. This is a comparable value to Mexico city (2.3 km), venue for the 1970 and 1986 World Cup finals. Heart rate, blood lactate and ventilatory response to a standardised intermittent exercise test performed on a cycle ergometer were 5, 16 and 19 % higher than values obtained at sea level. Such changes will lead to the preferred work-rate in matches being reduced.

It is clear that an individual's preferred work-rate will be compromised under conditions of environmental stress. Little information is available regarding the factors that affect soccer-specific intermittent exercise performance at increased ambient temperatures despite the importance of such information to the soccer playing population. An understanding of such factors may be provided by examining the energy provision for soccer match-play.

2.2. ENERGY PROVISION FOR SOCCER MATCH-PLAY

Physiological responses to match-play indicate that a variety of demands are placed on the individual participant during soccer games. The majority of match activities are performed at a low or sub-maximal level and tax predominantly the oxygen transport system while critical phases of play call for anaerobic efforts, both with and without the ball. The ability to develop high power outputs (force) in single match situations is also important as the performance of match activities e.g. tackling, kicking is dependent on such factors. The following sections will outline the available literature regarding the aerobic and anaerobic contributions to match-play. Substrate utilization during matches will also be reviewed.

2.2.1. Aerobic energy production

The capability to endure high work-rates is important in soccer. Attempts have been made to assess directly the aerobic contribution to match-play by measuring oxygen uptake. Ogushi et al. (1993) examined the actual oxygen uptake for two players during a game. Values of around 35 to 38 $ml.kg^{-1}.min^{-1}$ were observed. The values produced by such methods are probably not representative of the actual $\dot{V}O_2$ values during real match-play as the collecting procedure interferes with normal play and only small parts of a game have been analysed. Portable telemetry systems such as the K2 (Cosmed, Italy) have recently been employed in an attempt to overcome some of the problems associated with the gas collecting procedure. Kawakami et al. (1992) assessed the $\dot{V}O_2$ as a result of performing various soccer activities such as dribbling - both opposed and unopposed- and kicking and passing. Dribbling produced the highest $\dot{V}O_2$ values of around 4 $l.min^{-1}$ with drills such as 1 vs 1 and 3 vs 1 eliciting values of between 2 and 4 $l.min^{-1}$.

A more usual approach to determining the aerobic contribution to the energy expenditure during match-play is to monitor heart rate (HR) continuously and subsequently estimate energy expenditure from the individual's HR-$\dot{V}O_2$ relationship obtained during an incremental exercise test in the laboratory. The HR measurements can be made without any restrictions on the player and as a result may represent a more exact picture of the contribution of the aerobic energy system in soccer. Mean HR values obtained for male soccer players have ranged from 157 beats.min^{-1} for English players in friendly games (Reilly, 1986) to 175 beats.min^{-1} for a single Swedish player during a match (Agnevik, 1970). Mean HR values vary with respect to the period of the game when observations are made. Van Gool et al. (1988) recorded mean HR of 169 and 165 beats.min^{-1} for the first and second half of play respectively for a Belgian university team in a non-competitive match. Such a trend was also found for 6 Danish players (Bangsbo, 1994). Mean HR during the first half was 164 beats.min^{-1} with a 10 beats.min^{-1} reduction in the second half. Such values represent a substantial load on the cardiovascular system. Rohde and Espersen (1988) examined the percentage of playing time during a match that the HR was higher than 73 % of maximum. The HR of the players in their sample was between 73 and 92 % of maximal for 63 % of the time (57 minutes) and higher than 92 % of maximal for 26 % of the time (23 minutes). The heart rate response in the second half may not, however, reflect the decline in work-rate as HR may be maintained as a consequence of thermal stress and cardiovascular drift despite the decline in work-rate (Florida-James and Reilly, 1995)

Mean values of around 75 % of $\dot{V}O_2$ max have been attributed to soccer by estimating $\dot{V}O_2$ from HR observations during match-play (Ekblom, 1986). Such methods provide a indirect indication of aerobic energy production and, as a consequence, problems relating to the transformation of HR to $\dot{V}O_2$ need to be considered. Bangsbo (1994a) outlined some of the difficulties involved in the transformation of HR to $\dot{V}O_2$, stating that HR does not always reflect the actual $\dot{V}O_2$ during exercise. The HR will be elevated beyond the normal HR- $\dot{V}O_2$ relationship during static contractions, under emotional and thermal stress and during exercise with small muscle groups. It has also been suggested that the HR- $\dot{V}O_2$ relationship is altered after sprint running (Balsom et al., 1991). Bangsbo (1994b) claimed that such activities are observed infrequently in soccer, resulting in only very short periods of time when the HR- $\dot{V}O_2$ relationship is different from that obtained in the laboratory. The relationship is most often obtained from continuous submaximal treadmill running. Such a relationship may not be a valid expression of the two variables when the exercise pattern is intermittent, as occurs during soccer match-play. Such problems probably lead to an oversetimation of the $\dot{V}O_2$ involved in match-play. It appears, therefore, that this overestimation is relatively small and that the mean relative work-rate should still be around 70 % of $\dot{V}O_2$ max (Reilly, 1990).

The maintenance of such high work-rates during soccer match-play is primarily the result of the performance of energy demanding activities. Accelerations, decelerations, changes of direction, kicking, dribbling and tackling should all raise the energy cost of the activity. The effect of such activities upon the physiological load imposed on players was assessed indirectly by Bangsbo (1994). Players were videotaped during a non-competitive match for 4 x 5 minute periods. Heart rate was also assessed during the playing periods by means of short range radio telemetry. Each player then performed four exercise bouts on a treadmill, which corresponded to the pattern of running observed during the match. Blood lactate and mean HR during the treadmill runs was reduced compared to match-play. The $\dot{V}O_2$ were also reduced to about 70 % of that estimated from the HR- $\dot{V}O_2$ relationship obtained during the match. It was thus concluded that the higher values obtained during the game were a direct consequence of the energy demanding activities not included during treadmill running.

Attempts have been made in laboratory settings to quantify the additional demands of game skills, such as dribbling. Reilly and Ball (1984) examined the physiological responses to dribbling a football on a treadmill for 5 min periods at speeds of 9, 10.5, 12 and 13.5 $km.h^{-1}$. The energy cost of dribbling was found to increase linearly with running speed. The added cost of dribbling the ball was constant at 5.2 $kJ.min^{-1}$. Such increases may be the result of alterations in stride rate and stride length as increasing or decreasing the stride length beyond that freely chosen by the individual has been shown to lead to increases in oxygen consumption for a given speed (Cavanagh and Williams, 1982). Reilly and Bowen (1984) examined the extra energy cost of unorthodox directions of movement, e.g. backwards, sideways, at treadmill speeds of 5, 7 and 9 $km.h^{-1}$. The extra energy cost increased disproportionately with speed, with no differences observed in terms of the energy expenditure or the rating of perceived exertion between backwards and sideways running.

Another possible reason for the high energy demands during a soccer match despite the low relative work intensity is the intermittent nature of the exercise performed during soccer. The physiological responses to intermittent exercise have been examined and compared to continuous work at the same average intensity in an attempt to evaluate the differences between the exercise patterns (Astrand et al., 1960; Christensen et al., 1960; Edwards et al., 1973; Essen, 1978). Edwards et al. (1973) examined the physiological responses to intermittent and continuous exercise performed on a cycle ergometer. Subjects performed either 10 s or 30 s exercise periods interspersed with 30 s recovery periods at 100 % of the maximal work-rate and a continuous test for the same total time at the same average power output corresponding to either 25 % or 50 % of maximal work-rate. Measurements were made throughout the 12 min exercise session and a 30 min recovery period following exercise. Mean HR, minute ventilation, respiratory exchange ratio and oxygen consumption during the exercise were all increased in the intermittent exercise session over the mean values for continuous work. The total HR, minute ventilation and oxygen cost were also found to be greater during the intermittent exercise. The greatest amount of difference between the two exercise modes was during the recovery periods. The increased oxygen consumption during recovery was linked to the repletion of oxygen stores used during the preceeding bouts, the repletion of muscle phosphagen stores and the oxidation of lactate while the increased HR and minute ventilation were related to the increased oxygen consumption.

Nevill et al. (1994) found significant increases in HR, oxygen consumption, blood lactate levels and ammonia during intermittent exercise compared to continuous exercise at the same average intensity. Their protocol provided a much better representation of the activity profile observed in soccer than the previous investigations into intermittent exercise. The intermittent protocol consisted of 30 min of repeating cycles of 90 s activity at 40 % $\dot{V}O_2$ max followed by a 6 s sprint and 24 s passive rest.

The duration of the exercise and rest periods is important in determining the physiological responses to intermittent work as oxygen consumption, minute ventilation and blood lactate levels have all been shown to be sensitive to changes in exercise:rest ratios (Christensen et al., 1960b). The sensitivity of the physiological responses to factors relating to the intensity and duration of exercise makes it difficult to generalise further from the results than the contribution of variables studied in each experimental protocol (Ballor and Volovsek, 1992). Such factors make it difficult to evaluate the extra physiological costs of intermittent exercise over continuous exercise sessions.

Exercise performance is associated with an increased metabolic heat production in skeletal muscle. This increase in heat production results in a linear increase in core temperature as a function of relative exercise intensity (Saltin and Hermansen, 1966). Smodlaka (1978) reported mean rectal temperatures of 39 ^{o}C for players at the end of a match. Ekblom (1986) noted mean ± s.d. higher rectal temperatures for Swedish First Division players over 6 games (39.5 ± 0.3 ^{o}C). Slightly lower rectal temperatures were observed for players from three lower divisions (39.2 ± 0.4 ^{o}C, 39.1 ± 0.4 ^{o}C and 39.0 ± 0.4 ^{o}C). Such temperatures are consistent with a work-rate of 70-80 % VO_2 max when the loss of fluid, without a concomitant increase in energy consumption, is taken into account (Ekblom et al., 1970).

Determinations of aerobic energy expenditure during match-play display large inter-individual variation (Reilly, 1994). The aerobic energy production is affected by such factors as physical capacities, position in the team and motivation. Despite this variability the mean relative work-rate of soccer is around 75 % of $\dot{V}O_2$ max. This high energy demand is a consequence of the performance of specific match activities such as ball contacts. The intermittent exercise pattern associated with the game may also increase the energy cost of exercise. Little information is, however, available relating soccer-specific intermittent exercise patterns and continous exercise at the same average intensity.

2.2.2. Anaerobic energy production

Sprinting occurs approximately once every 90 s during a game, with each sprint lasting a mean duration of around 2 s (Reilly and Thomas, 1976). Other match activities e.g. jumping, tackling also add to the anaerobic energy cost. A substantial amount of the energy for such activities during game play is provided by the degradation of creatine phosphate (CP) and the stored adenosine-triphosphate (ATP) as a result of the shortness and infrequency of such actions. The remaining anaerobic energy demands are fulfilled by glycolysis. Glycolysis makes a significant contribution to the energy demands of short-term exercise. Boobis (1987) has shown glycolysis and phosphagen breakdown each accounts for approximately half of the anaerobic energy production during 6 s maximal exercise. A similar contribution from phosphagen breakdown and glycolysis was also noted for 6 s maximal sprints performed on a cycle ergometer (Gaitanos et al., 1993). With longer durations glycolysis increases in its contribution to around 64 % of the total demand (Cheetham et al., 1986).

In view of the duration and infrequency of the exercise bouts during soccer, a large amount of the anaerobic energy production results from degradation of CP and to a lesser extent ATP. The CP stores can supply energy during maximal exercise for only a few seconds. Continual resynthesizing is therefore needed to ensure the maintenance of performance as depletion of CP leads to muscle fatigue. Concentrations of CP have been shown to alternate continuously in intermittent exercise protocols. Bangsbo (1994) examined the effects of a 6 min intermittent exercise bout on CP concentrations using nuclear magnetic resonance. The intermittent exercise period was separated into 3 x 2 min repetitive bouts and contained activities similar in intensity and pattern to those observed in soccer. Concentrations of CP decreased during the maximal contractions yet had almost re-attained pre-exercise levels at the end of the 2 min intermittent exercise period. The results indicate the importance of CP as an energy buffer during intense periods of exercise even though the net utilisation of CP is quantitatively small.

The severity of exercise during soccer may be indicated by measurement of blood lactate concentrations as it provides an indication of the anaerobic lactacid contribution to metabolism (Ekblom, 1986). Difficulties in obtaining samples during competitive events have led to the majority of samples being collected at half and full-time. Agnevik (1970) found a mean blood lactate concentration of about 10 $mmol.l^{-1}$ when studying Swedish First Division players. Ekblom (1986) studied players from all four Swedish divisions finding values of 9.5 and 7.2 $mmol.l^{-1}$ for first and second half play in First Division players. Such values are above that which can be sustained continuously and hence reflect the intermittent activity of the sport. The concentrations were reduced in players from the lower divisions with values of around 4.0 $mmol.l^{-1}$ being observed for players in the Fourth Division. These reductions are probably the result of the lower total distance covered in high intensity activity in the lower divisions (Ekblom, 1986). Lower blood lactate levels have been found in several studies for second half play compared to first half (Rohde and Espersen, 1988; Gerisch et al., 1988). Such reductions in blood lactate concentrations could be the result of a decline in the total distance covered by players at a high intensity. It is, however, difficult to make conclusions regarding the changes in work-rate profile and hence the anaerobic energy demands of players based purely on blood lactate determinations. Large variations in blood lactate concentrations have been observed between games and for the individuals during the same game (Bangsbo et al., 1991). Blood lactate concentration represents the balance between production, release and removal (Weltman, 1985). Muscle is capable of both producing and removing lactate simultaneously (Jordfeldt, 1970) with the net output of lactate from the muscle being time dependent and regulated by the exercise intensity. Lactate will be metabolised within the active muscle following maximal exercise (Boobis, 1987) with the rate of removal being elevated if low intensity activities are performed during recovery (Hermansen and Stensvold, 1972). The lactate produced and released in the blood is also taken up by inactive muscles (Ahlborg, 1985) and tissues such as the heart, liver and kidney (Astrand et al., 1986). Measurements of concentrations in the blood therefore offer little information about the rates of blood lactate appearance due to the metabolite's simultaneous production and removal. This has led to the relevance of blood lactate as an indicator of lactate production being questioned, since not all of the lactate produced in the muscle will appear in the blood (Jacobs and Kaiser, 1982).

Single blood lactate determinations cannot therefore be considered to be representative of lactate production during an entire match as the sample merely reflects lactate production in the short period prior to sampling (Bangsbo, 1994). The data do nevertheless suggest that lactate production during match-play may be high at certain times, indicating the importance of energy provision at a very high rate during intense periods of activity.

Blood ammonia/ammonium levels are also elevated during match-play (Bangsbo, 1994b). The release of this substance is a direct function of the amount of high intensity exercise performed as a result of an impairment in the capacity to rephosphorylate adenosine di-phosphate. Accumulation is not observed until exercise intensities over 70 % VO_2 max are reached (Sahlin and Broberg, 1990). Such findings therefore imply the performance of intense periods of activity during a game. This is further supported by the findings of lower ammonia concentrations during the second half of play when compared to first half values as a consequence of the lower number of high intensity activity periods observed during the second half (Bangsbo, 1994a).

2.2.3. Substrate utilization

Responses to match-play reflect the variety of demands that are placed on the individual during the game. During exercise, carbohydrates and lipids are important for oxidative metabolism (Hargreaves, 1994) with the relative dominance of each substrate been dependent upon the intensity and duration of exercise. Increases in the intensity of exercise cause a greater reliance on carbohydrate utilisation with increases in exercise duration leading to a greater contribution from lipids. Protein metabolism has also been shown to play a role in exercise performance (Lemon, 1991) but its overall contribution tends to be small (Wagenmakers et al., 1991). No evidence is available regarding the role of protein in soccer; it seems carbohydrate and fat, either stored within the muscle or delivered via the blood, are the dominant substrates for metabolism (Bangsbo, 1994). Muscle glycogen and carbohydrate metabolism have been shown to play a crucial role in energy provision in intensive work of long duration or when repeated intensive exercise is performed (Karlsson and Saltin, 1971).

2.2.3.1. Carbohydrate metabolism

The consumption of carbohydrate during soccer has been evaluated by the examination of blood glucose and muscle glycogen levels after match-play or laboratory based intermittent protocols. The data from such studies suggest a heavy reliance on muscle glycogen during performance (Hargreaves, 1994). Saltin (1973) observed a similar response in muscle glycogen levels as a result of playing a match. The mean glycogen levels from the thigh muscle (M.vastus lateralis) of 5 players were 96, 32 and 9 mmol.kg^{-1} wet weight before, at half time and at the end of the game. A further 4 players who started the game with low muscle glycogen levels (45 mmol.kg^{-1} wet weight) were also studied. The muscle glycogen for these 4 subjects was almost depleted before half-time. Bangsbo (1994) claimed that the difference in the glycogen content of the muscle before and after the game represents the net utilisation of muscle glycogen as opposed to the total turnover as resynthesis probably occurs during the rest and low intensity periods. Jacobs et al. (1982) have demonstrated that muscle glycogen stores are not always empty at the end of the game. A mean glycogen concentration of 46 mmol.kg^{-1} wet weight was noted for 15 players at the end of a match. Glycogen content, however, varies between muscle fibres thereby providing the possibility of a number of fibres being depleted despite the average concentration being quite high (Bangsbo, 1994a). The information regarding the utilization of substrates in match-play can be supplemented by examining the substrate utilization during intermittent exercise. High intensity running has been proposed as a suitable model for the study of physiological and metabolic responses of soccer. Cheetham et al. (1986) reported that a significant reduction in muscle glycogen occurred during a 30 s maximal sprint performed on a non-motorised treadmill, thereby illustrating the importance of muscle glycogen in supporting high intensity exercise performance. Glycogen breakdown has, however, been shown to be reduced in the later bouts of exercise when bouts of high intensity work are repeated (Gaitanos et al., 1993; Spriet et al., 1989; Karlsson and Saltin, 1971; McCartney et al., 1986). The mechanism for this reduced muscle glycogen utilization is not clear though the down-regulation of glycogen phosphorylase activity by increasing levels of hydrogen ions has been proposed (Spriet et al., 1989).

The liver seems to release enough glucose to maintain and even elevate the blood glucose concentration during a match (Leatt and Jacobs, 1989). Maintainence of normal blood glucose levels may have a favourable effect on performance as they have been shown to prolong time to exhaustion and help maintain power output in the later stages of prolonged intermittent exercise (Shepard, 1992). Ekblom (1986) believed this situation persists as long as liver glycogen and glucose precursors are available. Bangsbo (1994) observed higher blood glucose concentrations during a competitive match than at rest with no player having values below 4 $mmol.l^{-1}$. Concentrations obtained after completion of a game have tended towards the lower end of the normal resting response and have ranged from 3.2 to 4.5 $mmol.l^{-1}$ (Bangsbo, 1994a).

In summary, large reductions in muscle glycogen concentrations as a result of match-play demonstrate a reliance on carbohydrate metabolism to support the exercise. Depletion of muscle glycogen stores is not thought to be complete at the end of 90 minutes. Evidence exists to indicate that depletion may be present in selected fibres. The reliance on carbohydrate stores is, however, reduced as intermittent exercise is repeated though the mechanism for this down-regulation is not clear.

2.2.3.2. Fat oxidation

As duration of exercise increases, the contribution from lipids increases (Romijn et al., 1983). The major lipid substrates are plasma free fatty acids (FFA), mobilised from adipose tissue reserves, and intra-muscular triglycerides (TG). Data are sparse regarding lipid metabolism during actual soccer match-play though data from laboratory based studies suggest that fatty acids and triglycerides are used as well as the endogenous carbohydrates reserves (Hargreaves, 1994). Essen (1978) demonstrated triglyceride degradation and uptake of FFA as well as degradation and uptake of glycogen and glucose during intermittent exercise performed on a cycle ergometer in 15 s exercise and rest periods for a duration of 60 min. These findings would suggest that the delivery and uptake of oxygen are increased enough for FFA oxidation to provide an important source of energy provision during intermittent exercise. Keul et al. (1974) examined the effects of the length of the exercise and rest periods on the utilization of FFA during intermittent work. With brief exercise intervals (2 min) changes in arterial FFA levels were small compared to those associated with longer exercise intervals (4 min). This would suggest that FFA utilization is increased with increasing exercise duration.

The FFA concentration in the blood is the net result of the uptake of FFA in various tissues and the release of fatty acids from the adipose tissue. Bangsbo (1994) has shown that FFA concentration in the blood is increased during a competitive soccer match. The increased levels are probably the result of an elevated blood flow to the adipose tissue, as a result of frequent rest and low intensity exercise periods promoting a high FFA level. Free fatty acid concentrations are further increased during the second half of match-play. Such increases can be explained by the decline in work-rate observed during the second half of games and the elevated catecholamine levels associated with match-play.

Glycerol is liberated when FFA are mobilised from triglycerides. Plasma glycerol levels have also been observed to increase to almost 500 % of resting level following the fourth bout of intermittent isokinetic maximal intensity cycling (McCartney et al., 1986). Subjects performed four 30 s periods of maximal exercise separated by 4-min periods of recovery. Such metabolic responses reflect an increased use of intramuscular triglycerides stores and probably help in the maintenance of exercise performance after the decrease in glycogen utilization observed during intermittent work.

Only minor increases have been noted in glycerol concentration during games (Bangsbo, 1994). This is in contrast to the marked elevation observed in continuous exercise (Kjaer et al., 1988). Glycerol levels are not found to increase during match-play as a result of uptake in various tissues, primarily the liver. High splanchnic blood flow in the recovery periods results in glycerol uptake and the possibility of glycerol representing an important gluconeogenic precursor during match-play (Bangsbo, 1994).

2.3. PERFORMANCE TESTS

An indication of the importance of the aerobic and anaerobic energy systems to energy provision during soccer can also be provided by examining an individual's performance on exercise tests that attempt to quantify the aerobic and anaerobic capacities of players. Such test results may reflect a level of adaption to the stresses of the exercise and thereby provide an indication of the physiological demands of the sport. Such tests, if soccer-specific, also reflect the attempts made by previous investigators to recreate the exercise pattern associated with match-play in both laboratory and field conditions. Balsom (1994) highlighted some of the considerations that should be noted when attempting to evaluate an athlete's performance. Factors such as test selection, test administration and the interpretation of test results are all crucial considerations in performance testing. The test selected should be specific to the event as the information gained will be of no benefit to either coach or performer unless it can be applied to the sport in question. This section of the review of literature will attempt to highlight the different forms of performance assessments that have been used with soccer players to assess both aerobic and anaerobic capacities. Special consideration will be given to soccer-specific assessments.

2.3.1. Soccer-specific testing

The best overall test for a player is performance in a competitive match. It is, however, very difficult to isolate the different physical components related to soccer match-play. The most important physical factors can, however, be evaluated outside of the game using soccer-specific test programmes (Balsom, 1994).

Soccer-specific assessments can take place in either field or laboratory settings. Laboratory procedures have the advantage of controlled environments and superior forms of assessment to allow a greater depth of analysis while field protocols possess a higher degree of ecological validity and can be easily incorporated into training sessions with a minimal alteration to players' routines. The two forms of assessment can be regarded as complementary to each other as coaches can gain useful information from evaluations in the field regarding the level of performance with laboratory data providing indications of the basic physiological functions which influence the individual's ability to perform intermittent exercise (Balsom, 1994).

2.3.1.1. Assessment of aerobic function

For decades $\dot{V}O_2$ max has been deemed to be synonymous with aerobic power. Maximal aerobic power is the maximal energy output that can be produced by aerobic processes within the limitation of the functional capacity of the circulatory system (Astrand and Rodahl, 1986). Assessment takes place on a motor driven treadmill or cycle ergometer. Exercise intensity is raised progressively until the subject reaches voluntary exhaustion. Expired air is collected during the test and the oxygen consumed recorded, the highest value of which constitutes $\dot{V}O_2$ max.

Mean maximal values for male elite teams have ranged from 56 to 69 $ml.kg^{-1}.min^{-1}$ (Reilly, 1990). Such values are comparable to those observed in other team sports (Reilly, 1990) but lower than those values seen in elite endurance athletes (Maughan, 1990). Such values are in excess of those reported for the sedentary population by around 15 $ml.kg^{-1}.min^{-1}$ and hence underline the aerobic contribution to the match-play. There is a tendency for $\dot{V}O_2$ max to increase with the level of play (Ekblom, 1986). Apor (1988) provided evidence that a team's mean $\dot{V}O_2$ max could be related to playing success. A high rank order correlation was found between mean $\dot{V}O_2$ max of the individuals within the team and their finishing position in the Hungarian first division championship. Mean $\dot{V}O_2$ max for the first, second, third and fourth placed teams were 66.6 $ml.kg^{-1}.min^{-1}$, 64.7 $ml.kg^{-1}.min^{-1}$, 63.3 $ml.kg^{-1}.min^{-1}$ and 58.1 $ml.kg^{-1}.min^{-1}$ respectively.

Positional variations are observed in the data relating to $\dot{V}O_2$ max. Reilly (1979) found midfield players possessed significantly higher $\dot{V}O_2$ max values than all other positions. Central defenders exhibited the lowest scores while forward players and full backs had values that were intermediate. These findings have been replicated by Puga et al. (1993). They examined the maximal oxygen uptakes of 19 players in the Portuguese First Division. The mean ± s.d was found to be 59.6 ± 7.7 $ml.kg^{-1}.min^{-1}$ with the mean value for goalkeepers and central defenders being lower than 60 $ml.kg^{-1}.min^{-1}$ while the mean value for midfield players and forwards was above 60 $ml.kg^{-1}.min^{-1}$. Large individual variations in positions do, however, exist which makes it difficult to draw clear conclusions regarding positional role and $\dot{V}O_2$ max values (Bangsbo, 1994). These differences have been related to the differences in the distance covered by players during match-play. Both Reilly (1979) and Bangsbo and Lindquist (1992) have shown $\dot{V}O_2$ max values were significantly correlated with the total distance covered during match-play. Reilly (1979) found a correlation coefficient of 0.67 between $\dot{V}O_2$ max and the total distance covered during match-play while Bangsbo and Lindquist (1992) observed a correlation of 0.64 between the two variables. Bangsbo et al. (1991) claimed that the true physical capacity of players is seldom demonstrated during match-play as a result of the tactical restraints placed upon players during games by coaches. This is supported by modest correlations between the performance of players on a soccer-specific intermittent endurance test and $\dot{V}O_2$ max (Bangsbo and Lindquist, 1992). It may, therefore, be the case that $\dot{V}O_2$ max is not a sensitive indicator of the ability to perform prolonged intermittent exercise though it may be useful to predict performance capability during soccer match-play (Bangsbo, 1994).

Direct assessments of maximal oxygen consumption are often difficult or impractical to obtain. Indirect assessment techniques can then be employed to provide an estimation of maximal oxygen uptake. One such test that has become popular with the soccer playing population is the progressive shuttle run test (Leger and Lambert, 1982). This test involves an endurance shuttle run over a 20 m course performed in time to a series of audio signals whose pace is increased every 2 minutes. Reported estimated $\dot{V}O_2$ max (58 to 61 $ml.kg^{-1}.min^{-1}$, Brewer and Davis, 1992) on such assessment procedures are comparable to laboratory protocols, thereby indicating the usefulness of the tests as an expression of physical capacity. Dunbar and Power (1995) found little difference in estimated $\dot{V}O_2$ max values with level of play using the multi-stage shuttle run test, a trend that has been replicated with direct assessments. Senior professional players from the English Premier League possessed a mean ± s.d estimated $\dot{V}O_2$ max of 60.7 ± 2.9 $ml.kg^{-1}.min^{-1}$ compared to the 58.8 ± 3.2 $ml.kg^{-1}.min^{-1}$ observed for English players in the Third Division.

The exercise pattern in soccer is intermittent with repeated bouts of high intensity exercise being separated by periods of running at lower intensities. Continuous tests, such as the multi-stage shuttle run, though easy and quick to administer, do not adequately replicate the intermittent exercise pattern observed in the game. Tests that replicate this intermittent pattern as well as the different modes of activity should then be utilised to determine the individual's "soccer specific endurance capacity" (Balsom, 1994).

The "yo-yo" intermittent endurance test (Bangsbo, 1994c) is based on the same principle as the multi-stage shuttle run except that 5 s recovery period is permitted after every pair of 20 m shuttles. The inclusion of such a recovery period means that the test closely simulates the intermittent exercise pattern of the game. The time allowed to complete a shuttle is progressively decreased with the test being terminated when the player can no longer maintain the required speed. The aim of the subject in the test is to complete as many shuttles as possible, the score being the total distance covered in metres before exhaustion. Differences in performance have been found between positions with forwards covering less distance than centre backs or midfielders. Distances completed for the test are in the order of 1893-2360 m (Michalsik and Bangsbo, 1995).

Ekblom (1989) devised a continuous running test for soccer players that included forward, backward and "slalom" running, turning and jumping. Figure 2.3.1 is a diagrammatic representation of the test circuit. The test circuit is constructed within the perimeter of a football field. Up to 8 players can be tested at a time with players starting at 15 s intervals. The test result is the time taken to complete 4 laps of the 540 m course. Values of around 9 min have been recorded for 11 semi-professional Swedish players with a reduction in performance time being observed in the competitive season as opposed to the pre-season performance.

Bangsbo (1994c) developed another intermittent endurance test for assessment of an individual's "soccer-specific endurance capacity". The test result is the total distance covered during 40 periods of high intensity running which are performed in 15 s intervals interspersed with 10 s recovery periods. Figure 2.3.2 illustrates the test circuit employed in the intermittent endurance test and the modes of activity designated for each section.

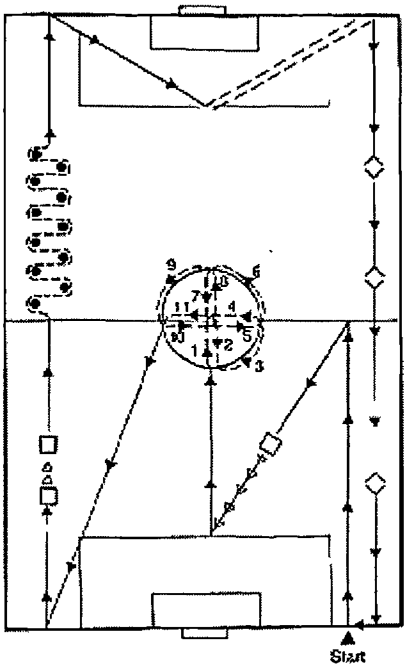


Figure 2.3.1. Diagrammatic representation of the soccer specific test devised by Ekblom (1989)

Performance in the test correlated with performance on an intermittent endurance test (r = 0.83), thereby indicating its usefulness as a predictor of an individual's soccer-specific intermittent endurance capacity (Bangsbo and Lindquist, 1992). Additionally, it elicits mean heart rate responses and blood lactate levels that are similar to those observed in periods of intense match-play (Bangsbo, 1994). The mean distance covered during the test for 41 Danish players was 1926 m (range 1688-2126) (Bangsbo, 1994c). Midfielders produced the longest distance although comparisons between positions are difficult to make as a result of a relatively small number of observations in each group.

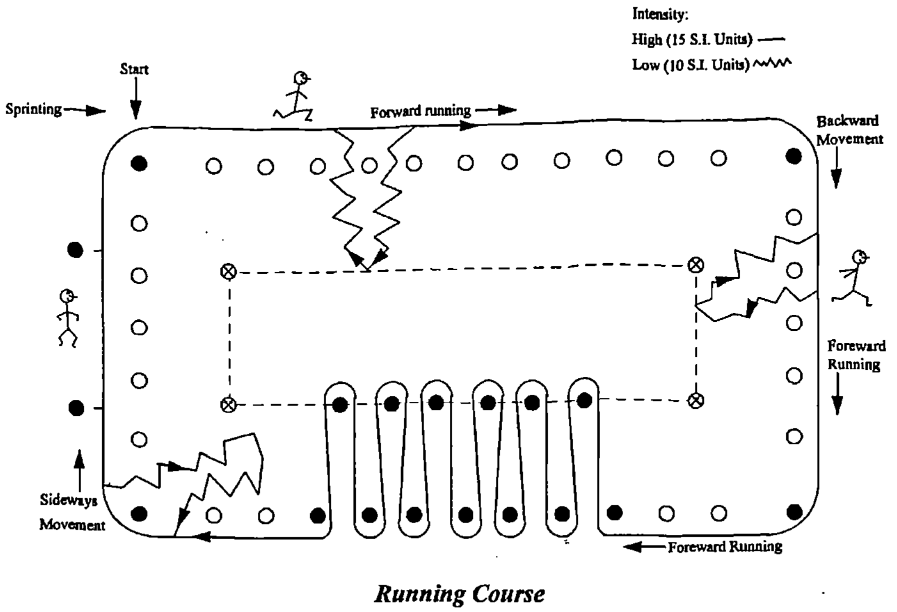


Figure 2.3.2. Diagrammatic representation of soccer specific intermittent endurance field test (Bangsbo, 1994c)

2.3.1.2. Assessment of anaerobic power

Sprinting, jumping and tackling all tax the anaerobic energy systems. The shortness and infrequency of such actions probably result in a greater emphasis being placed on the ATP-CP energy system than on anaerobic glycolysis for energy provision. An indication of the anaerobic power of soccer players has traditionally been provided by the vertical and standing broad jumps, although these assessments are not direct measurements of power. Mean values for the vertical jump test have ranged from 41-60 cm (Reilly, 1990) while a score of 219 (s.e ± 3) cm has been observed for English league players performing the standing broad jump (Reilly, 1979). Goalkeepers were found to possess the highest values with central defenders and forwards who acted as target men following. Midfielders exhibited the lowest scores, a fact that can be partly explained by the infrequent involvement of these players in jumping for possession of the ball (Reilly, 1979). Repeated jump tests as proposed by Bosco, Luhtanen and Komi (1983) have also been used to evaluate soccer players (Bosco, 1990; Kirkendall, 1985). Kirkendall (1985) using a 60 s repeated jump protocol showed professional indoor players slightly outperformed college players whose values were in turn consistent with those obtained for volleyball and basketball players.

An individual's maximum power output can also be calculated from performance on the stair run test (Margaria et al., 1966). The test involves running between two steps on a staircase, the vertical distance between which is known. Photo-electric cells are used to record the performance with the test result being the time taken to complete the run. Di Prampero et al. (1970) found sprinters, pentathletes and middle distance runners all performed better than soccer players while Withers et al. (1977) found Australian state players produced 15 % better scores than endurance trained athletes.

Soccer players must be prepared to repeat high intensity bouts of activity during match-play (Reilly, 1994b). Such activities are supported energetically by anaerobic glycolysis which implies a need for a high anaerobic capacity. The "Wingate" anaerobic test is one commonly employed tool for the determination of anaerobic power and capacity. Subjects are required to perform a 30 s all out-sprint from a rolling start on a cycle ergometer with an applied load relative to body mass. Bergh and Ekblom (1979) observed an average of 13.5 ± 1.3 $W.kg^{-1}$ for Swedish international players. The use of cycle ergometry is, however, a major limitation with measurements obtained on a treadmill constituting a much better form of assessment (Reilly, 1994b).

Rhodes et al. (1986) have utilised Cunningham and Faulkner's (1969) treadmill test to evaluate the anaerobic capacities of players. Time to voluntary exhaustion is assessed on a motorised treadmill at a speed of 12.8 $km.h^{-1}$ and an incline of 20 %. A mean running time of 92 s was reported for the Canadian Olympic team. Such tests are again not directly relevant to soccer and so may be of superficial value to the coach and performer.

Sprint tests can be viewed as the most relevent form of anaerobic assessment for soccer players. Both English and German professional players have been shown to be faster than amateurs (Kollath and Quade, 1993; Brewer and Davis, 1992) over 30 and 40 m distances. Brewer and Davis (1992) found a significant difference between professional and semi-professional players over a 40 m sprint. Professional players covered the 40 m courese in a mean ± s.d time of 5.5 ± 0.1 s compared to 5.8 ± 0.1 s for the semi-professional squad. Split times were also reduced indicating the importance of acceleration in top level match-play. Even though speed in soccer is determined by a combination of factors e.g. perception, skill, tactics and so on, "pure" sprinting ability seems to be an important factor (Balsom, 1994).

Bangsbo (1994c) stated that the pattern of sprinting within a game is not predictable. The ability to recover quickly from high intensity exercise is therefore crucial to prevent decrements in sprint performance. Researchers have developed repeated sprint tests that can be performed under laboratory or field conditions to assess decreases in performance as a consequence of the previously performed high intensity activity. Fallowfield et al. (1997) developed a 90 min non-motorised treadmill protocol to evaluate the influence of water ingestion on repeated sprint performance. The simulation consisted of 30 maximal 6 s sprints each contained within a 3 min repeating cycle of activity. Ingestion of water before, at half-time and throughout the protocol (every 15 min) helped to improve sprinting capacity and maintain body mass. Balsom (1990) designed a test that comprised 20 repeated 10x10x10 m sprints interspersed with a 42 s active recovery period. The sprint circuit consists of a triangle with three identical 10 m sides which is travelled in the shortest possible time. The subject then moves onto a recovery circuit. This possesses the same dimensions as the perimeter of the penalty area and is completed in the 42 s allowed for the active recovery. Circuits are completed alternatively until all 20 trials have been performed. The data yielded by the test relates to the fastest sprint, the sum of the 20 high intensity bouts and a fatigue index which is determined by the difference between the means of the first two and the last two sprint times.

Bangsbo (1994c) developed a similar test to Balsom (1990) in an attempt to examine repeated sprint performance. Figure 2.3.3 outlines the dimensions and form of the test circuit. The test consists of 7x34 m sprints, each separated by a 25 s active recovery period. Subjects are required to sprint from point A to B navigating the "slalom" section along the way. The circuit is then completed within 25 s by jogging back to the start. The duration of each sprint is recorded with the test result being divided into 3 different components namely best time, mean time (the average of the 7 sprint times) and the fatigue time (the difference between the slowest and fastest time for each bout). The best time provides an indication of the individual's "pure" speed while the mean time expresses the ability to repeat bouts of high intensity activity within a short period of time. The "fatigue time" gives an indication of the ability of an individual to recover from a sprint. Such tests are probably a good reflection of the ability to perform high intensity intermittent activity. Recovery bouts are, however, uniform in nature unlike the unstructured profile of match-play.

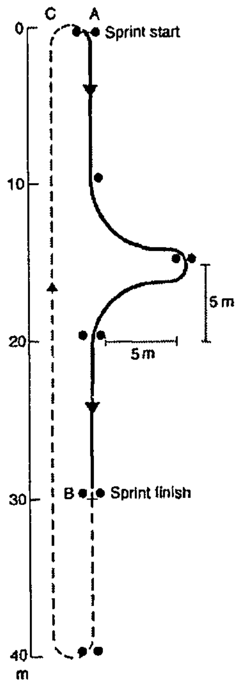


Figure 2.3.3. Diagrammatic representation of the repeated sprint test (Bangsbo, 1994c)

2.4. THERMOREGULATION

The following sections of the review of literature outline the body's responses during exercise in hyperthermic conditions. Both cardiovascular and metabolic responses to intermittent exercise will be discussed with special reference given to intermittent exercise performance and soccer. The effects of whole-body pre-cooling on thermoregulatory responses will also be evaluated.

2.4.1. Response to exercise

The transition from rest to exercise is associated with cardiovascular adjustments necessitating an increased oxygen delivery to the active muscle. Metabolic heat production in skeletal muscle is also rapidly increased with the rest-exercise transition (Young, 1990). One consequence is a requirement for an increase in skin blood flow (Skbf) to promote heat dissipation to the environment. These challenges are met by alterations in cardiac and peripheral circulatory processes. A large portion of cardiac ouput is thus shared between skin and muscle during exercise in hot conditions. Kenney and Johnson (1992) stated that there is a direct competition between these reflexes as they subserve two disparate functions. Dynamic exercise creates a drive for the redistribution of blood away from metabolically inactive tissues (including the skin) and to the active muscle while an increased Skbf accommodates the thermoregulatory dissipation of the heat stored as a result of the muscular activity. Internal temperature is then a result of the competing nervous influence on skin vasculature as cardiac ouput and Skbf cannot be driven continually upward to meet the demands to lose heat (Rowell, 1983).

The vast majority of the literature available regarding the thermoregulatory responses to exercise under hot conditions refers to sub-maximal continuous exercise. An appreciation of the body's responses to such protocols must be presented before the effects of intermittent exercise can be discussed.

Increases in core temperature at the onset of exercise are the result of the storage of heat produced in metabolism. Core temperature continues to increase until the drive for heat dissipation is strong enough to stimulate thermosensitive neurones in the central nervous system. Between 3 and 10 min into exercise the initial peripheral vasoconstriction, especially of the cutaneous vessels, that leads to a transient fall in Skbf (Bevegard and Shepard, 1966) is replaced by an initiation of the active vasodilation mechanism (Johnson, 1992). Skin blood flow begins to rise and eventually surpasses pre-exercise levels (Rowell, 1993). A sustained relative reduction in Skbf is, however, observed in a hot environment under exercise conditions compared to rest (Johnson, 1987) thus affecting the body's ability to lose heat. Johnson et al. (1974) argued that such reductions in Skbf during exercise in the heat (compared to rest) are a product of the cutaneous vessels being under the competing drives of the vasodilatory response to increased internal temperature and the vasoconstrictor response to exercise per se. Increased vasoconstrictory drives during exercise have also being shown for splanchnic (Rowell et al., 1965), resting muscle (Bevegard and Shepard, 1966) and renal circulations (Rowell et al., 1968). An exercise induced vasoconstrictor effect is less directly evident in the skin than the visceral circulation; however, the cutaneous circulation is still affected. The maintenance of cutaneous vasoconstriction in exercise has been demonstrated by Johnson et al. (1974). They examined the relationship between Skbf and oesophageal temperature during exercise and supine resting conditions. Skin blood flow was consistently lower (approximately 30 %) at a given level of oesophageal temperature compared to supine rest.

The Skbf response during exercise is also attenuated by changes in the active vasodilation mechanism. Kellogg et al. (1991) have shown that although rising core temperature is accompanied by significant cutaneous vasodilation, the elevation in Skbf is delayed until a higher core temperature is reached during exercise than during rest. The increase in internal temperature for cutaneous vasodilation is believed to be a direct consequence of an exercise induced delay in the vasodilator system as opposed to a removal of vasoconstrictor tone (Kellogg et al., 1991b). Therefore the result of the upward shift in the core temperature threshold for vasodilation is that Skbf is lower at any given core temperature during exercise than at rest. Such relative reductions are a consequence of the need to mainatin blood flow to active muscle to support activity and to maintain mean arterial pressure. This is especially important when the exercise pattern can vary between maximal and sub-maximal intensities as in soccer.

The thermal drive from rising core temperature during prolonged exercise, as in soccer match-play (see Section 2.4.4), results in further cutaneous vasodilation. This vasodilation continues at a rate of increase parallel to the rise in core temperature (Nadel et al., 1979) and necessitates an increase in cardiac output (an additional 2-3 $l.min^{-1}$ during sub-maximal exercise under hot conditions, Rowell et al., 1965; Rowell et al., 1968; Rowell, 1983). Such figures are likely to be exaggerated during intermittent exercise as the activity will be maximal at some stages. The increase in the total percentage of cardiac output directed to the skin is met also by a redistribution of blood from other regions of the body. Both renal and splanchnic circulations possess high blood flows that can be restricted without compromising the tissue's oxygen supply. The splanchnic and renal circulations are therefore placed under a greater than normal vasoconstrictory stimulus in exercise (Rowell, 1993). The observed increase in cardiac output is limited by the translocation of blood volume into dependent veins (Rowell, 1983) as a result of the increased Skbf. If such increases are uncompensated, a progressive decrease in central blood volume will lead to a progressive decrease in cardiac filling pressure, resulting in tachycardia and ultimately circulatory collapse (Nadel et al., 1979). During exercise the body does attempt to compensate for this translocation of blood. Exercise is an added stimulus to cutaneous vasoconstriction thus lowering the filling rate of cutaneous veins while muscle contractions also help in decreasing the average venous volume though the muscle pump is less efficient due to the rapid refilling of cutaneous veins (Henry and Gauer, 1950). Despite these attempts at preservation of the central blood volume, the cutaneous venous volume still increases resulting in a decrease in other volume reservoirs.

The effect of exercise in the heat on such volume reservoirs was investigated by Rowell et al. (1966) who examined the exercise response to a heat stimulus of 43 $^{\circ}$ C. Subjects walked on a treadmill at 5.6 $km.h^{-1}$ for 15 min at 4 different inclinations (7.5, 10, 12.5 and 15 %). Central blood volume and stroke volume decreased while mean arterial pressure, total peripheral resistance and cardiac output were maintained. Cardiac output was maintained as a result of tachycardia. This phenomenon is known as cardiovascular drift and is a consequence of the progressive increase in the percentage of cardiac output directed to the skin as core temperature increases (Rowell, 1993). This may also help to explain part of the increases in heart rate that are observed during soccer match-play as it can be recalled from Section 2.2.1 that heart rate is increased as the match progresses.

The loss of central blood volume results in a further alteration of the thermoregulatory response during exercise compared with rest. A plateau in Skbf is observed when the internal temperature reaches 38 ^{o} C (Kenney and Johnson, 1992) mediated by the baroreflex response (Nadel, 1983). This limit on Skbf is mediated by a reduction in active vasodilator tone which triggers visceral and cutaneous vasoconstriction as a result of increasing sensitivity to a decrease in central venous pressure (Rowell, 1983). This relative vasoconstriction contributes to the maintenance of an adequate stroke volume thus preventing a fall in cardiac output during exercise. The limit on Skbf will ultimately result in a increased core temperature if exercise is continued. This suggests that blood pressure regulation and metabolic demands have precedence over thermoregulatory concerns (Rowell, 1983). Nadel et al. (1979) demonstrated the precedence of circulatory regulation over temperature regulation using an experimental protocol that is similar in intensity to that observed for soccer match-play. Cardiac output was maintained at similar levels during a 20 min exercise period performed at 70 % $\dot{V}O_2$ max at room temperatures of 20, 26 and 36 ^{o} C. Cardiac output was maintained as a result of increased heart rates and a relative cutaneous vasoconstriction. This ensures an adequate central circulating blood volume, thus preventing a fall in stroke volume. The attenuation of Skbf leads to a vast reduction in the rate of heat loss from the body, thereby necessitating an increase in the evaporative heat loss to the environment.

Evaporative heat loss only becomes important following the reduction in vasodilation though sweating is initiated soon after the onset of exercise. With prolonged exercise a progressive decrease in sweat rate is observed despite elevated core and skin temperatures. The decline in sweat rate is brought about by a need to conserve body water as fluid balance is critical for optimal cardiovascular and thermoregulatory function. A large proportion of the water lost in sweat comes from the blood with decreases being observed in plasma volume during exercise (Brandenberger et al., 1989). Decreases in plasma volume will adversely affect the circulatory capacity, leading to decreases in blood pressure. Decreases in blood pressure will subsequently reduce the blood flow to skin and muscle as the body attempts to maintain central blood volume and stroke volume. Such cardiovascular adjustments will have further consequences for the heat dissipation mechanisms and core temperature.

Continuous sub-maximal exercise in a hot environment results in increases in Skbf as a result of the need for heat dissipation. This causes competition between the active muscles and the skin for blood flow. Cardiac output is therefore increased, by increases in heart rate and a reduction in blood flow in the splanchnic and renal areas. The cutaneous vasodilation leads to shifts in blood volume to the skin and a lower central blood volume. Reduced cardiac filling as a result of this redistribution reduces stroke volume. The loss of central blood volume leads to a sub-maximal plateau in Skbf, thus reducing heat loss and increasing the need for evaporative losses to be made. The circulatory adjustments to sub-maximal exercise are likely to be further exaggerated under intermittent exercise as the physiological demands will be increased above those associated with low intensity sub-maximal exercise. This may have consequences for the performance of soccer players during match-play in relation to the energy provision and substrate utilization to support the activity.

2.4.2. Metabolic responses to exercise in the heat

An individual's capacity for exercise is decreased in hot environments. Such reductions in performance occur in maximal exercise tests (Sawka, 1985), prolonged sub-maximal exercise (MacDougall et al., 1974), during isometric contractions (Edwards et al., 1972) and in soccer match-play (Ekblom, 1986). This decreased exercise tolerance is believed to be a consequence of increased heat storage and subsequent cardiovascular strain leading to a greater thermoregulatory demand for Skbf and sweating (Young et al., 1985). Of critical importance for muscle function during exercise is the blood flow through active muscle (Savard et al., 1988). Any large redirection of blood flow away from contracting muscle to the skin results in a decrease in work output. Attempts have been made to assess blood flow changes in skeletal muscle during exercise under heat stress by measurements of changes in oxygen content (Williams et al., 1962) and lactate concentration in blood from the active muscle (Rowell et al., 1969).

Research on the effects of acute heat stress on $\dot{V}O_2$ response to exercise have proved inconclusive. Oxygen consumption has been reported to increase (MacDougall et al., 1974; Fink et al., 1975; Nielsen et al., 1990), decrease (Smolander et al., 1986; Brouha et al., 1960) and remain unchanged (Rowell et al., 1969) during exercise at the same intensity in the heat compared to thermoneutral conditions. Increases in oxygen consumption in hot conditions have been related to the additional energy requirements for thermoregulatory adjustments i.e. tachycardia, sweating and increases in tissue metabolism due to increases in tissue temperature (Fink et al., 1975) while decreases in oxygen consumption are believed to be due to increases in mechanical efficiency or a decreased oxygen delivery and uptake at the muscle (Smolander et al., 1986). Young (1990) argued that such contradictions merely reflect methodological differences between studies. Such variations could be the result of factors such as the condition of the subjects and their degree of heat acclimation, the skill and severity of the task and the degree of environmental stress (Rowell et al., 1969). The $\dot{V}O_2$ during exercise, however, only reflects the aerobic metabolic rate. Such assumptions therefore neglect the existence of the anaerobic component in energy provision. Increases in anaerobic energy provision could lead to an increase in the total metabolic rate irrespective of changes in the oxygen transport system (Young, 1990). This is particularly relevant to soccer which already possesses an anaerobic component to its energy provision (see Section 2.2.2).

Information on the anaerobic contribution to exercise can be obtained by examining glycolytic metabolism. Evidence indicating an enhanced glycolytic metabolism during exercise in the heat comes from the examination of lactate values. Blood lactate accumulation has been shown to be increased during "steady-state" submaximal exercise under heat stress conditions compared to a thermoneutral environment (MacDougall et al., 1974; Edwards et al., 1972). Blood lactate concentration is a consequence of production and release from active muscle into the blood and uptake by liver, heart and skeletal muscle. Changes in blood lactate concentration could therefore be the result of increases in production and release or a decrease in the uptake by tissues. Rowell et al. (1968) examined the effects of heat stress on splanchnic blood flow and metabolism in 11 males during cycling to exhaustion at 48.9° C at 42-56 % of maximal oxygen consumption. Hepatic blood flow was observed to be low compared to resting values but quite stable throughout the exercise period. Normal splanchnic metabolic function was maintained though arterial lactate levels were abnormally high for the relative severity of exercise. The hepatic rate of extraction was observed to be normal with the percentage extraction being reduced (58 % of normal). The total increase in lactate concentration during exercise in the heat compared to thermoneutral conditions does not seem to be the result of decreases in hepatic lactate extraction.

Increases in lactate concentration during heat stress could also be explained by a redistribution of blood flow away from the active muscles during exercise compromising lactate removal (Fink et al., 1975). Direct assessments of muscle blood flow using thermodilution techniques (Savard et al., 1988 and Nielsen et al., 1990), yielded no evidence for decreases in leg blood flow compared to control values during one legged knee extension or two legged cycling when heat stress was imposed using a water perfused suit. Nielsen et al. (1990) also failed to find a decrease in leg muscle blood flow in a warm environment (40 ^{o} C) during exercise at 60 % $\dot{V}O_2$ max. Unlike Savard et al. (1988) water perfused suits were not used to increase body temperature thus removing the artificial conditions created by such apparatus. Young (1990) argued that the experimental design used in the above studies precludes comparison of the physiological and metabolic responses to exercise with and without heat stress as the measurements obtained for the hyperthermic period may already have reflected the effects of thermoregulatory strain. Therefore redistribution of blood flow away from muscle remains a potential factor to explain increase blood lactate accumulation during exercise in hot environments.

Lactate accumulation has also been shown to be accelerated within active muscle during exercise in hot conditions. Edwards et al. (1972) found significantly higher muscle lactate concentrations after an isometric contraction at a muscle temperature of 39 ^{o} C than at a muscle temperature of 22 ^{o} C. Muscle temperature was altered by immersion of the test leg in water at 12 and 44 ^{o} C. Pyruvate concentration was also significantly greater at the higher temperature. Changes in muscle temperature were therefore linked to changes in the content of glycolytic metabolites, indicating an increased glycolytic rate. Such increases were, however, not associated with increased tension development, suggesting that ATP is utilized at a higher rate under heat stress for generation of the same tension.

Young et al. (1985) reported similar increases in muscle lactate accumulation during continuous dynamic exercise under heat stress. They claimed that the case for a decrease in muscle blood flow was inconclusive. Increased muscle lactate may therefore be the result of an alteration in the neuromuscular recruitment pattern of fibres in the heat or a Q_{10} effect on glycolytic enzymes.

Fink et al. (1975) employed 3 x 15 min cycling bouts at 70 to 85 % $\dot{V}O_2$ max to examine the effects of temperature of leg muscle metabolism. Glycogen utilization and lactate accumulation were approximately twice as great during exercise at an ambient temperature of 41 $^{\circ}$C compared to 9 $^{\circ}$C. No significant differences were observed between the hot and cold conditions for free fatty acid concentration while glucose and triglyceride concentrations showed inverse patterns in the heat and cold. Significant increases in muscle glycogenolysis and post-exercise muscle lactate accumulation were also observed by Febbraio et al. (1994). Such increases in glycogen utilization were not observed by Young et al. (1985) though the respiratory exchange ratio during exercise was slightly higher in hot conditions suggesting that oxidation of carbohydrate substrate other than muscle glycogen may have been increased. Such effects of high temperatures on metabolism may merely reflect the general inaccuracy of energy metabolism during exercise as fuel mobilization is rarely adjusted to energy demands of muscle (Galbo et al., 1986).

The metabolic response to exercise does seem to be affected during continuous performance in a hot environment. No clear pattern has emerged regarding changes in oxygen consumption though an increase in blood lactate levels during sub-maximal steady state exercise over those observed in thermoneutral conditions would suggest a higher glycolytic rate and an increased anaerobic contribution to energy provision. Such factors could have consequences for the preferred work-rate of players during games. Blood lactate levels may, however, simply reflect changes in the uptake and removal of lactate as a consequence of the redistribution of blood to aid heat dissipation.

2.4.3. Intermittent exercise in hot conditions

The thermal response to exercise is influenced by the intensity and type of exercise (Smolander et al., 1991). Core temperature is regulated at a higher level during exercise than at rest with the adjustment being dependent on work-rate and independent of environmental temperature and the duration of the exercise (Nielsen, 1938). Saltin and Hermansen (1966) have, however, demonstrated that the absolute level of work performed is not the decisive factor for temperature regulation. They assessed rectal, oesophageal and muscle temperatures (in the lateral part of the quadriceps) during submaximal exercise at three different intensities (25 %, 50 % and 70 % of $\dot{V}O_2$ max). Core temperature was observed to be related to the relative work-load and not to the absolute work level. Smolander et al. (1991) have shown that the linear relationship between core temperature and work-load only holds true up to an exercise intensity of 75 % $\dot{V}O_2$ max. When exercise is performed above this level, the relationship between core temperature and $\dot{V}O_2$ becomes curvilinear with large increases in core temperature being observed when exercise intensity approaches maximum. Such increases are believed to be the result of an altered vasoconstrictor response at such high work-rates (Fortney and Vroman, 1985), though changes in cutaneous vasodilation have also been noted with high intensity exercise (Kenney and Johnson, 1992).

High intensity anaerobic exercise seems to alter the thermoregulatory response to exercise by enhancing cutaneous vasoconstriction in a graded manner in relation to intensity, thus raising the core temperature response to exercise intensity. The rate and onset of vasodilation are also affected in a graded manner resulting in a decreased or attenuated Skbf-core temperature relationship and an increased internal temperature threshold for vasodilation (Kenney and Johnson, 1992). In response to such changes heat loss is maintained by an increase in sweat loss. The majority of the literature that has been discussed with respect to the body's thermal response to exercise has been concerned with continuous exercise patterns at submaximal exercise intensities. Only a small amount of the available literature relates to anaerobic exercise and intermittent patterns.

The thermoregulatory response to intermittent exercise has been examined by comparing continuous and intermittent exercise patterns performed at the same average exercise intensity. Ekblom et al. (1971) looked at the influence of "work factors" (stimuli induced specifically by muscular activity) on temperature regulation. Three subjects were exercised continuously and intermittently for 1 hour at a work-rate that elicited approximately 60 % of $\dot{V}O_2$ max on a cycle ergometer. The intermittent exercise session consisted of repeated bouts of 30 s exercise interspersed by 30 s recovery periods. Rectal temperature was 0.35 ^{o} C higher at the end of the intermittent session compared to the continuous bout. The increase in rectal temperature was also different between sessions, being 0.41 ^{o} C higher in the intermittent session. The increases in rectal temperature were accounted for by a decrease in total sweat loss in the intermittent session. This indicated a reduced efficiency of the thermoregulatory system. A reduced efficiency of the thermoregulatory system was observed to be a result of reflex circulatory adjustments at the onset of exercise and a non-linearity in the contribution of non-termal inputs at work-rates above 100 % $\dot{V}O_2$ max. Skin temperature was also greater in intermittent work though it decreased steadily throughout the protocol. This decrease in skin temperature is thought to be related to the action of noradrenaline which reduces blood flow to the skin. Ekblom et al. (1971) suggested that the decrease in blood flow is a consequence of the increased vasoconstriction needed to return blood centrally to maintain cardiac output due to blood pooling in the legs during the recovery phases.

Similar results have also been produced by Cable and Bullock (1996). The total work done was identical between continuous (30 min at 60 % $\dot{V}O_2$ max) and intermittent sessions (20 x 1 min work bouts separated by 2 min rest periods at 90 % $\dot{V}O_2$ max) on a cycle ergometer. Significantly higher rectal temperatures were observed in the intermittent session along with significantly lower mean skin temperatures compared to the continuous session. Sweat production rate was significantly attenuated during intermittent exercise. The aforementioned variables were also recorded during a 30 min supine recovery period. No significant differences were observed in mean skin temperature between conditions during recovery though rectal temperature was altered in terms of the magnitude and pattern of response during recovery. The adaptations in both the exercise period and recovery were thought to be a consequence of increases in cutaneous vasoconstriction in an attempt to maintain central blood volume and blood pressure during periods of thermoregulatory and metabolic competition.

The differences found in core temperature during intermittent and continuous exercise at the same average intensity may not be solely the result of changes in skin temperature and sweat production rate. The 33 % greater rise in rectal temperature observed by Kranning and Gonzalez (1991) after 30 min intermittent exercise, (walking, jogging and seated rest) implies an increase in the rate of deep body heat storage. Such changes can be brought about by differences in heat production or heat dissipation. Kranning and Gonzalez (1991) believed that an adequate explanation was not provided by either mechanism and that as well as the alterations in the usual rate of heat transport via the cutaneous circulation and changes in skin evaporation rate, there may also be contributions from non-thermal factors associated with postural change and variations in exercise intensity.

The data provided by Kraning and Gonzalez (1991) were obtained during intermittent exercise protocols that were performed under uncompensable heat stress conditions (under such conditions a thermal steady state cannot be achieved). When heat stress was compensable (a thermal steady state can be achieved), rectal temperature values were similar for both intermittent and continuous exercise at the time-weighted average of heat production. Other investigators have also failed to find significantly different thermoregulatory response to intermittent and continuous work (Belding et al., 1966). Lind (1963) examined rectal temperature, sweat loss and pulse rate in 2 subjects during 8 hours of continuous and intermittent marching on a treadmill. Rectal temperature was observed to follow changes in the exercise:rest pattern though no demonstrable differences were found in any of the variables measured. Heart rate and rectal temperature increased during the final 2 hours in the condition that posed the greatest climatic stress on the individual (41° C). Such data suggest evidence of cumulative thermal strain during intermittent exercise due to progressively slower rates of recovery during rest periods as climatic stress increases.

The findings of Lind (1963) may have little application to the thermoregulatory demands associated with exercise, and specifically soccer, as the test duration is far in excess of the majority of sporting events. The findings have, however, been supported in experimental protocols that have more relevance to a sports performance. Nielsen (1968) utilised 30 s bouts of cycle ergometry separated by 30 s periods of rest to compare intermittent exercise with continuous work at the same average intensity. Increases in oesophageal temperature were almost equal for the same metabolic rate in both protocols. It was concluded that the increases in core temperature were in proportion to the actual oxidative activity and independent of the relative strain on the muscle group involved. Thermoregulatory reactions were not influenced by neuromuscular events during exercise, unlike other physiological responses i.e. respiratory, circulatory.

Both of the studies mentioned previously utilised small samples and are therefore better viewed as indicative as opposed to definitive of the thermoregulatory response to such exercise. The failure to find an altered thermoregulatory response may also be an artefact of the protocols employed in the investigations. Belding et al. (1966) argued that increases in core temperatures in intermittent work will not be observed when exposure extremes are limited to conditions in which a thermal steady state would have been achieved given sufficient exposure time under stable conditions. When a steady state is not achievable i.e. at the upper limits of thermal and work strain, an altered thermoregulatory response is observed. The thermoregulatory strain can then also be affected by the number and duration of pulses. Extra cost occurs when the body's compensatory mechanisms are required to adjust more frequently to changes in demand. Similarly, if the recovery phase is too short to allow a complete dissemination of heat, there may be an incremental loading leading to increases in internal temperature. Soccer involves around 1000 changes in activity during a 90 min game, with these changes occurring approximately every 4 s. The activity pattern is characteristic of the conditions discussed above, therefore suggesting that a high degree of thermoregulatory strain may be associated with match-play.

Previous work with respect to intermittent exercise and temperature regulation has interspersed periods of exercise with static recovery periods. The intensity and duration of both the work and recovery periods affect the metabolic and physiological responses to intermittent exercise (Christensen et al., 1960b) and these factors could also have implications for thermoregulatory response. Recovery during intermittent exercise is not restricted to static periods and can involve exercise at a reduced intensity. Such patterns are observed in the so-called multiple sprint sports e.g soccer, hockey. Some investigators have examined the effects of such procedures on thermoregulatory and physiological variables (Garrett and Boyd, 1995; Nevill et al., 1994).

Nevill et al. (1994) investigated intermittent and continuous work at the same average intensity on a cycle ergometer at environmental temperatures of 10 and 35 ^{o} C. The intermittent protocol consisted of 90 s exercise at 40 % $\dot{V}O_2$ max, a 6 s sprint and a 24 s passive rest. The protocol approximates the activity pattern observed in soccer though the mode of exercise is different. Intermittent exercise induced significantly greater increases in rectal temperature heart rate, blood lactate, ammonia and oxygen consumption when compared to the continuous bout with a further significant difference being observed in hot compared to cold conditions, thereby indicating a greater thermal and physiological strain during intermittent work. Such findings were also observed by Garrett and Boyd (1995) though no quantitative statistical analysis was performed on the data. Higher rectal temperature, oxygen consumption, blood lactate, heart rate and RPE were noted during a 45 min cycle at the same average intensity. Time to perform a constant work sprint was also recorded throughout the protocol to provide an indication of performance. The decrement in performance was observed to be positively correlated (0.96) with the increase in rectal temperature, suggesting a deterioration of performance with overheating.

In summary, intermittent exercise has been shown to result in changes in cutaneous circulation and skin evaporation that imply a decreased efficiency in temperature regulation resulting in a increased core temperature. Non-thermal factors associated with the onset and completion of exercise have also been implicated. Such changes are thought only to occur when the exposure extremes are limited to conditions in which thermal steady state would not be achieved given sufficient exposure time. The number, duration and intensity of exercise bouts are therefore an important consideration in evaluating the core temperature response to intermittent exercise. The large number of activity changes associated with soccer match-play, especially when combined with high ambient temperatures, may have implications for the thermoregulatory responses to intermittent exercise.

2.4.4. Soccer

Very limited data are available on the body's thermoregulatory responses to soccer match-play. The high energy turnovers involved in soccer involve large heat production and therefore necessitate a release of the heat produced primarily by the evaporation of sweat. Soccer players may lose around 3 l or more of fluid during a game in the heat. These figures represent an average value that can vary with the level of environmental stress and also between individuals (Reilly, 1996).

Mustafa and Mahmoud (1979) found a fluid loss of 3.1 % body mass during a match at an air temperature of 33 ^{o} C and relative humidity of 40 %. Similar fluid losses were also observed when the ambient temperature and humidity were 26.3 ^{o} C and 78 % respectively. Despite the loss of heat via evaporation, body temperatures still rise during soccer match-play. Ekblom (1986) examined the core (rectal) temperature response of 125 players during games played in environmental temperatures between 20 and 22 ^{o} C. The First Division players were found to have a slightly higher (39.5 ± 0.3 ^{o} C) average rectal temperature than players from the lower 3 divisions (39.2 ± 0.4 ^{o} C, 39.0 ± 0.4 ^{o} C, 39.1 ± 0.4 ^{o} C). The results indicate that players from lower divisions tax aerobic energy system to a lesser degree as indicated by a decreased rectal temperature (Saltin and Hermansen, 1966).

Such core temperatures are above those that will adversely affect many components of soccer performance (Reilly, 1996). These include mental as well as physical and psychomotor aspects of skill. These decreases in performance can be offset to some degree by fluid replacement. The differences in core temperature response for the different levels of play may also be attributed to the players' conditioning. The thermal strain on the player is a function of the relative exercise intensity as opposed to the absolute work-load (Saltin and Hermansen, 1966). Therefore the higher the maximal aerobic power and the cardiac output, the lower the thermal strain on the player.

2.4.5. Thermoregulatory response to exercise after whole-body pre-cooling

Endurance training has been shown to produce an adaptive thermoregulatory response. These changes include an enhanced sweating sensitivity (Gisolfi and Robinson, 1969), lowered threshold temperatures for sweating (Nadel et al., 1974) and enhanced forearm skin vasodilation (Roberts et al., 1977). Such modifications may contribute to the lower rectal temperature values observed for physically fit subjects during exercise. This may be useful during exercise performance, as the danger of reaching a critically high exercise body temperature that may limit performance is counteracted.

An elevated body temperature is one of the factors that has been shown to limit endurance performance (Adams et al., 1975). It has therefore been suggested by some researchers that a reduction in body temperature at the start of exercise may influence exercise performance. Schmidt and Bruck (1981) argued that by decreasing the starting temperature at the onset of exercise, the margin to the attainment of a critical limiting body temperature is increased. This results in improvements in performance in terms of both endurance time (Olschewski and Bruck, 1988) and increased work-rate (Hessemer et al., 1984).

Limited data are available regarding the effects of whole body pre-cooling on the body's physiological responses to exercise. Decreases in core temperature have been observed during exercise after a whole-body pre-cooling manoeuvre (Schmidt and Bruck, 1981; Hessemer et al., 1984; Lee and Haymes, 1995). Lewke et al. (1995) found that oesophageal temperature was decreased by 0.6 ^{o} C during exercise on a cycle ergometer. The exercise period consisted of 16 min of exercise divided into 4 individual 4 min work-rates at 35, 45, 55 and 65 % $\dot{V}O_2$ max respectively. The difference in oesophageal temperature between conditions was observed to be constant irrespective of work-rate or experimental time course. Lee and Haymes (1995) also observed decreased mean skin temperatures as a result of exposure to a pre-cooling stimulus (approximately 33 min in an environmental chamber at 5 ^{o}C) during exercise to exhaustion at 82 % $\dot{V}O_2$ max. Mean skin temperature was lower for the entire duration of exercise though the values were only significantly lower for the first 25 min of the exercise session.

The effects of a lowered core temperature on prolonged exercise performance have also been investigated as it is under such conditions that body temperture becomes limiting. Hessemer et al. (1984) exercised 8 subjects for 60 min on a cycle ergometer at work-rates of approximately 50-60 % VO_2 max. Decreased tympanic and oesophageal temperatures were observed at the onset of exercise with the maximum difference between the two conditions being observed after 5 to 10 min. From this time point the differences in tympanic and oesophageal temperature gradually diminished with only tympanic temperature still being lower upon completion of exercise.

The decrease in core temperature has been shown to affect both heart rate and sweat production rate. Heart rate response was found to be lowered during exercise at a given work-rate following pre-cooling (Schmidt and Bruck, 1981; Lewke et al., 1995; Olschewski and Bruck, 1988) while the onset of sweating has been shown to be delayed by 12 min (Lewke et al., 1995) resulting in a decrease in the total amount of sweat secreated (Schmidt and Bruck, 1981). The decrease in core temperature results in a higher work-rates and a decrease in the thermoregulatory strain associated with the exercise (Hessemer et al., 1984). Peak oxygen consumption remained unchanged after pre-cooling (Schmidt and Bruck, 1981) though oxygen pulse was significantly increased in the first 30 min of a 60 min exercise session (Hessemer et al., 1984).

The effects of lowered ambient temperature on metabolism appear to depend on the magnitude of the decrease in core and muscle temperature (Young, 1990). Effects on metabolism are probably mediated directly through the effects of reduced body temperature or indirectly by the effects of shivering and/ or neurohumoral responses to cold-induced changes in body temperature. Muscle cooling has been associated with increased muscle lactate production as a result of accelerated muscle glycogenolysis (Blomstrand et al., 1986). Blomstrand et al. (1986) investigated the effects of reduced muscle temperature on muscle metabolism during exhaustive cycle exercise (370 W). Oxygen consumption during the exercise was unaltered at low muscle temperatures suggesting that the increased glycolytic rate may be the result of a reduced mechanical efficiency during exercise or an elevated level of catecholamines.

Some evidence does exist in the literature to support the notion of a decreased physiological strain and a consequent increase in exercise performance as a result of a pre-cooling manoeuvre prior to exercise performance. There is also some evidence for a change in muscle metabolism dependent upon the degree of reduction in muscle temperature. The data are, however, limited and relate almost exclusively to short duration sub-maximal continuous exercise performance. No data are available regarding the effects of pre-cooling on intermittent performance especially with specific reference to the exercise pattern observed in soccer. Given that the thermoregulatory responses to intermittent exercise patterns similar to soccer are augmented, the use of a whole-body pre-cooling manoeuvre may be beneficial during such exercise performances.

2.5. SUMMARY

The findings of this review of literature have been directed towards the quantification of the physiological and metabolic responses to soccer match-play. Methodological problems associated with the nature of the sport limit the techniques that can be applied in its investigation. Techniques of motion-analysis have been used to help estimate the energy expenditure associated with match-play. The total distance covered by players during a game is around 10 km, with the majority of this distance been covered at low sub-maximal levels that will predominantly tax the aerobic energy system. High intensity bouts of activity comprise a small proportion of the total distance covered. They are, however, an important component of the game as they are mainly centred around crucial match activities e.g. sprinting to win the ball. There are large variations in the work-rate profiles of players. Factors such as playing position, style of play and environment have all been shown to affect work-rate. The literature suggests that the mean relative work-rate, despite the low intensity nature of the game, is still around 70 % of the maximal oxygen uptake, with muscle glycogen supplying a large component of the energy demand. Such figures have been based upon the assessment of the physiological responses to match-play e.g. heart rate, core temperature. This high relative work-rate is a direct consequence of the intermittent nature of the game and the performance of specific match activities such as kicking and tackling.

There is a lack of adequate experimental models that can be used to study physiological aspects of soccer. Performance tests have been developed that attempt to replicate the movement patterns of soccer, and as a consequence the physiological demands of match-play. These tests have concentrated primarily on the assessment of the physical capacity of players as opposed to the physiological demands of the sport. This existing knowledge will serve as a background to the first section of the study. Laboratory based soccer-specific intermittent protocols will be developed that allow the quantification of the metabolic and physiological responses to soccer-specific intermittent exercise.

Ambient temperatures have been shown to affect exercise performance. Such changes are the result of alterations in the cardiovascular and metabolic responses to the stimulus of exercise due to the need for increased heat dissipation. Very little research is available regarding the body's thermoregulatory response to intermittent exercise as the majority of the data relates almost exclusively to continuous sub-maximal exercise. The data that exist seem to suggest that intermittent exercise performance results in a decreased efficiency of the thermoregulatory system, leading to increases in core temperatures over those observed for continuous exercise at the same average exercise intensity. These findings were derived from intermittent protocols incorporating exercise and rest periods as opposed to exercise periods of different intensities that are characteristic of activity patterns of soccer. Evidence suggests that the adjustment in the thermoregulatory system is affected by the number and duration of pauses. The activity pattern employed may lead to further changes in the heat production and dissipation mechanisms associated with exercise. Further details regarding the thermoregulatory response to intermittent exercise are therefore needed, with this issue being addressed in the later chapters of this thesis.

Whole-body cooling prior to exercise performance reduces the thermoregulatory strain associated with exercise and leads to improvements in performance. The data available on the effects of pre-cooling are exclusively concerned with continuous exercise protocols and neglect the effects of pre-cooling on intermittent exercise performance. Investigations are needed to evaluate the usefulness of a pre-cooling manoeuvre on the physiological and metabolic responses to soccer-specific intermittent exercise performance.

CHAPTER 3

THEORETICAL AND METHODOLOGICAL BACKGROUND

3. THEORETICAL AND METHODOLOGICAL BACKGROUND

This chapter contains results of two studies, which combine to provide information relating to the development of a soccer-specific intermittent protocol. The development of the intermittent protocol is described in the first study, while the physiological responses to the protocol, with specific reference to the blood lactate response to intermittent exercise, are investigated in the second..

3.1. PRODUCTION OF A SOCCER-SPECIFIC INTERMITTENT PROTOCOL

3.1.1. Introduction

The initial step in training prescription in soccer is analysis of the physical requirements of match-play (Withers et al., 1982). The demands of match-play can be examined by making relevant observations during a game, obtaining physiological responses during real or simulated matches and assessing the physical capacity of elite players. This information can then be utilised to devise laboratory based protocols that attempt to recreate the work-rates observed in match-play. Such procedures can help increase the depth of understanding of the physiological responses to soccer-specific intermittent exercise. Reilly (1990) stated that many scientists have been discouraged in their attempts to study soccer as a result of the lack of adequate experimental models that can be used in the laboratory.

The exercise pattern in soccer is intermittent with activities ranging from maximal sprints to standing still. Various researchers have examined the body's responses to intermittent activity (Holmyard et al., 1988; Balsom et al., 1992 and Gaitanos et al., 1993). The intermittent activity patterns employed in these investigations have primarily been in the form of repeated bouts of short duration (6 s) sprinting in order to examine the physiological stresses associated with multiple sprint performance. Such models employ work-rest exercise patterns rather than the alternating intensities seen in soccer. Tests have been developed that are specific to soccer (Bangsbo, 1994). These have been aimed at performance assessment rather than the quantification of the physiological responses to intermittent activity. Such tests can take place in either field or laboratory sessions with the two methods being seen as being complementary to each other in the assessment of an individual's performance (Balsom, 1994). Bangsbo and Lindquist (1992) provided an example of such a intermittent exercise test. Tests were devised in order to evaluate the effectiveness of various procedures (i.e. field tests, laboratory tests) for determining the potential physical capacity of soccer players. Figure 2.3.2 in Chapter 2.3.1.1 illustrates the circuit in one of the tests completed by the players. Activity during the test is alternated between high and low intensities for 15 and 10 s periods. Players follow a pre-determined route during the high intensity exercise periods with different patterns of running (forwards, backwards, sideways). The low intensity periods consist of jogging, the test result being the total distance covered during the 10 min of high intensity exercise.

Laboratory based protocols corresponding to work-rates representative of match-play need to be devised for modelling the physiological loads involved in the game and for comparing how loads during intermittent activity relate to those during continuous steady-rate exercise. The aim of this study was to devise an intermittent exercise protocol that reflected match-play work-rates using a laboratory based motorised treadmill. Such a protocol would enable comparisons to be made between the physiological demands of continuous and intermittent exercise periods in later work (see chapter 5.1).

3.1.2. Methods

The intermittent protocol devised for the study consisted of different exercise intensities that are observed during soccer match-play (e.g. walking, jogging, sprinting). The proportions of the activities incorporated in the protocol were similar to those observed by Reilly and Thomas (1976). Four movement categories were incorporated; walking, jogging, cruising (defined as running with manifest purpose and effort; Reilly and Thomas, 1976) and sprinting. A static period was also included in which the subject remained stationery on the treadmill. A small proportion of the activity in soccer games involves the performance of backwards and sideways movements (6.7 %, Reilly and Thomas, 1976). These types of activies were not included in the protocol as a result of the technical limitations of the equipment used. The distance covered in these activity categories during match-play was initially divided between the remaining exercise patterns that were included in the protocol. This allowed the total duration of the time spent in each activity classification in the protocol to be calculated. The distribution of the utility movements was changed for the final version of the protocol as it was noted that such movements do not occur at cruising or sprinting speeds. The percentage of the total distance attributed to such movements were, as a consequence, only added to the low intensity categories (e.g. walking and jogging).

Treadmill speeds for each activity were determined from the data of Van Gool et al. (1988). The treadmill used (Quinton Instruments, Washington, USA) imposed restrictions on the speeds that were employed as its top speed capability was 24 $km.h^{-1}$. This was at the lower end of the range of sprinting speeds observed by Van Gool et al. (1988). The respective speeds chosen for each activity pattern, based on the data obtained during match-play, employed in the protocol were:- walking 6 $km.h^{-1}$, jogging 12 $km.h^{-1}$, cruising 18 $km.h^{-1}$ and sprinting 24 $km.h^{-1}$. The speeds for cruising and sprinting were later reduced by 3 $km.h^{-1}$, to 15 and 21 $km.h^{-1}$ respectively, as a result of pilot work. It was noted that subjects found the high intensity bouts too stressful when the time taken for the treadmill speed to increase up to the required level and then slow back down again was included with the performance time at the required intensity. This problem was overcome by reducing speed, though the speeds now incorporated were below those observed in the work of Van Gool et al. (1988). It was envisaged that this reduction in speed would be offset by the slightly longer duration of the bouts in the laboratory setting.

The determination of the order of presentation of the activity categories allowed the total time for the speed changes in the protocol to be calculated. This provided the test time of the protocol (the time of the protocol that would be performed at constant speeds) and the total time spent in the transition between the modes of activity. This was accomplished by the use of a stopwatch (Bentima, Switzerland) to determine the time taken to change between each activity bout throughout the protocol. The total time spent changing between modes of activity could then be calculated by the addition of all the changes made throughout the protocol. This time period was then subtracted from the duration of the protocol to provide the total time for the test. The test time (the total time for the protocol minus the total time in transition between modes of exercise) was then divided by the percentages for each activity, based upon the data of Reilly and Thomas (1976) to give the duration that each classification would occupy in the protocol. This was finally divided by the number of bouts in each classification to provide a time for each discrete period (see Appendix 1 for full calculations).

The protocol was arranged around two identical 22.5 min intervals separated by a 71 s static recovery period. This figure was half of the total time players stood still during a 90 min game (Reilly and Thomas, 1976). This gave a total test duration of 46 minutes 11 seconds. Such a time period is comparable with one half of a soccer match with the addition of some stoppage time (i.e. for injuries). The use of two identical repeated cycles was to allow comparisons between the physiological responses of the two periods of activity. The order of presentation of the activities was determined by the researcher. High intensity bouts were separated by low intensity recovery periods in an attempt to replicate the acyclical nature of the exercise pattern in a soccer game. It was decided to incorporate a large number of high intensity sprinting bouts (n = 16) in the protocol. This would result in each discrete bout being short in duration as is observed during game-play.

3.1.2.1. Repeatability

The repeatability of the time taken for the treadmill to change between each activity bout throughout the protocol was assessed. The consistency of the time to alternate between speeds is important as large variations would result in the timing of the protocol becoming variable and consequently affect the physiological responses of the individual. The repeatability of the time taken for the treadmill to change between each activity bout was assessed by timing each specific speed change on an unloaded treadmill with a stopwatch over 10 trials. A one-way ANOVA was used to determine if any large systematic bias were detected between the samples of data. No significant bias was detected in any of the samples tested. The data were further explored using coefficient of variation, limits of agreement (Bland and Altman, 1986) and the coefficient of variation of the limits of agreement. All these quantities are ways of presenting the measurement error based on the variance within the sample. The coefficient of variation of the limits of agreement was calculated as it reflects a greater percentage of the population sample than the 67 % represented by the coefficient of variation.

3.1.3. Results

Table 3.1.1 shows the mean ± s.d. for the time taken (s) for the treadmill to change between each bout of activity incorporated in the protocol. The low s.d shows a small degree of variability for the sample. The coefficient of variation, limits of agreement and the coefficient of variation of the limits of agreement were calculated for the treadmill speed changes. The limits of agreement for the treadmill speed changes were observed to be ± 3.6 s. The coefficient of variation and the coefficient of variation of the limits of agreement also indicated a small degree of variability for the sample. The coefficient of variation was found to be 4.8 % with the coefficient of variation of the limits of agreement being 9.4 %.

Table 3.1.1. Mean ± s.d. of the time taken (s) for the treadmill speed changes ($km.h^{-1}$) incorporated in the protocol.

Speed change ($km.h^{-1}$)	Mean ± s.d.
6 to 21	46.2 ± 1.6
21 to 12	18.8 ± 0.6
12 to 21	23.7 ± 0.6
21 to 6	35.1 ± 0.4
6 to 15	30.8 ± 0.3
15 to 12	7.7 ± 0.7
12 to 6	17.8 ± 1.0
12 to 15	9.2 ± 0.6
15 to 6	24.8 ± 0.8
6 to 12	22.7 ± 0.6

Each section of the 22 minute 30 second protocol comprised of 6 discrete bouts of walking, 6 bouts of jogging, 3 cruises and 8 sprints (Figure 3.1.1). The total time spent alternating between intensities (i.e. transition time) was 598 s giving a total test time of 752 s. Walking accounted for 28.2 % of this test time, with jogging making up 40.2 % and cruising and sprinting 20.5 and 11.2 % respectively.

15	12	21	6	12	21
6	21	12	15	6	21
12	21	6	15	6	21
12	21	12	6	21	STATIC

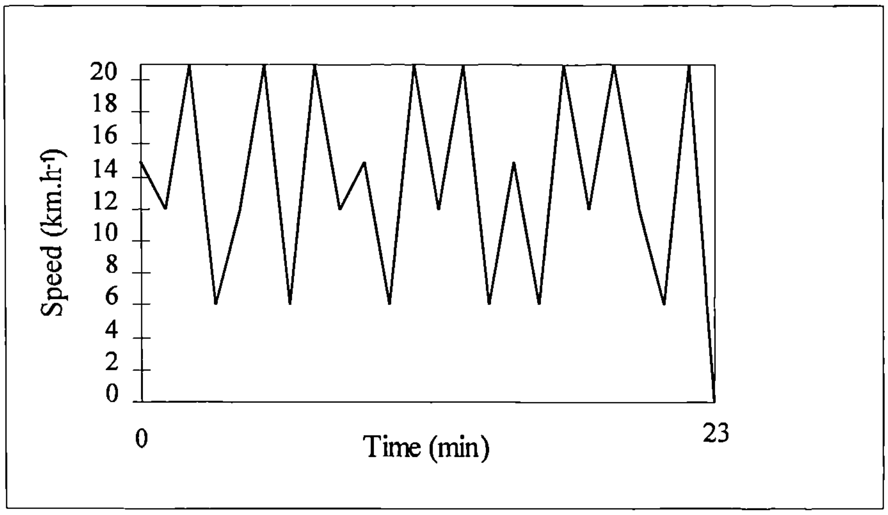


Figure 3.1.1. Diagrammatic representation of one half of the soccer-specific intermittent protocol. The top section provides a breakdown of the order of presentation of the speeds ($km.h^{-1}$) (reading from left to right) while the bottom section shows a graphical display of the changes.

The time for each discrete bout was calculated for each activity (see Appendix 1 for full calculations). The duration of each walking period was 35.3 s with each bout of jogging in the protocol lasting 50.3 s (Table 3.1.2). High intensity exercise was divided into two categories (cruising, sprinting). Each cruise lasted 51.4 s with each sprint being performed for 10.5 s.

Table 3.1.2. Time (s) for each discrete bout of each exercise pattern incorporated in the intermittent protocol.

Activity pattern	Time for each discrete bout (s)
Walk	35.3
Jog	50.3
Cruise	51.4
Sprint	10.5

3.1.4. Discussion

The aim of the study was to devise an intermittent protocol that reflected match-play work-rates using a laboratory based motorised treadmill. This would enable comparisons to be made between the physiological demands of steady-rate and intermittent exercise periods in later work.

The protocol devised was based upon the motion-analysis research of Reilly and Thomas (1976). The data from this study have been shown to be still applicable to the work-rate profiles observed in modern soccer match-play (Reilly, 1994). All major exercise patterns observed in game play (jogging, walking, sprinting, cruising) were incorporated at speeds closely resembling those observed during real games (Van Gool et al., 1988). Backing and sideways movements were not included due to technical limitations of the equipment used. The variability of the treadmil speed changes in the protocol were determined using coefficient of variation, limits of agreement and the coefficient of variation of the limits of agreement. The coefficient of variation and the coefficient of variation of the limits of agreement were found to be 4.8 and 9.4 %, respectively. Both of these values are within the 10-15 % range suggested as acceptable for biological systems (Stokes, 1985). The limits of agreement were ± 3.6 s. Repeatability measurements should involve the determination of the amount of variation in context to what the equipment or test is to be used for (Bland and Altman, 1983). It was deemed by the experimenter that the limits of agreement for the treadmill speed changes were of an appropriate level for the requirements of the investigation. A maximum variation of ± 3.6 s should not affect the overall physiological loading placed on the subjects as the time to alternate between speeds is relatively consistent.

The total duration of the protocol was 46 minutes 11 seconds when the two sections were combined with the static period. This time period closely replicates that of one half of a game with some additional time that could be attributable to stoppages e.g. injuries. Twelve discrete bouts of walking, 12 bouts of jogging, 6 cruises and 16 sprints were completed in this time period. These frequencies are less than those observed for one half of match-play, though the percentages that each activity pattern takes up are very similar (Reilly and Thomas, 1976). This factor is a consequence of the equipment used as it was impossible to replicate the constant changes in the activity profiles that are observed during match-play. The changes in activity employed in the protocol only embrace alterations in the intensity of activity. Match performance involves not only changes in running pace but also frequent alterations in direction as well as the performance of specifc game skills (i.e. kicking, tackling, heading). Such activities have been shown to increase the physiological cost over intermittent treadmill exercise (Bangsbo, 1994). The additional demands of the performance of a game skill have also been demonstrated by Reilly and Ball (1984). The energy cost of dribbling a soccer ball was found to increase linearly with the speed of running with the added cost of dribbling being constant at 5.2 kJ (1.24 kcal) min^{-1}.

The mean duration of each low intensity period (walking, jogging) for the protocol was 42.8 s. This figure is slightly less than the mean duration of 51.6 s found for each discrete low intensity bout during match-play in the work of Withers et al. (1982). The high intensity periods of activity in match-play have been shown to have a mean duration of 3.7 s (Withers et al., 1982). This is substantially less than the time periods involved for the high intensity bouts during the protocol (crusing 51.4 s, sprinting 10.5 s). However, the intensity at which such bouts were performed was reduced compared to match-play.

In conclusion, the protocol devised was an attempt to replicate the work-rate profiles of soccer players under laboratory conditions on a motorised treadmill and replicate physiological stresses of exercise patterns in soccer matches. The protocol can be deemed to approximate the intermittent activity pattern of soccer with high intensity exercise periods being separated by low intensity exercise bouts. Static pauses were also included. It is recognised that the protocol may have limitations with respect to the number of changes in the activity profile compared to match-play and the duration of the high intensity bouts of activity. Such a protocol was, however, only a model of match-play work-rates and was deemed sufficiently robust to be used in future investigations of metabolic responses to intermittent and continuous exercise at the same average intensity (see Chapter 5.1).

3.2. DETERMINATION OF BLOOD LACTATE SAMPLING INTERVALS DURING THE SOCCER-SPECIFIC INTERMITTENT PROTOCOL

3.2.1. Introduction

Adenosine-triphosphate (ATP) is the immediate energy source for muscular contractions. The body's ATP stores are limited and so therefore require continuous resynthesis during exercise. During periods of high energy demand where the oxygen availability is limited, the resynthesis of ATP takes place anaerobically. Phosphocreatine (PCr) forms an immediate reserve for the resynthesis of ATP with glycolysis also being of importance. Recent research suggests that glycolysis is activated almost immediately with the onset of vigorous exercise, leading to lactate formation (Boobis, 1987). The lactate response is mediated by factors such as exercise intensity (Stanley et al., 1986) and beta-adrenergic stimulation (Brooks, 1991).

The concentration of lactate in the blood is used as an indicator of "anaerobic lactacid" energy production in soccer. Blood lactate concentration represents the balance between production, release and removal (Bangsbo, 1994) as muscle is capable of simultaneously producing and removing lactate (Jordfeldt, 1970). This relationship is further altered during exercise (Mazzeo et al., 1986). Measurements of concentration in the blood therefore offer little information about rates of lactate appearance in the blood due to the simultaneous production and removal. Before the usefulness of blood lactate as an indicator of lactate production can be determined, a variety of factors need to taken into consideration.

The net output of lactate from muscle is time dependent and regulated by exercise intensity (Brooks, 1991). Lactate is metabolised within the active muscles following high intensity activity (Boobis, 1987). This removal is enhanced if low intensity activities are performed between high intensity bouts (Bangsbo and Saltin, 1993) as the metabolic clearance rate is increased. The lactate produced and then released to the blood is taken up by active muscle fibres for ATP resynthesis (Nordheim and Vollestad, 1990), by inactive muscles (Ahlborg,

1985) and tissues such as the heart, liver and kidney (Astrand et al., 1986). The uptake of lactate has been shown to be related to arterial lactate concentration. As a consequence not all of the lactate produced appears in the blood, resulting in an underestimation of lactate production. This idea is further supported by the finding of significantly higher lactate concentrations in muscle compared to blood. Jacobs and Kaiser (1982) observed that muscle lactate values varied between 4.5 and 14.4 $mmol.kg^{-1}$.w.w. at a blood lactate concentration of 4 $mmol.l^{-1}$ for individual subjects.

Evaluations of blood lactate concentrations are further complicated when the exercise is intermittent. The physiological responses to intermittent exercise have been shown to be mediated by factors concerning the exercise : rest periods (Christensen et al., 1960; Ballor and Volovsek, 1992). The duration of the exercise is believed to be the most critical factor in determining the level of lactate accumulation during high intensity intermittent exercise with the length of the rest pause also being of concern (Saltin et al., 1976). Blood lactate reaches more or less constant levels after an initial increase during intermittent exercise performance (Astrand et al., 1960; Karlsson and Saltin, 1971). Margaria et al. (1969) argued that this decrease in lactate production with time during intermittent exercise is the result of a reduced "oxygen" debt following the activity as the number of exercise bouts progresses due to a greater aerobic contribution to energy provision with time. Some evidence also exists for an inhibition of glycolysis with repeated maximal bouts (Spriet et al., 1989; McCartney et al., 1986; Gaitanos et al., 1993).

High intensity exercise (sprinting and cruising) is crucial in soccer match-play despite the total distance covered in the two activities being small compared to that covered in other activity categories. The frequency of high intensity bouts is also reduced compared to the that of lower intensity bouts (i.e. walking and jogging). Degradation of PCr and stored ATP will provide a considerable amount of energy required for these sprints due to their short duration, with glycolysis leading to lactate formation supplying the remainder. Blood lactate determinations during soccer match-play vary widely, both between players (Bangsbo, 1994) and for the same player during the same match (Bangsbo et al., 1991). These differences in concentration reflect the different activities performed prior to sampling. These factors have led Bangsbo (1994) to state that single blood lactate determinations cannot be considered to be representative of lactate production during an entire match as samples merely reflect and underestimate the lactate production in the minutes preceding sampling.

Blood lactate concentrations then are not only a function of the activity at the time of sampling but also of the previously performed activity. This has consequences for the conclusions that can be made from samples obtained during an intermittent exercise period as the activity is non-steady state. The aim of this study was to examine differences in blood lactate concentrations obtained at a constant speed during an intermittent exercise protocol. The findings from the investigation could also be used to evaluate the validity of the soccer-specific intermittent protocol devised in Chapter 3.1 as a model of match-play work-rates.

3.2.2. Methods

3.2.2.1. Subjects

Six male university soccer players were studied, mean ± s.d. characteristics shown in Table 3.2.1. Each subject was tested in the post-absorptive state, having performed no vigorous exercise or consumed any alcohol for 24 hours prior to testing. All the exercise periods were scheduled for the same time of day (15:00 hours) to remove the effects of any circadian variation on the variables measured (Reilly and Brooks, 1986).

Table 3.2.1. Mean ± s.d. anthropometric characteristics of the subjects

	Age (years)	Height (m)	Mass (kg)
Mean	24	1.77	72.8
s.d.	± 3.7	± 2.7	± 2.8

3.2.2.2. Procedure

Subjects' heights (m) and body masses (kg) were determined using a stadiometer and precision calibrated weighing scales . Each subject completed a standardised warm up prior to the experimental protocol. This involved 3 min of sub-maximal running on a motorised treadmill (Quinton instruments, Washington, USA) at 12 $km.h^{-1}$ followed by a short period of high intensity running at 21 $km.h^{-1}$. Subjects were also encouraged to perform some passive stretching. This was primarily concentrated on the lower extremities. Each subject then completed the soccer-specific intermittent protocol described in Chapter 3.1. This involved two identical 22.5 min intermittent exercise periods comprised of 6 discrete bouts of walking, 6 bouts of jogging, 3 cruises and 8 sprints separated by a 71 s static recovery period. Heart rate was measured continuously (5 s intervals) using short range radio telemetry (Sports Tester, Polar Electro, Kempele, Finland) during the protocol to provide an indication of circularory strain. Mean heart rates were calculated every minute for each subject. A heart rate range was also determined from the second minute of exercise to the end of the protocol (heart rate maximum during the exercise period - minimum heart rate during the exercise period). Finger prick blood samples (n=8) were taken for the assessment of blood lactate concentrations. These were taken immediately after the completion of the warm-up period and following the experimental protocol. The remaining 6 samples were taken whilst walking at 6 $km.h^{-1}$ in the low intensity recovery periods during the protocol, as shown in Figure 3.2.1.

15	12	21	6 (Sample)	12	21
6	21	12	15	6 (Sample)	21
12	21	6	15	6	21
12	21	12	6 (Sample)	21	Static

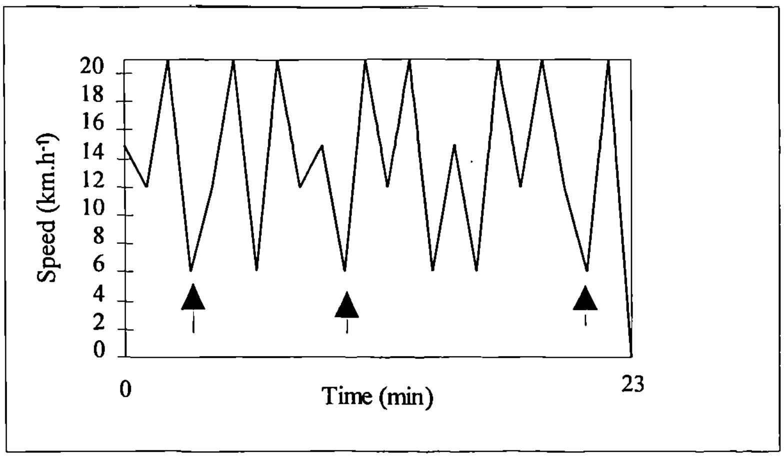


Figure 3.2.1. Diagrammatic representation of blood sampling intervals used in one period of the soccer-specific intermittent exercise period. Identical sampling intervals were employed during the second period. Figures in the diagram refer to treadmill speeds ($km.h^{-1}$).

Three samples were obtained during each repeating 22 minute 30 s exercise period. These were taken after exercise bouts at 21, 15 and 12 $km.h^{-1}$ during each half to examine any differences in blood lactate concentration at a 6 $km.h^{-1}$ period. The timing of the samples was identical in both exercise periods. All samples were kept under refrigerated conditions until analysis. Analysis of blood lactate was performed using an Analox GM-7 analyser (London, England).

3.2.2.3. Statistics

Differences between blood lactate concentrations obtained at 6 separate 6 $km.h^{-1}$ constant work periods during the intermittent exercise session were determined by a one-way analysis of variance test (ANOVA). The probability level for statistical significance was set at $P < 0.05$.

3.2.3. Results

Mean blood lactate concentrations ranged from 6.1±0.9 $mmol.l^{-1}$ to 8.5 ±1.7 $mmol.l^{-1}$ (Table 3.2.2). Mean lactate concentration was 7.7 ±0.6 $mmol.l^{-1}$.

Table 3.2.2. Mean ± s.d. blood lactate concentrations for the intermittent protocol

Sampling time	Mean	s.d.
After warm up	6.1	± 0.9
After 21 $km.h^{-1}$ period	6.8	± 1.2
After 15 $km.h^{-1}$ period	7.8	± 1.7
After 12 $km.h^{-1}$ period	8.0	± 1.4
After 21 $km.h^{-1}$ period	7.2	± 1.8
After 15 $km.h^{-1}$ period	7.6	± 1.2
After 12 $km.h^{-1}$ period	8.5	± 1.7
End of protocol	6.9	± 0.9

A one-way analysis of variance test was performed on the lactate values obtained during the protocol. No significant differences ($P< 0.05$) were observed between any of the sampling times. Figure 3.2.2 shows the blood lactate response in relation to the treadmill speed changes.

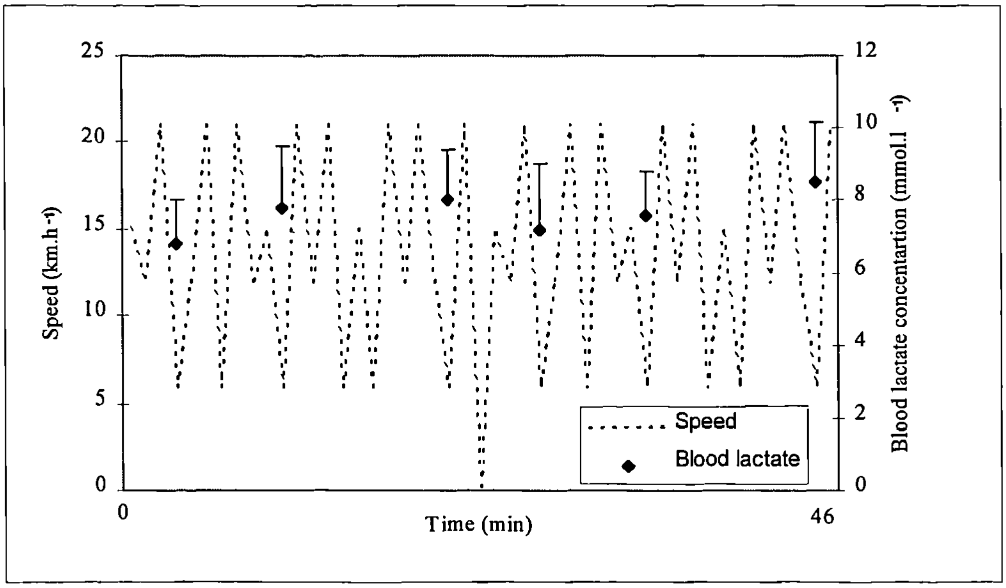


Figure 3.2.2. Mean ± s.d. blood lactate response ($mmol.l^{-1}$) in relation to treadmill speed ($km.h^{-1}$) to the soccer specific intermittent exercise protocol.

Figure 3.2.3. shows the mean heart rate and blood lactate response to the exercise period. The mean ± s.d. heart rate during the protocol was 172 ± 1 $beats.min^{-1}$ (Figure 3.2.3). The mean heart rate range was seen to be 41 ± 7 $beats.min^{-1}$.

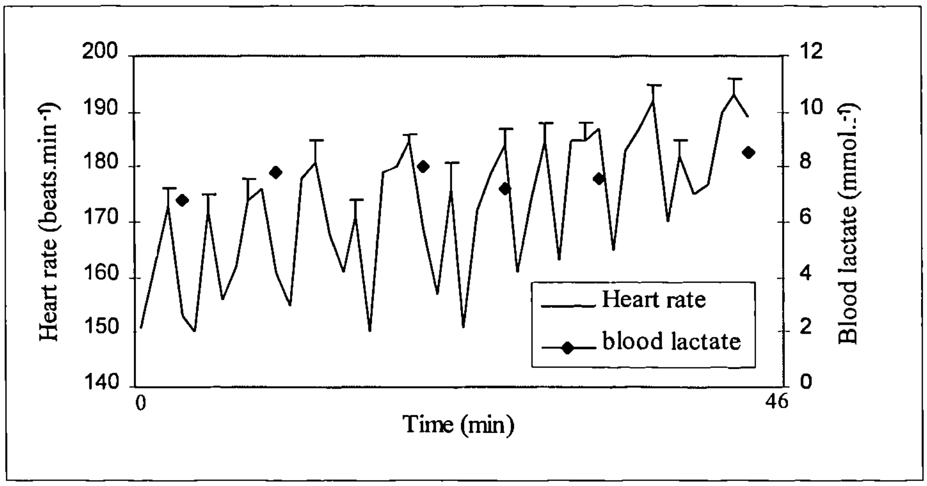


Figure 3.2.3. Mean ± s.d. heart rate and blood lactate response to the soccer-specific intermittent protocol.

3.2.4. Discussion

Blood lactate responses to a soccer-specific intermittent protocol were determined in an attempt to examine the effects of previous activity on blood lactate concentration. The mean blood lactate concentration during the protocol was 7.7 ± 0.6 mmol.l^{-1}. This is in close agreement with the blood lactate values obtained at half time for Swedish second division players (Ekblom, 1986) and slightly higher than the 4-6 mmol.l^{-1} found by Gerisch et al. (1988) in German amateur matches. Large variations have been observed in lactate production between individuals during game play (Bangsbo, 1994). Factors such as motivation, tactics, style of play and team strategy all affect the distance covered at a high intensity by an individual. These can be crucial in determining blood lactate concentration as a result of the close relationship between the high intensity running prior to sampling and blood lactate concentration (Bangsbo et al.,1991). The lactate levels observed as a result of the intermittent protocol indicate high levels of lactate production and suggest substantial anaerobic energy production.

A one-way analysis of variance revealed no significant differences between the six samples obtained during the protocol. This suggests that blood samples can be taken at any time during a constant work period to assess possible changes in blood borne substrates. A constancy of blood lactate level, during exercise indicates the balance of entry and removal from the blood (Brooks and Fahey, 1985). Table 3.2.2 shows that there was a tendency for the blood lactate concentration to increase at the corresponding sampling time during the second half of the protocol but this difference was not significant. This may simply reflect an increased anaerobic contribution to the energy demands as performance during high intensity exercise has been shown to be dependent on the ability to recover from the previous workbout (Jabobs, 1986). The blood lactate response has also been shown to be affected by the type of muscle fibres activated in response to the exerise stimulus (Jacobs, 1981). As the exercise intensity increases more fast twitch fibres, which possess a greater potential for lactate formation, are recruited. It is possible that recruitment patterns are altered as the protocol progresses due to fatigue thus resulting in a greater proportion of the muscle fibres producing lactate. The results obtained do, however, suggest that large amounts of lactate are removed during the low intensity recovery periods as no significant increases in blood lactate concentrations were observed. It is well documented that the rate of lactate clearance is increased if low intensity activity periods follow intense bouts of exercise (Brooks, 1991; Mazzeo et al., 1986). The most pronounced decreases have been shown to occur at work-rates of 60-70 % of maximal oxygen consumption (Hermansen and Stensvold, 1972). Fox et al. (1989) suggested that for optimal clearance rates active recovery should be performed at approximately 70 % of $\dot{V}O_2$ max for the first minute after exercise then at a reduced level of around 40 % in the remaining recovery period. The recovery bouts incorporated in the protocol are very close, and follow a similar pattern, to these suggestions thus implying possible optimal clearance rates. Lactate removal is therefore dependent on its concentration in muscle and blood and is likely to be increased as a result of the increased blood lactate levels observed in the protocol compared to resting conditions.

The mean heart rate of 172 $\pm$ 1 beats.min^{-1} is very similar to values obtained during match play. Van Gool et al. (1988) recorded values of 169 and 165 beats.min^{-1} for first and second half play respectively for Belgian university players while Bangsbo (1994) observed 6 Danish players with mean heart rates of 164 beats.min^{-1} for first half play. The heart rate range during exercise (41 $\pm$ 7 beats.min^{-1}) indicates the maintenance of a high heart rate throughout the protocol. High heart rates are probably maintained due to the short recovery period occurring in the protocol. It can be seen in Figure 3.2.3 that the heart rate gradually increases as the exercise period progressed. This increase in heart rate is due to a drop in stroke volume throughout the exercise period as a result of the redistribution of blood to subserve thermoregulation (Rowell, 1993). These alterations are referred to as cardiovascular drift.

In conclusion, blood lactate concentrations did not differ significantly though the blood lactate level did depend on the exercise intensity performed prior to sampling. This could be attributed to high clearance rates as a consequence of the low intensity recovery periods incorporated in the protocol or a reduction in the importance of glycolysis as an energy source as the subjects progressed through the protocol. Heart rate responses and blood lactate concentrations produced as a result of the exercise protocol were similar to those observed during match-play. Such similarities provide an indication of the usefulness of the soccer-specific intermittent protocol as a model of work-rates associated with match-play. The work-rate profiles associated with soccer are investigated in Chapter 4.1.

CHAPTER 4

QUANTIFICATION OF THE DEMANDS OF SOCCER MATCH-PLAY

4. QUANTIFICATION OF THE DEMANDS OF SOCCER MATCH-PLAY

This chapter contains results of two studies conducted in an attempt to quantify the demands of soccer match-play. In the first study techniques of motion-analysis were utilised to determine the work-rate profile of elite players and the relationship of such variables to individual anthropometric characteristics were investigated. The second study comprised an investigation into the usefulness of the doubly-labelled water technique as an indicator of energy expenditure during elite soccer match-play.

4.1. A MOTION-ANALYSIS OF WORK-RATE PROFILES OF ELITE INTERNATIONAL SOCCER PLAYERS

4.1.1. Introduction

The physiological demands of soccer can be examined by making relevant observations during match-play or obtaining physiological measures during real and simulated games : some indications of the demands of the game may be realised by determining the physical capabilities of elite players (Bangsbo, 1994). The application of time and motion analysis to soccer allows the objective recording and interpretation of match events (Reilly, 1994). The total distance covered during a game has been employed as an index of work-ratc (Reilly, 1990), as an individual's energy expenditure is directly related to mechanical work output (Reilly and Thomas, 1976). Such procedures provide only a crude estimation of the demands of the game as the activity pattern embraces frequent changes in activity. The data, as a consequence, have been used to determine work-rate profiles of players, the classification of actions being made with respect to type, intensity, duration and frequency of activities. Additionally the data can be set against a time base to provide an indication of the exercise:rest ratios observed.

Several investigators have used a wide variety of techniques to examine the motion characteristics of soccer players (Brooke and Knowles, 1974; Reilly and Thomas, 1976; Ohashi et al., 1988 and Bangsbo et al., 1991). Top level players cover around 10 km during a game with the vast majority of this distance being completed at low intensities. High intensity activity is relatively infrequent and short in duration. These activities can, however, be crucial to match outcomes. The physiological demands vary with the level of competition, playing style, positional role and environmental factors (Reilly, 1994). No data are available on the work-rate profiles of elite players during international competition. It is generally regarded that international level match-play imposes different technical and tactical restraints on players compared to domestic club competitions. Such changes may have a direct consequence for an individual's work-rate profile. As the present championship team at World Cup level is from Brazil, it is reasonable to focus on top South American teams as typical of international level. The null hypothesis can be formed as follows

Hypothesis 1: Elite South American international soccer players exhibit work-rate profiles that are no different from those observed for elite professional players in the English league

Past studies have highlighted that the anthropometric profile is an important selective factor for success in sport. Data from large studies, most notably at the Olympic Games, have shown differences in the anthropometric profile of athletes between sports and within sports by different events (Carter, 1976). Such findings have led to the belief that the quantification of these aspects of physique can lead to a better understanding of the relationship between physique and performance. There have, however, been few studies relating physical characteristics and performance, as previous work has primarily focused on the description of athletes and comparisons between and within sports. Direct experimental study of the relation between physical structure and performance is difficult because the athlete's training and development cannot be interfered with. The problem is further confounded by the fact that every successful athlete may possess exclusive qualities and characteristics that the somatotype, training and technique cannot describe or account for.

Some fitness and motor ability tests have been used in studying the relationship between somatotype and performance. Stepnicka et al. (1986) examined the relationship between the somatotypes of university students and performance on six performance tests e.g. pull ups, standing broad jump, 5 x 20 m shuttle run. The results indicated that the somatotype could predict 60 % of the dispersion of scores for the pull up result and 25 % of the dispersion for the shuttle run. Carter and Honeyman-Heath (1990) claimed that the relationship between an individual's anthropometric profile and performance is only relevant for gross motor skills such as strength, endurance and flexibility with performance on fine motor skills e.g. finger dexterity and typing being unrelated. It is therefore possible that physical activities which rely on strength, power, speed and endurance confine successful participation to somatotypes best suited for the requirements of the activity. Soccer match-play involves a combination of gross and fine motor skills in its performance. The relationship between a player's anthropometric profile and match performance has not yet been evaluated in the literature. It would therefore be of interest to examine the relationship between the player's anthropometric profiles and work-rate during games.

4.1.2. Methods

4.1.2.1. Subjects

Twenty eight (7 defenders, 8 midfielders and 7 forwards) full-time professional male soccer players were filmed for the determination of work-rate profiles. Twenty two of these were South American international players filmed while competing for their countries at the Copa America in Uruguay, 1995. The remaining 6 players (2 defenders and 4 midfielders) were full-time professional players from the English Premier League. It was originally intended to have identical numbers in the samples of South American and English Premier League players. The sample of English Premier League players represented the maximum amount of players that could be filmed due to difficulties in obtaining permission from the clubs and television companies for filming games. The English Premier League players were taken from two teams employing a 4-4-2 formation during the 1994-95 season. None of the players had any knowledge that he was being filmed. Five of the 22 South American international players were substituted during the 90 min of play in which they were being filmed in the time available. The failure to complete the entire match resulted in their exclusion from the final data analysis. This reduced the initial sample of 22 international players to 17 (7 defenders, 6 midfielders and 4 forwards).

4.1.2.2. Anthropometric profiling

Eleven of the 22 international players filmed were also included in a study to determine the anthropometric characteristics of elite soccer players. This was part of a project in collaboration with the International Society for the Advancement of Kinanthropometry (ISAK). Both filming and anthropometric assessment were facilitated by the medical physician of the Uruguayan Football Association. Forty five measurements were taken from each player. These included height (m), body mass (kg), 8 skinfolds (mm), 8 limb lengths (cm), 13 breadths (cm) and 12 diameters (cm). Measurements were taken by a trained Uruguayan team of physicians. The training sessions were observed by the experimenter and involved instruction on the appropriate technique and the assessment of the selected anthropometric characteristics of a group of volunteers. Anthropometric measurements were obtained using portable measurement devices. Calibrated precision weighing scales were used to evaluate body mass. A cursor placed upon the subject's head was used to measure height. Skinfold thicknesses were measured using a Harpenden skinfold caliper. Skinfold measures were taken at four sites, triceps, biceps, subscapular and suprailiac for the calculation of percentage body fat (Durnin and Womersley, 1974). Variables were chosen to examine any relationships between the individual's anthropometric profile and work-rate during the game. Both the total distance covered and the total distance covered in each activity category during match-play were related to the sum of 3 (triceps, subscapular and suprailiac), 6 (triceps, subscapular, suprailiac, abdominal, front thigh and calf) and 8 (triceps, subscapular, suprailiac, abdominal, front thigh, calf, bicep and iliac crest) skinfolds, the ratings of endomorphy, mesomorphy and ectomorphy (Heath and Carter, 1967), body mass and muscle mass (calculated from the equation of Martin et al., 1990) using Pearson's Product moment correlation coefficients.

4.1.2.3. Procedure

The following procedure relates to the filming and analysis of the Copa America games. Identical techniques were employed for the filming and analysis of the English Premier League games (only one player per game was filmed for the sample of English players whereas two experimenters, with one camera each, were employed at the Copa America). The activities of one player during the 90 min of match-play were recorded using a video camera (Sony TR 75E, Taiwan). The camera was positioned in a stand overlooking the pitch and close to the half-way line. This reduced the possibilities of other players restricting the view of the subject and also aided the positioning of the subject on the graphical representation of the pitch during the subsequent analysis. Two players were filmed per game at Copa America: in the majority of cases one player from each side was filmed. The players who were filmed were matched according to playing position (i.e. 2 forwards filmed in one game). These controls were made in an attempt to prevent the match outcome affecting the work-rate profile. On four occassions the two players observed were taken from the same side. This was done to increase the number of players that corresponded in both the anthropometry and work-rate studies. Under such circumstances the positions were again balanced so as to reduce any potential effects of the match result.

Videotapes were replayed on a television monitor and video (Sony Trinitron, Taiwan; Panasonic NV-F77) and analysed using a personal computer (Amstrad PC7486). Activities were separated into four activity categories based on the intensity of action. These were walking (divided into forward and backward movements), jogging (foreward, backward and sideways), cruising and sprinting. Static pauses were also recorded. The total distance covered for each 45 min period in each activity classification was estimated by plotting the players' movement patterns around the pitch in each activity category since the pitch dimensions were known. Data were thus provided on the total distance covered at each exercise intensity, the percentage of the total distance covered at each intensity, the average distance per exercise bout and the total distance covered during a match, calculated by the addition of the distances covered during each type of activity. Analysis was also linked to a time base to enable the percentage of the total time, average time and the total time for each movement classification to be determined.

4.1.3. Repeatability and Objectivity

Some of the observed differences between the results in the published studies can be a consequence of the methodologies applied to obtain the data on the players and subsequently to convert these readings to an estimation of the distance covered during game play (Bangsbo, 1994). Reilly (1994) stated that the methodologies employed for the measurement of distance must be reliable, objective and valid. The data collected previously have been affected from the weakness of the statistical techniques employed to establish the criteria stated above. The vast majority of studies have utilised correlation coefficients on the game totals to assess agreement. The high reliability values quoted in the previous research (e.g. Mayhew and Wenger, 1985) do not necessarily reflect high levels of agreement. Such analyses are strongly influenced by the range of scores (these tend to be wide in motion-analysis) and provide a measure of the relationship rather than the agreement between a test and re-test (Bland and Altman, 1986). The degree to which the correlation coefficient is affected by the range of values from a motion-analysis system when used to assess repeatability and objectivity has been established by Drust et al. (1997). It was shown that the assumptions regarding the repeatability and objectivity of a system are dependent upon the statistical procedures employed. The aim of the current investigation was also to develop statistical and methodological techniques to ensure the repeatability, objectivity and validity of the data.

Objectivity and repeatability were assessed by re-analysing one 45-min period of a designated game from the Copa America tournament. Repeatability was initially assessed 3 days after completion of the first analysis and was repeated after analysis of every 7 games throughout the data collection period (approximately every 7 days). This was done to determine the effects of any practice or learning effects on the data collected.

Another observer, who had previous experience in the use of computerised notation systems, was used for the determination of the objectivity of the system. Prior to the evaluation of the designated tape for the assessment of objectivity, both observers examined another game verbally coding match activities. This allowed some level of agreement in the classification of actions to be established between observers before the determination of objectivity.

The objectivity and repeatability of the motion-analysis were assessed in two ways. The motion-analysis system could only be deemed to be repeatable and objective if there was agreement between both the classification of activities during the match and the distance covered in each category. The level of agreement between the activity classifications for both repeatability and objectivity was determined using the number of exact agreements observed. A second by second breakdown of the results was obtained for each repetition of the 45 min period analysed. The 2700 observations obtained for each analysis were then compared manually and noted down in the form of a contingency table to allow the calculation of the exact number of agreements between data sets to be compared. This approach was then supplemented by the calculation of the number of agreements that could be expected by chance. The name for this measure of agreement is Kappa. Kappa statistics relate the number of exact agreements observed to that which can be expected by chance. Kappa can be assumed to have a maximum value of 1.0 when agreement is perfect and a value of zero when the agreement is no better than that which is expected by chance. No absolute definitions are available regarding the interpretation of kappa values between zero and 1, though Altman (1991) provided the guidelines for the assessment of agreement shown in Table 4.1.1.

Table 4.1.1. Guidlines for the assessment of kappa values (adapted from Altman, 1991)

Value of 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

Table 4.1.2 shows the number of exact agreements *k* values and the strength of the agreement according to Altman (1991) for all the repeatability assessments and the objectivity assessment. The percentages of the exact agreements for repeatability assessments were all observed to be 0.8 (80 %) the exception being the percentage for the second assessment. This figure has been determined as suitable for a complex system (van der Mars, 1989). All *k* values were in the bands moderate to good agreement, again suggesting a suitable level of agreement with respect to the classification of actions. The objectivity figures were similar to those obtained for repeatablity. The exact agreement for the objectivity assessment was 0.8 (80 %) with a *k* rating of 0.67 (good agreement).

Table 4.1.2. Number of exact agreements and *k* values for repeatability and objectivity assessments for the soccer motion system

	Exact agreements (%)	*k* value	Strength of agreement
Initial repeatability	80	0.71	Good
Second assessment	63	0.5	Moderate
Third assessment	80	0.71	Good
Final assessment	80	0.67	Good
Objectivity	80	0.67	Good

The repeatability and objectivity of the total distance covered in each activity category were examined using coefficients of variation, limits of agreement (Bland and Altman, 1986) and the coefficient of variation of the limits of agreement. A one-way ANOVA was used to determine if any large systematic bias existed between any of the samples of data. If significant bias is detected, the methodology employed should not be considered as repeatable or objective. No significant bias was detected in any of the samples tested. The difference between the first analysis and each subsequent set of data collected against the mean are shown on the Bland-Altman plots (Figure 4.1.1 and Figure 4.1.2). The difference between the two observers for the objectivity assessment against the mean is shown in

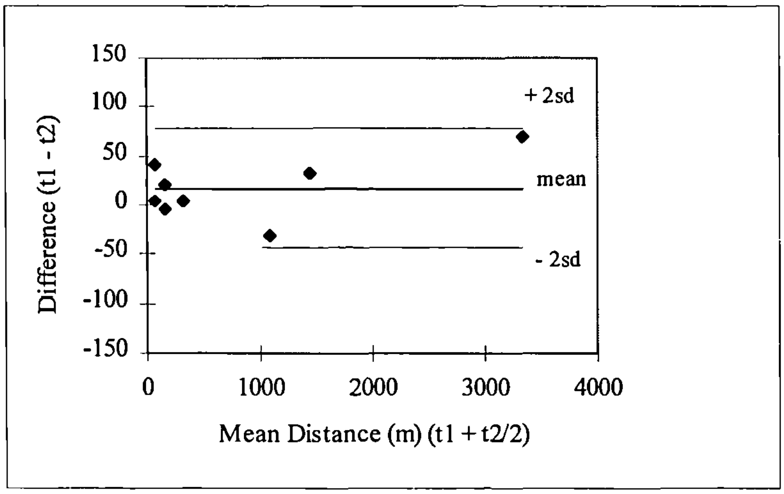
Figure 4.1.3. It is expected that 95 % of differences will lie between these limits. This variation represents measurement error. The Bland-Altman plots in Figure 4.1.1-4.1.3 would seem to suggest that a degree of heteroscedasticity is present in the data, implying that the coefficient of variation should also be calculated.

Table 4.1.3 shows the coefficient of variation, the limits of agreement and the coefficient of variation of the limits of agreement. Bland and Altman (1986) suggested that the amount of variation be ascertained correctly and meaningfully in context to what the equipment or test is to be used for. The limits of agreement ranged from ± 56.6 m up to ± 162.3 m for the repeatability checks and ± 172.5 m for objectivity. No other data are available in relation to motion-analysis systems using such techniques which makes interpretation of the current data difficult.

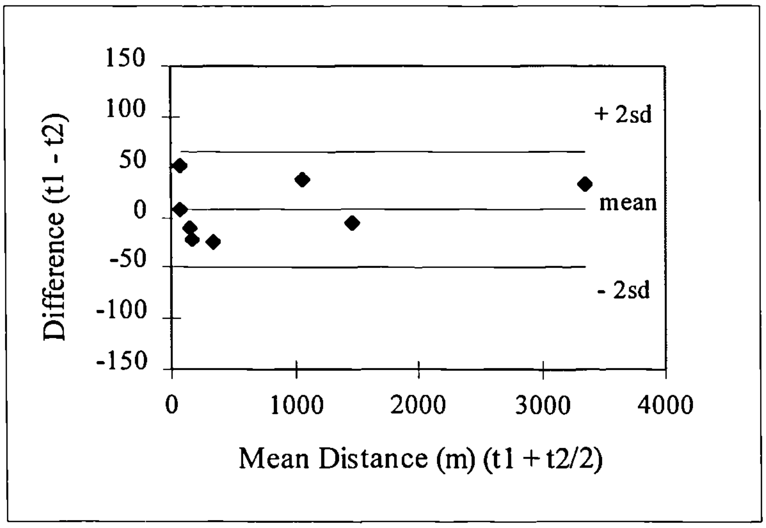
The coefficient of variation ranged from 3.7 % for the initial repeatablity check up to 10 % for the final assessment made after 22 games had been notated. All the coefficient of variation values were within the 10-15 % range suggested as acceptable for biological systems (Stokes, 1985). The coefficients of variation of the limits of agreement were calculated as these reflect a greater percentage of the population sample than the 67 % that is represented by the coefficient of variation. The coefficients of variation of the limits of agreement for repeatability and objectivity checks were, with the exception of the final repeatability check, below 15 %. The data would seem to suggest that the methodology for the determination of the total distance covered and the total distance covered in each category satisfies the criteria of repeatability and objectivity based on the current results.

4.3.1. Statistical Analysis

A three-way analysis of variance (ANOVA) was performed to compare differences in the total distance covered in the game between the international and Premier League players and the different playing positions. Significant differences were then explored using a one-way analysis of variance. The probability level for statistical significance was set at $P < 0.05$.

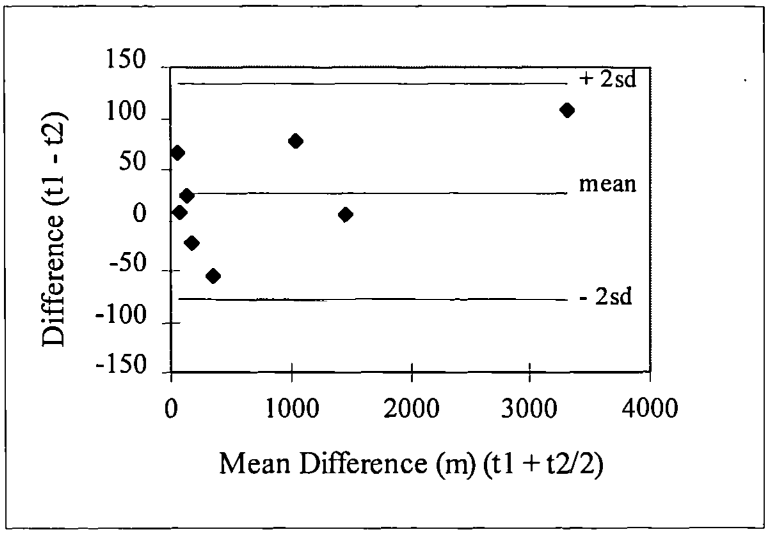


(a)

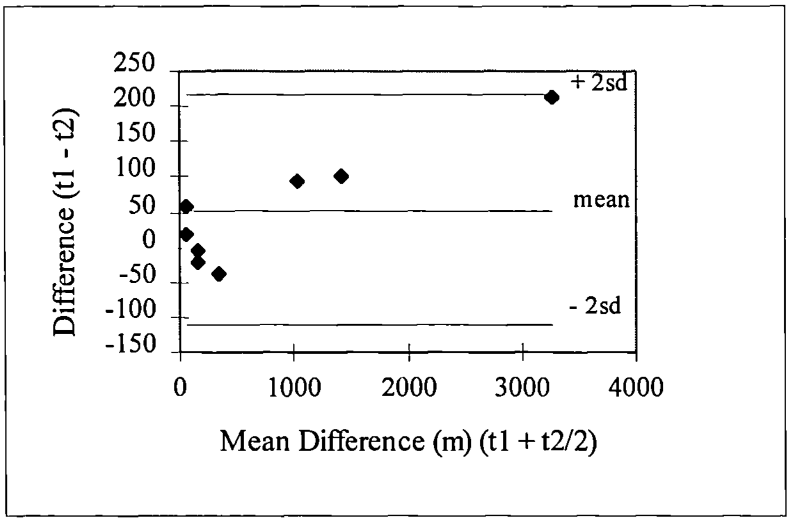


(b)

Figure 4.1.1. Bland-Altman plot for the distance covered in each category for the initial (a) and second (b) repeatability assessment



(c)



(d)

Figure 4.1.2. Bland-Altman plot for the distance covered in each category for the third (c) and final (d) repeatability assessment

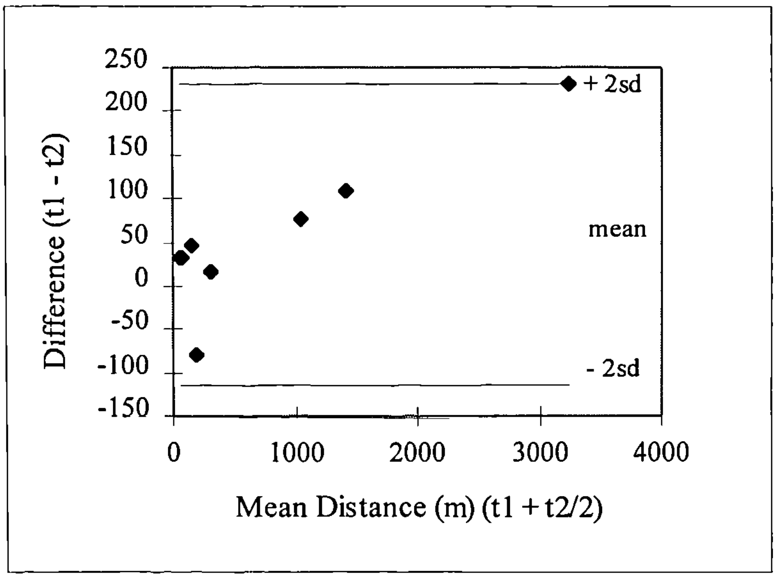


Figure 4.1.3. Bland-Altman plot for the distance covered in each category for the objectivity assessment

Table 4.1.3. Coefficient of variation, limits of agreement and the coeficient of variation of the limits of agreement for repeatability and objectivity assessments for the soccer motion system

	Coefficient of variation (%)	Limits of agreement	Coefficient of variation of the limits of agreement (%)
Initial repeatability	3.7	-42 to 77.6	7.2
Second assessment	3.5	-48.5 to 64.7	6.8
Third assessment	6.5	-78.7 to 132.9	12.7
Final assessment	10	-109.2 to 215.4	19
Objectivity	7.1	-114.8 to 230.2	13.9

4.1.4. Results

Figure 4.1.4 shows the total distance covered during first and second half match-play for the international players (first half 4389 ± 549 m; second half 4248 ± 628 m). The total distance covered was 8638 ± 1158 m. The English Premier League players covered a significantly ($P < 0.05$) greater distance during game play than the international players. The English Premier League players completed a total distance of 10104 ± 703 m over the 90 min playing period (first half, 5216 ± 388 m; second half 4889 ± 379 m). The total distance covered in each half differed significantly ($P < 0.05$) between the English Premier League and international players. A significant ($P < 0.05$) reduction was noted in the total distance covered in the second half compared to the first when the sample as a whole is examined.

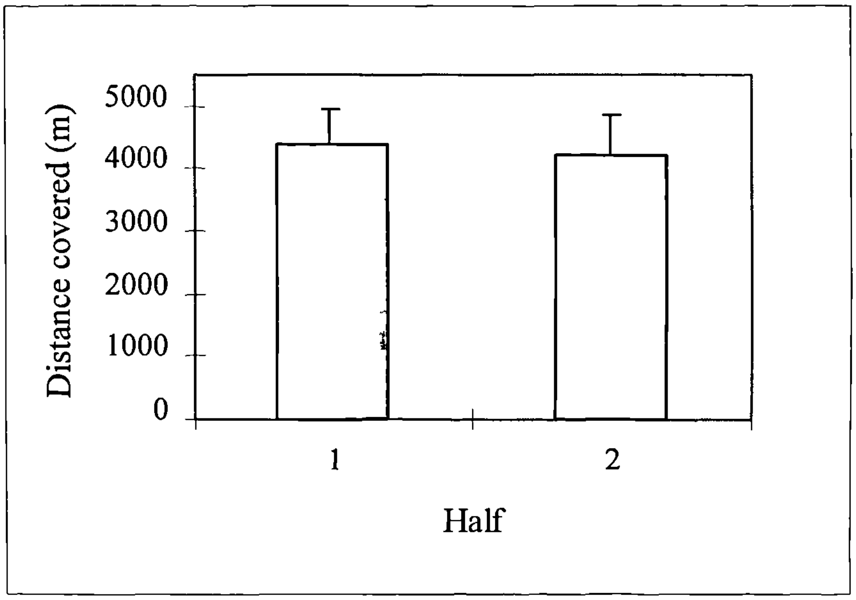


Figure 4.1.4. Mean ± s.d. covered during the first and second half for international players

The largest percentage of the total distance was covered jogging (42 %) with walking forward accounting for a further 32 % of the total distance (Figure 4.1.5). High intensity activity (cruising and sprinting) made up 15 % of the total distance covered. The major component of this high intensity work was performed cruising (11 %), the remaining 4 %

being covered sprinting. Utility movements accounted for 11 % of the total distance covered. This total figure was comprised of walking backwards (6 %), jogging backwards (2 %) and jogging sideways (3 %).

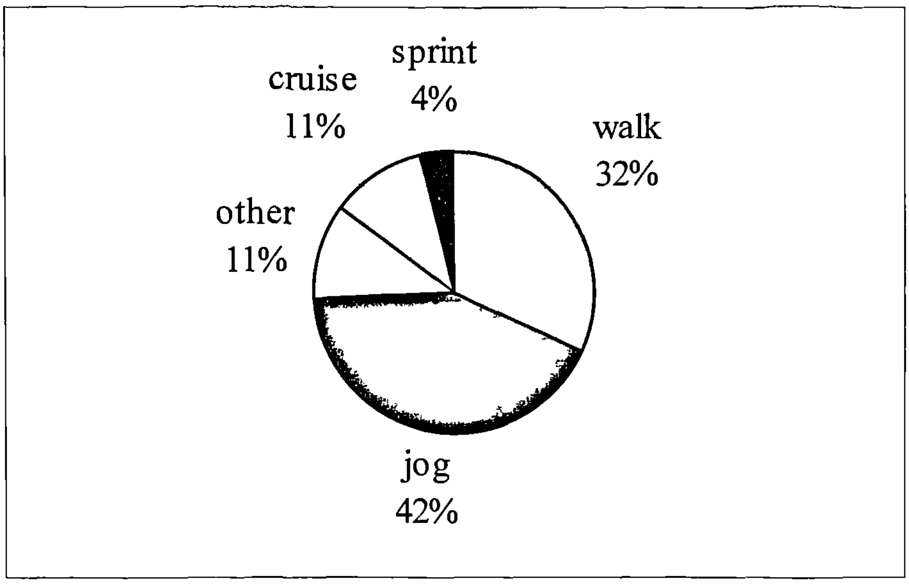


Figure 4.1.5. Percentages of the total distance covered in each activity category for the international players

These percentages can be further examined by relating them to the actual total distance covered in each category (see Figure 4.1.6). The total distance covered walking for the international players was 2721 ± 463 m. A further 530 ± 171 m was covered walking backwards. No significant differences were found between the international and English Premier League players for the total distance covered walking (International 2721 ± 463 m; English Premier League players 2427 ± 750 m). The distance covered walking backwards was significantly different ($P < 0.05$) between the groups with international players covering 530 ± 171 m compared to 641 ± 167 m for the English Premier League players. Jogging was comprised of forwards, backwards and sideways movements. No significant differences were observed between the international and the English Premier League players for the total distance covered in any of categories of jogging (forward, international 3702 ± 1152 m, English Premier League 5207 ± 1027 m; backwards, international 154 ± 103 m, English Premier League 525 ± 514 m; sideways, international 263 ± 182 m, English Premier League 379 ± 152 m). The high intensity distance was also similar between the 2 categories of players. The international players covered around 1268 m at a high intensity. Cruising accounted for 923 ± 360 m with the remaining 345 ± 222 m being performed maximally. English Premier League players were observed to cruise 887 ± 337 m and sprint 268 ± 136 m.

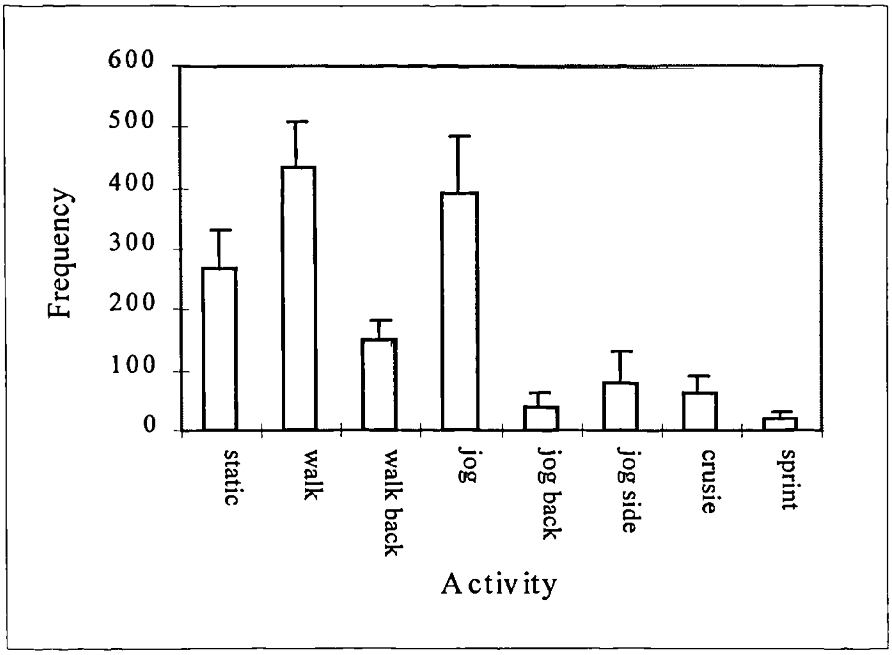


Figure 4.1.6. Mean ± s.d. frequency count for each activity category for the international players

The total number of activities performed during the game was 1431 ± 206. This amounts to a change in activity approximately every 4 s. The international players were observed to take 267 ± 64 static pauses during a game (Figure 4.1.6). Walking was the most frequently performed action with around 568 (forward 434 ± 75; backwards 150 ± 32) discrete bouts with players covering a slightly greater distance walking forward than walking backwards (Table 4.1.4).

Table 4.1.4. Average distance and average time spent in each movement category for the international players

Activity pattern	Average time (s)	Average distance (m)
Static	3.3 ± 0.7	NA
Walk	5.3 ± 1.2	6 ± 1
Walk back	3.7 ± 0.6	4 ± 1
Jog	3.8 ± 0.5	9 ± 1
Jog back	1.9 ± 0.4	4 ± 1
Jog side	1.6 ± 0.3	3 ± 1
Cruise	3.3 ± 0.8	14 ± 3
Sprint	2.8 ± 0.9	16 ± 6

The average distance covered jogging forward was larger than the average distance for jogging backwards and sideways. This difference was also reflected in the average duration of each bout. Jogging forward was performed more frequently (390 ± 97 bouts) than jogging backwards (39 ± 23) or sideways (80 ± 49). The largest distances covered per bout of activity were recorded for cruising and sprinting. These were also the least frequently performed of the major activities (cruising 65 ± 24; sprinting 21 ± 12).

Low intensity activities accounted for 80 % of the total time (Figure 4.1.7) with jogging (forwards, backwards and sideways) making up 30 % of the total and walking (forwards and backwards) 50 %. Cruising and sprinting accounted for 4 % and 1 % of the total time, respectively. The remaining 15 % of the total time was spent "static". The ratio of rest:low:high work was 3:16:1.

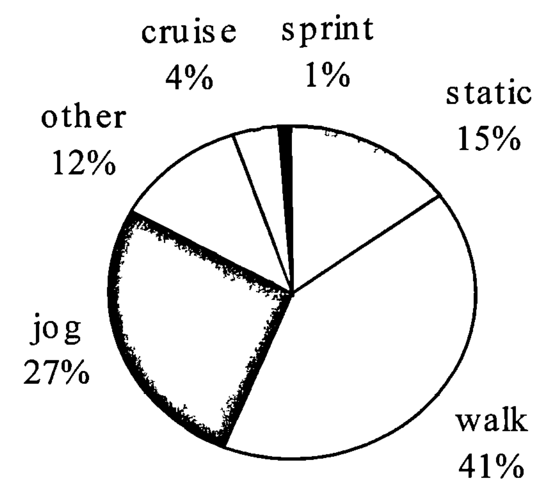


Figure 4.1.7. Percentage of the total time spent in each activity category for the international players

4.1.4.1. Variations according to playing position

No significant differences were found for any of the distance variables between positions for the international and English Premier League players separately (Figure 4.1.8). The two groups were also combined into one sample for analysis of any positional variations that may exist in the work-rate profiles. This increased the number of individuals in each playing position. Midfield players completed a significantly greater ($P < 0.05$) match distance than the forward players (midfield 9826 ± 1031 m; forwards 7736 ± 929 m). Defensive players covered a total distance of 8696 ± 976 m. A significant difference ($P < 0.05$) was also noted for playing positions for each half. Midfield players were found to cover a greater distance ($P < 0.05$) in the first and the second halves than forward players (midfield, first half 4999 ± 535 m, second half 4827 ± 511; forwards, first half 4076 ± 561, second half 3660 ± 384) with defenders covering an intermediate distance (first half 4402 ± 504; second half 4294 ± 493).

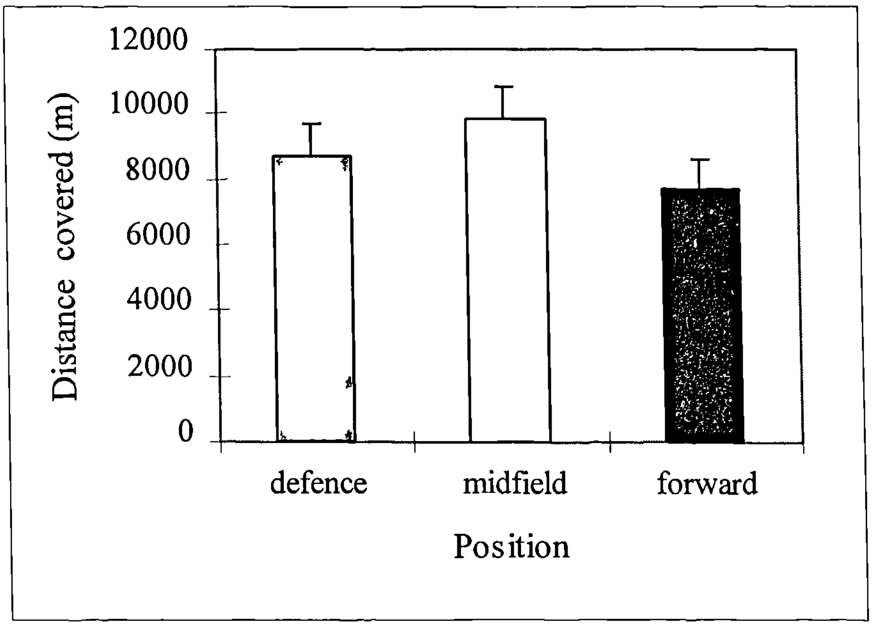


Figure 4.1.8. Mean ± s.d. total distance covered by playing position for all players

Differences between positions were further highlighted by examining the work-rate profiles for each position (see Figure 4.1.9). No significant differences were found between the total distance covered walking (defenders 2694 ± 324 m; midfielders 2454 ± 599 m; forwards 3008 ± 742 m). The total distance covered walking backwards was also similar in all three positions. Defenders covered 562 ± 161 m walking backwards with midfielders and forwards covering 569 ± 206 m and 526 ± 147 m, respectively. Significant differences were found between positions for the total distance covered jogging ($P < 0.05$). Midfield players covered a significantly greater distance jogging than forward players (midfield 4892 ± 1029 m; forwards 2606 ± 1383 m). Defensive players covered a significantly greater distance jogging backwards than the forwards. Defenders completed 276 ± 155 m jogging backwards with forwards and midfield players covering 68 ± 25 m and 300 ± 439 m. No significant difference was found between any of the positions for jogging sideways (defenders 362 ± 194 m; midfielders 319 ± 133 m; forwards 73 ± 25 m). The high intensity distance could be divided up into cruising and sprinting activities. Significant differences ($P < 0.05$) were found between positions for both the total distance covered cruising and sprinting. Midfield players (1110 ± 299 m) covered a significantly greater distance cruising than defenders (701 ± 276 m) with forwards covering a significantly greater distance sprinting than defenders (forwards 557 ± 288 m; defenders 231 ± 142 m).

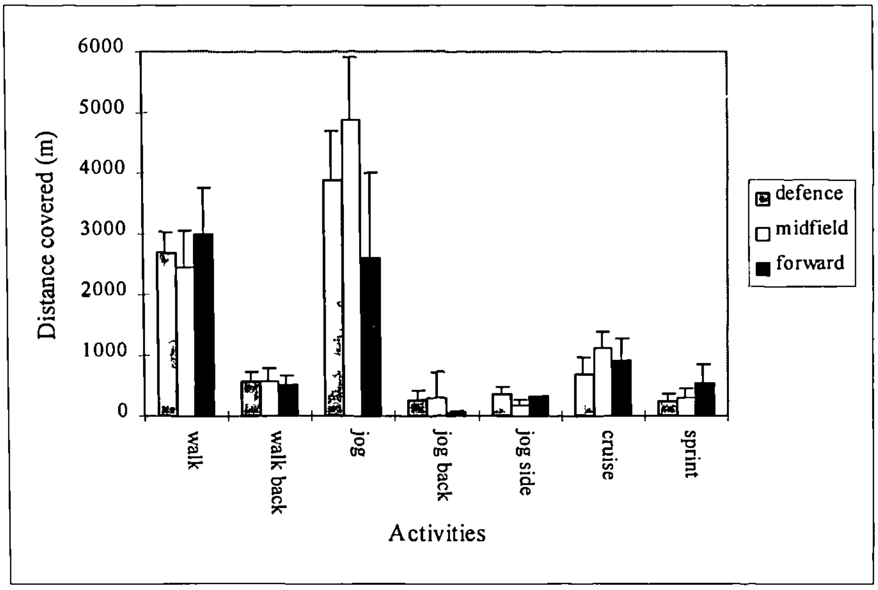


Figure 4.1.9. Mean ± s.d. total distance covered in each activity with respect to position in team

Figure 4.1.10 shows the frequency counts for the number of discrete bouts of each activity classification for defenders, midfielders and forwards for the 90 min game period. The total number of activity changes for defenders was 1459 ± 192 with midfielders and forwards changing activity 1440 ± 123 and 1205 ± 191, respectively.

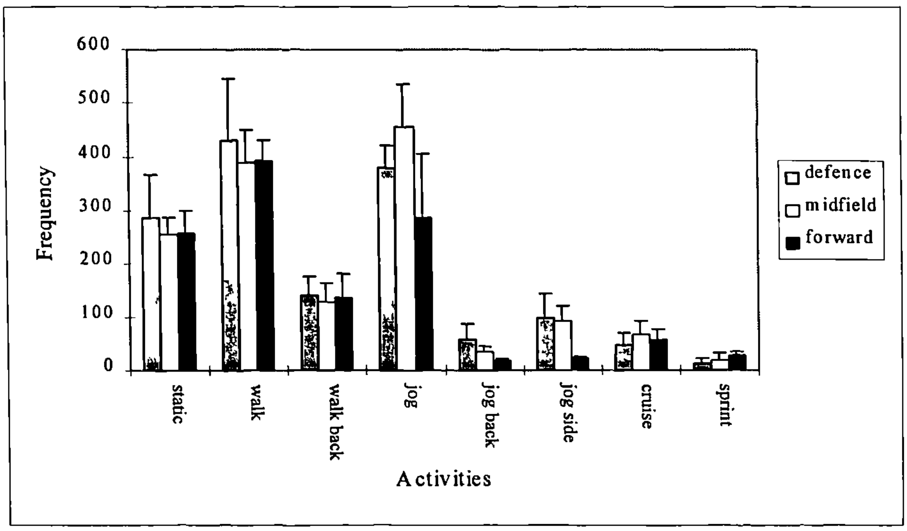


Figure 4.1.10. Mean ± s.d. frequency of activities with regard to playing position

Table 4.1.5. Mean ± s.d. average time (s) and distance (m) for each activity by playing position

	Average time (s)			Average distance (m)		
Activity pattern	D	M	F	D	M	F
Static	3.3 ± 0.3	3.1 ± 0.4	3.9 ± 1	NA	NA	NA
Walk	5 ± 0.7	4.8 ± 0.8	6.5 ± 1.6	7 ± 1	6 ± 1	8 ± 2
Walk back	3.6 ± 0.6	3.8 ± 0.4	4 ± 0.5	4 ± 1	4 ± 1	4 ± 1
Jog	4 ± 0.7	4.2 ± 0.4	3.7 ± 0.5	10 ± 2	11 ± 2	9 ± 1
Jog back	2.2 ± 0.6	2.2 ± 0.5	1.8 ± 0.4	5 ± 1	5 ± 2	4 ± 1
Jog side	1.8 ± 0.5	1.8 ± 0.3	1.6 ± 0.3	4 ± 1	4 ± 1	3 ± 1
Cruise	3.5 ± 0.1	3.9 ± 0.8	3.4 ± 0.7	16 ± 5	18 ± 5	15 ± 3
Sprint	3.1 ± 1	3.2 ± 1.3	3.2 ± 0.9	19 ± 8	19 ± 9	19 ± 5

Defenders (D), midfielders (M) and forwards (F) were observed to take 285 ± 79, 255 ± 31 and 260 ± 41 static pauses (Table 4.1.5). Each static pause lasted around 3 s on average. Walking and jogging were the most frequently performed activities occurring 406 ± 83 and 396 ± 94 occassions for the sample as a whole. No statistical analysis was performed on the frequency data as the frequency counts for the activity category were affected by the data entry procedure. Walking was performed most frequently by defenders (430 ± 115) with forwards performing 393 ± 37 and midfield players 389 ± 60 walks. Walking forward occurred more frequently than walking backwards (134 ± 35). Forward walks covered a greater distance for each position than backward walks (defenders, forwards 7 ± 1 m, backwards 4 ± 1 m; midfielders, forwards 6 ± 1 m, backwards 4 ± 1 m; forwards, forward 8 ± 2 m, backwards 4 ± 1 m). This trend was also reflected in the average time spent in each category (defenders, forward 5.2 ± 0.7 s, backwards 3.6 ± 0.6 s; midfielders, forward 4.8 ± 0.8 s, backwards 3.8 ± 0.4 m; forwards, forward 6.5 ± 1.6 s, backwards 4.1 ± 0.5 s).

Jogging was performed more frequently by midfield players than either forwards or defenders (midfield 456 ± 79, forwards 287 ± 117 and defenders 380 ± 39). Defenders, midfielders and forwards covered a similar distance (defenders 10 ± 2 m, midfielders 11 ± 2 m and forwards 9 ± 1 m) per jogging bout. These bouts also lasted for a similar duration (defenders 4 ± 0.7 s, midfielders 4.2 ± 0.4 s and forwards 3.7 ± 0.6 s). The average distance covered jogging forward was larger for all positions than the average distance for jogging backwards (defenders 5 ± 1 m, midfielders 5 ± 2 m and forwards 4 ± 1 m) and sideways (defenders 4 ± 1 m, midfielders 4 ± 1 m and forwards 3 ± 1 m). Jogging forward was performed more frequently for all positions (defenders 380 ± 39, midfielders 456 ± 79 and forwards 287 ± 117) than jogging backwards (defenders 58 ± 25, midfielders 35 ± 10 and forwards 18 ± 4) or sideways (defenders 99 ± 42, midfielders 91 ± 30 and forwards 21 ± 5).

The average distance per bout of cruising and sprinting was the same for all the playing positions. The average distance for each cruising bout was 16 ± 6 m for defenders, 18 ± 5 m for midfielders and 15 ± 3 m for forwards with the average distance per sprint being equal (defenders 19 ± 8 m; midfielders 19 ± 9 m and forwards 19 ± 5 m). The average time spent was also similar for the high intensity bouts (cruising, defenders 3.5 ± 1 s; midfielders 3.9 ± 0.8 s; forwards 3.4 ± 0.6 s; sprinting, defenders 3.1 ± 1 s; midfielders 3.1 ± 1.3 s; forwards 3.2 ± 0.8 s). Cruising was performed more frequently by midfielders (67 ± 25) than forwards (59 ± 10) or defenders (48 ± 23) with sprinting occurring more frequently in forwards (28 ± 3) than midfielders (19 ± 3) and defenders (14 ± 8).

4.1.4.2. Anthropometry and performance

The players' height and body mass (Table4.1.6) were 1.77 ± 0.4 m and 74.5 ± 4.4 kg respectively. The somatotype was 2.2 ± 0.7 - 5.4 ± 1.0 - 2.2 ± 0.6. The classification corresponds to a balanced mesomorph. The sums of 3, 6 and 8 skinfolds were 23 ± 6 mm, 48 ± 12 mm and 62 ± 16 mm. Percentage body fat of the players was 11.6 ± 3.3 %. Muscle mass calculated from the equation of Martin et al. (1990) was 47.9 ± 3.9 kg.

Table 4.1.6. Mean ± s.d. anthropometric characteristic of the international players (n=11)

Anthropometric variable	Mean ± s.d.
Height (m)	1.77 ± 0.4
Body mass (kg)	74.5 ± 4
Somatotype	2.2 ± 0.7 - 5.4 ± 1 - 2.2 ± 0.6
Skinfolds (mm)	
sum of 3	23 ± 6
sum of 6	48 ± 12
sum of 8	62 ± 16
Muscle mass (kg)	47.9 ± 3.9
Muscle mass (%)	63 ± 4.0

Pearson's product moment correlations between the anthropometric variables (sum of 3, 6 and 8 skinfolds, endomorphy rating, mesomorphy rating and ectomorphy rating, muscle mass and body mass) and the total distance covered in the game and in each of the activity classifications were calculated. Significant correlations were observed for the endomorphy rating and the total distance covered walking ($r = -0.66$, $P < 0.05$). No significant correlations were observed for any of the other relationships between the anthropometric variables and work-rate profiles. Some correlations, however, neared statistical significance. Endomorphy rating was found to correlate positively with the total distance covered jogging ($r = 0.60$). The total distance covered walking and jogging was also found to correlate with the sum of 3 (walking $r = -0.63$, jogging $r = 0.59$), 6 (walking $r = -0.62$, jogging $r = 0.60$) and 8 skinfolds (walking $r = -0.62$, jogging $r = 0.60$).

4.1.4. Discussion

The primary aim of the present investigation was to compare the work-rate profiles of South American international soccer players with those observed for elite professional players in the English Premier League during domestic club competitions. Anthropometric data were also available for the South American sample of players. This made it possible to investigate any relationships between an individual's anthropometric profile and the work-rate exhibited during a game.

The total distance covered provides a representation of the overall severity of the exercise and the individual contribution towards the total team effort (Reilly, 1994). The English Premier League players covered a significantly greater total distance during matches than did the South American international players. The total distance for the English league players is similar to the total distance covered by Swedish professional players (Ekblom, 1986), university players (Van Gool et al., 1988) and Danish professional players (Bangsbo et al., 1991). The total distance covered for the South American players is almost identical to the 8680 ± 1011 m observed by Reilly and Thomas (1976) for English First Division players (now the Premier League) in the 1970's.

Past research has shown that the work-rate profile can be altered as a result of factors such as level of play (Ekblom, 1986). It could be suggested that, based on these results, the English Premier League players are placed under a greater stress than the international players during match-play as the energy expended during a game has been shown to be directly related to the total distance covered (Reilly and Thomas, 1976). It is generally acknowledged that soccer in England is characterised by the need for players to display high work-rates during matches. The game is traditionally played at a very fast pace and requires individuals to perform a high level of activity in order to receive the ball from a team mate or to pressurise opponents in order to regain possession of the ball. The current data suggest that the international game is played at a slower overall pace. The tactical emphasis is placed on retaining possession and producing quick decisive passing movements when an opportunity is presented or created. Such tactical restraints reduce the need for players to perform a lot of unecessary activity and thereby may reduce their total distance covered. South American teams have also been associated with different playing styles from their European counterparts. The differences in work-rate may then be further compounded by the sample of international players being drawn from South American countries.

It is possible that the observed difference in the total distance covered between the English Premier League and the international players is the result of the sample of players as opposed to "real" differences between the groups. The Premier League players included in the sample were predominatly midfield players. This sub-group covers a significantly greater distance during match-play than the other positions (Reilly and Thomas, 1976). Examination of the total distance covered by the international midfield players allows a direct comparison to be made between the two groups. The international midfield players covered a total distance of 9402 ± 1065 m. This figure is less than the data available on the four English midfield players (10460 ± 5158 m). This would suggest that the difference in the total distance is not a direct consequence of the sample of players chosen. Nevertheless, the present data here demonstrated a difference between professional players in the English Premier League and individuals in the Copa America Championship that indicate real differences in behaviour of contemporary players.

More detail regarding the work-rate profile of players can be obtained by examining the total distance covered in each category for the two samples of players. The total frequency count for the number of discrete bouts of each activity classification for the international players for the 90 min game was 1431 ± 206. This amounts to a change in activity approximately every 4 s. No significant differences were observed for the total distance covered in any of the activity classifications between the English and international players, except for walking backwards. The English Premier League players covered a significantly greater distance walking backwards than the internationals (English Premier League 641 ± 167 m; international 529 ± 171 m). The English Premier League players also had a tendency to cover a larger distance than the international players in all the jogging categories though these differences were not significant. The international players showed a tendency to cover a greater distance walking forward than English Premier League players (international 2721 ± 463 m; English 2427 ± 750 m) but this difference was not significant. These observations would seem to suggest that there is a tendency for international players to walk during low intensity periods of play while English Premier League players tend to jog. These differences may be a function of the difference in the pace of the game between the two levels of play. The pace of the game at top club level in the English Premier League requires players to jog into position while the slower pace at which the international game is played allows them to walk.

If the details of the percentage of the total distance covered in each of the respective movement categories for the international sample are examined, it can be seen that around 42 % of the total distance was covered jogging with 32 % covered walking forward. Utility movements accounted for approximately 11 % of the total distance with walking backwards making up 6 % of the 11 % total and jogging backwards and sideways 2 and 3 %, respectively. The percentages for jogging, walking and utility movements are similar to those observed in the work of Reilly and Thomas (1976). These figures support those from the previous research suggesting that the majority of the total distance covered is performed at sub-maximal levels, illustrating the importance of the aerobic contribution to the energy expended. This is also illustrated by examining the percentage time spent in low intensity sub-maximal activities. Low intensity activities accounted for 80 % of the total time with jogging comprising 30 % and walking 50 % of the total time.

The distance covered in high intensity activities has been shown to be the most stable observation in the work-rate profiles of players (Bangsbo et al., 1991). The international players were found to cover 15 % of the total distance at a high intensity. The major component of this high intensity work was cruising (11 %) with the remaining 4 % covered sprinting. The percentage of high intensity work for the international players was greater than that observed for Danish players (Bangsbo et al., 1991) yet less than that observed by Reilly and Thomas (1976) and Withers et al. (1982). High intensity work accounted for 5 % of the total time, with static pauses making up the remaining 15 %. The mean ratio of rest : low intensity work : high intensity work was observed to be 3 : 16 : 1. Bangsbo (1994) quoted a mean ratio between high speed running, low speed running and standing/walking for Danish players of 1 : 4.3 : 7.1. The difference between the two ratios are probably more a function of the interpretation and classification of the types of activity than differences in the work-rate profile. The ratio for rest : low intensity work : high intensity work observed in the current investigation again suggests that the majority of the energy demands of soccer are sub-maximal and aerobic in nature. The high intensity bouts are infrequent and short in duration. These work : rest ratios can only give a rough indication of the activity pattern for a player during a match as the pattern can vary greatly from player to player and from game to game.

No significant differences were found between the playing positions (defenders, midfielders and forwards) for either the English Premier League or the international players in terms of the total distance covered. When the two groups were combined in order to increase the sample size some positional variations in the data became apparent. Midfield players covered a significantly greater distance than forward players. The different playing styles and the limited number of observations in past studies make it difficult to draw firm conclusions regarding the differences in work-rate between positions. It is, however, generally acknowledged that midfield players cover larger distances during a match than other players (Reilly and Thomas, 1976; Withers et al., 1982 and Ekblom, 1986). This greater distance has been attributed to two, or a combination of both, factors (Bangsbo, 1994). Midfield players serve as a link between the forward and defensive players in the team. Their duties include not only supporting attackers in the pursuit of goals but also assisting defenders in their defensive duties. Such requirements require a greater total distance to be covered during the game as the running is sustained. Midfield players are also characterised by higher aerobic fitness levels than other positions, thus making them less susceptible to the reduction in work-rate associated with fatigue (Reilly and Thomas, 1976). Midfield players also generally have the most tactically flexibile roles within the team. This allows them to come closest to utilising their full performance capacity.

Defensive players, in the current investigation, covered a significantly greater distance jogging backwards than did forward players. Bangsbo et al. (1991) provided some evidence from their research on Danish players to indicate that defenders covered a larger distance travelling backwards than the other two positional groups. The increased distance covered jogging backwards for defensive players is also a result of their specific positional requirements. Defenders are often required to retreat towards their own goal as the attacking team advances. It is advantageous for this movement to be completed while defenders are still facing the direction of play. This will require them to travel in a backwards motion towards their own goal. Defenders are also called upon to "jockey" attacking players who are in possession of the ball in order to get themselves in an appropriate position to attempt a tackle and possibly win the ball. Such jockeying activities are almost exclusively performed in one of the utility categories. Midfield players are also frequently required to perform defensive activities. This may provide an explanation for the large total distance covered moving backwards by midfielders.

Significant differences were also noted between positions with respect to the total distance covered at a high intensity. This is in contrast to the work of Bangsbo et al. (1991) who did not find any significant differences between positions for the distance covered at a high intensity. Midfield players covered a significantly greater distance cruising than defenders while forward players covered a significantly greater distance sprinting than defenders. The forward players' work-rate profile is characterized by sudden bursts of high intensity activity in order to facilitate a positive creation of space or to move on to a goal scoring opportunity. These high intensity bouts are interspersed with low intensity recovery periods that seem to indicate a lack of direct involvement in the play. It can thus be assumed from the data available from the present investigation that the forward players exhibit a more anaerobic profile of activity than the other positions.

The average distance and time spent in high intensity bouts were similar between all three positions. The average time and distance spent cruising was to 3.6 s and 17 m. Discrete sprinting bouts were found to cover 19 m and last 3.1 s. These figures are almost identical to the mean duration of 3.7 s found by Withers et al. (1982) and the 2.0 s observed by Bangsbo et al. (1991). The data suggest that high intensity exercise is relatively infrequent with bouts being short in duration. The importance of high intensity activity cannot be over-emphasised in match-play despite their relatively small quantitative contribution (Reilly, 1996). Cruising was performed more frequently by midfield players, sprinting being performed more frequently by forward players. Midfield players and strikers have previously been shown to sprint more frequently than defensive players (Reilly and

Thomas, 1976) though no significant differences have been observed between the three positions in terms of the total distance covered (Bangsbo et al., 1991). This was not the case in the current investigation as significant differences were found between positions for both the total distance covered cruising and sprinting. It has already been suggested that an individual's physiological attributes can influence the work-rate profile. Complementing the high positive correlations that have been observed between aerobic power and the distance covered per game is the finding that $\dot{V}O_2$ max can also influence the number of high intensity bouts that players attempt in a match (Smaros, 1980). The findings of the present study, in relation to the high intensity activity, are therefore easily explained if superior fitness levels are observed among the midfield players and forwards, in the current sample, as the literature suggests.

The total distance covered in the second half was reduced compared to the first for the sample as a whole, irrespective of position. A reduction in the total distance covered in the second half has also been observed by Reilly and Thomas (1976) and Van Gool et al. (1988). The difference between the two halves was around 6 % for the data in the current investigation. This figure is in the order of 5 % reported by Bangsbo et al. 1991. Bangsbo et al. (1991) performed a more detailed analysis of the work-rate patterns in the first and second halves and found that the difference was caused by more low intensity exercise in the first and last 15 min in the first half when compared to the second. No difference was observed in the high intensity running distance throughout a match so it was concluded that the shorter distance covered was not a reflection of a decreased performance potential. The data in the present study did not demonstrate any significant differences between the first and second halves for any of the activities classified. This would seem to suggest that the decline in work-rate is not at the expense of any one intensity but rather is distributed evenly across all categories. There was a tendency for the jogging ($P = 0.09$) and sprinting distance ($P = 0.11$) to be lower in the second half than in the first. The total distance covered walking was also increased in the second half compared to the first. These differences were not significant. Players may therefore exhibit a reduction not only in the total distance that they can cover but also in the exercise intensity that the remaining distance can be performed at.

Towards the end of the game the fatigue that is manifest as a reduction in work-rate may occur as a result of the exercise performed earlier in the match. The extent that this fatigue is experienced by players has been shown to be negatively related to aerobic power (Reilly, 1990). Nutritional status may also play a role in the onset of fatigue (Saltin, 1973) as performance decrements are often related to a decrease in muscle glycogen (Bangsbo, 1994). There may also be a role for other physiological factors in the onset of fatigue. Bangsbo (1994) demonstrated that potassium may be implicated in muscular fatigue due to its progressive accumulation which leads to ion disturbances over the sarcolemma affecting excitation-contraction coupling. It is possible that reductions in the total distance covered in the second half of games do not have physiological causes at all but are simply a factor inherent in match-play. Performance in soccer is the result of the interplay of a number of inter-dependent factors. There is a tactical, technical and psychological component as well as the physical input. As a game progresses the outcome of the match becomes more certain. This will have tactical consequences for the teams involved in the game and also psychological effects, in terms of motivation, for the players. Such factors may affect an individual's willingness or ability to perform and hence affect the work-rate displayed. The information obtained from the total distance covered during a game is limited as these distances only partially represent the physiological demands placed on players (Bangsbo, 1994). No information is provided about other characteristics of the actions (e.g. speed of performance, tactical consequences of the action) that are crucial to the activity.

Data available on the anthropometric characteristics of soccer players suggest that a wide variety of body shapes and sizes is evident (Reilly, 1996). Certain characteristics are not determinants of success but may rather lead to individuals being more predisposed to specific positions. The height and body mass for the international players were 1.77 ± 0.4 m and 74.5 ± 4.4 kg, respectively. These figures are similar to the heights and body masses observed for Italian professional players (Faina et al., 1988) and English League First Division players (now Premier League) by Reilly (1979). Data from other studies have observed taller and heavier individuals (Bansgbo and Mizuno, 1988). Such average values have a limited use for comparative purposes when the variability is large (Reilly, 1990). The interpretation of the average body size may be further complicated as the samples of players may also be made up of different racial or ethnic groups. A large proportion of the sample in the current investigation was made up of players of different racial backgrounds. These ranged from white to Mestizo (South American Indian) and black players. Such factors will directly contribute to the variability of the sample and make comparisons difficult.

Somatotyping is a technique that provides a quantitative description of the present morphological confirmation and composition of the body. It therefore reduces body measurements to a simple overall description of physique. The somatotype is represented on three dimensions - endomorphy, ectomorphy and mesomorphy. The somatotype for international players was 2.2 ± 0.7 - 5.4 ± 1 - 2.2 ± 0.6, representing a trend towards mesomorphy or muscularity. This somatotype rating is similar to the 2.1 - 5.1 - 2.3 observed for top Hungarian players (Apor, 1988). Such a muscular profile would be of benefit to a player in the performance of match activities. Heading, tackling, kicking, accelerating and turning would be among the match actions that could be related to the level of muscular development especially in the lower limbs (Reilly, 1996).

Body composition is important for soccer performance as superfluous adipose tissue acts as a dead weight where body mass must be lifted repeatedly against gravity (Reilly, 1990). The sums of 3, 6 and 8 skinfolds are reported in the current investigation. The sums of 3 skinfolds was 22.8 ± 5.8 mm with 47.9 ± 12.1 mm and 61.8 ± 16.3 mm being recorded for 6 and 8 skinfolds, respectively. Such data are difficult to compare with the values produced in the past research as the sum of skinfolds are rarely reported. A comparison between the relative adiposity of the players can be made by examining the percentage body fat. The percentage body fat of the South American players was 11.6 ± 3.3 %. This is in the range reported by Reilly (1990) for soccer players. The habitual activity of players at the time of their assessment as well as their diet and the stage in the competitive season have all been shown to be important in the assessment of body composition (White et al., 1988). Observations may also depend on the technique of the measurement or estimation of the percentage body fat (Reilly, 1990).

An alternative to adiposity ratings is to produce an estimation of muscle mass from a selection of anthropometric measures using the equation of Martin et al. (1990). Muscle mass was observed to be 47.9 ± 3.9 kg. This figure again reflects the tendency for a muscular make up amongst players and is larger than the 43.3 ± 7.3 kg observed for 48 undergraduate students who regularly participated in sport (Coldwells et al., 1993). This trend is still evident when the muscle mass is expressed as a percentage of body mass (South American players, 63 ± 4.0 %; students 58.4 ± 5.2 %).

Pearson's product moment correlation coefficients were utilised to examine the relationship between anthropometric varaibles and work-rate profile. No significant correlations were found for any of the relationships between the anthropometric variables and work-rate except the endomorphy rating and the total distance covered walking ($r = -0.66$). The endomorphy component of the somatotype relates to the body's "roundness" and adiposity. A significant negative relationship between the total distance covered walking and endomorphy rating implies that a leaner individual walks further than a player with a larger proportion of his body composition made up of fat mass as extra adipose tissue does not have to be repeatedly lifted against gravity during movement. Players with extra adipose tissue may therefore require longer static rest pauses between bouts of exercise as opposed to the active walking recovery sessions demonstrated by leaner individuals. This may have consequences for performance since work-rate may be compensated.

Performance of gross motor skills (e.g. pull ups, standing broad jumps) has been found to be positively correlated to an individual's anthropometric profile (Stepnicka et al., 1986). The relationships between anthropometric characteristics and performance in intermittent exercise have not yet been evaluated. Performance in soccer is the result of a variety of interdependent factors. Players very rarely tax their physical capacities to the limit during a soccer match due to the tactical responsibilities placed upon them. There is a need for individuals to possess a high degree of both aerobic and anaerobic fitness. The majority of top class soccer players only possess a high capacity within some of the physical categories (i.e. aerobic power, anaerobic capacity). The success of a team depends on its ability to choose a playing strategy that fits the strengths of the available players. The same is true of the players' anthropometric characteristics. The variability in the anthropometric profile is large, with players being chosen for certain positions depending on their physical characteristics. The failure to observe significant correlations between anthropometric profiles and work-rates may be due to the difficulty in examining such a relationship when there are many other factors that may mask the relationship. For example, players may be unable to perform to their maximum capabilities due to the tactical restrictions placed upon them by the coaches. The relationship between anthropometry and work-rate is complex though it is possible that factors such as somatotype and body composition may only prove to be an overiding concern for work-rate during performances that require a maximal stress being placed on the bodys'energy systems.

To summarise, differences in total distance covered in South American internationals and English Premier League players may be the result of tactical differences between the levels of competition or between the different continents. A significant reduction was also observed to occur in the total distance covered in the second half for the both groups of players. This difference was not at the expense of any particular activity category but was dispersed across the categories. No significant differences were found between the different positions for the different countries. Nevertheless when the sample size of professional players was increased by combining the two groups of players, some significant differences between the playing positions were found. Midfield players covered a significantly greater total distance due to a larger distance covered jogging and cruising than forwards and defenders. The larger total distance is probably the result of their linking function between the defence and attack and their greater tactical flexibility. Defenders performed more utility movements as they return to their position to make tackles and win the ball. Forward players exhibited a more anaerobic profile with sudden bursts of activity being interspersed with low intensity recovery periods that seem to indicate a lack of direct involvement in play. The anthropometric profile observed for the South American players was similar to that previously observed in the literature. No significant relationships were observed between the individual's anthropometric profile and work-rate except for endomorphy rating and the total distance covered walking. The failure to find significant correlations between the two variables is probably the result of the complex interaction between the variables that determine an individual's match performance.

In conclusion, the total distance covered during soccer match-play varied with the type of competition and between different elite playing populations. Differences in work-rate profiles were also observed between positions, thus indicating some degree of positional specificity in the demands of the game. Despite these differences the major demands are still placed on the aerobic energy systems with anaerobic efforts being concentrated around critical match actions. Work-rate was reduced in the second half of games compared to first half play. This reduction was not at the expense of any specific activity and reflects the onset of fatigue as the game goes on. The anthropometric characteristics of elite South American soccer players indicate that players are highly muscular but low in adiposity. Relationships between anthropometric profile and work-rate are difficult to determine due to the complex interaction between the variables that determine work-rate.

4.2. INVESTIGATION INTO THE USEFULNESS OF THE "DOUBLY-LABELLED WATER" TECHNIQUE TO INDICATE ENERGY EXPENDITURE DURING ELITE SOCCER MATCH-PLAY

4.2.1. Introduction

The measurement of energy expenditure in free-living humans has been carried out in the past by making estimations based on heart rate, food intake diaries and activity questionnaires. One of the more recent developments in this area has been the development of the doubly-labelled water technique (DLW). The DLW technique involves the use of stable isotopes to measure energy expenditure. The first recorded use was on animals by Lifson et al. (1955) with Schoeller and Van Santen (1982) pioneering the technique in humans. This was primarily a result of improvements in the precision of mass spectrometry, an increase in the availability of the isotopes and a reduction in their cost.

The DLW technique is based on the observation that the oxygen in expired carbon dioxide is in isotopic equilibrium with the oxygen in body water. Consumption and equilibration of a dose of isotopically enriched water containing the stable isotopes ^{18}O and deuterium (D) result in the loss of the two isotopic labels, during physical activity through normal physiological mechanisms (sweat), in proportion to their concentration in the body water. However, the turnover rate of oxygen is higher than D since it is also lost during expiration as carbon dioxide. The difference in the turnover rates of the two isotopes is therefore proportional to carbon dioxide production. Using a measured or assumed respiratory exchange ratio, along with estimated carbon dioxide production, the oxygen consumption and energy expenditure can be calculated (Stager et al., 1995).

The DLW technique has been calibrated for use on humans by comparison with respirometry (Klein et al., 1984; Schoeller and Webb, 1986; Ravussin et al., 1991 and Schultz et al., 1992), dietary intake (Schoeller and Van Santen, 1982; Edwards et al., 1993 and Westerterp et al., 1986), combined heart rate and indirect calorimetry (Emons et al., 1992) and heart rate profiles combined with physical activity reporting (Racette et al., 1995). The accuracy of the technique has been found to be in the region of 2-8 % in the above studies. The precision of the data obtained is known to be affected by the level of activity of the subjects (Westerterp et al., 1988) and an individual's body composition, the technique underestimating the energy expenditure in obese subjects (Ravussin et al., 1991).

Techniques that result in the determination of energy expenditure in free-living humans have possible implications for use in soccer match-play. It is generally impractical to make physiological measurements on players during serious competitions (Reilly, 1990). This makes it very difficult to obtain valid estimations of an individual's energy expenditure during games. The DLW technique requires an optimal observation period of 1-3 half-lives in order to obtain accurate estimates of energy expenditure. In view of the estimated energy expenditure in soccer (75 % $\dot{V}O_2$ max for 90 min), it is likely that such turnover rates are not present over the period of a soccer game which would therefore result in the technique being unsuitable for use during matches. The aim of the current investigation was to confirm that the DLW technique is inappropriate for the assessment of energy expenditure during soccer match-play. Comparisons of the results produced by the DLW technique with those produced by techniques of motion-analysis were also made.

4.2.2. Methods

4.2.2.1. Subjects

Two full-time professional male soccer players from the English Premier League were studied. These were taken from the same team which employed a 4-4-2 formation. Data were collected on both players in the same first team home league match during the 1994-95 playing season. One of the two players was a central midfield player, the other being a central defender. Video motion-analysis was employed, as well as the DLW technique, to provide an indication of energy expenditure.

4.2.2.2. Procedure

4.2.2.2.1. Video analysis

Each player was filmed by means of a video camera (Sony TR75E, Taiwan) for the entire duration of the 90 min game. The total distance covered during match-play has been employed as an indicator of a player's energy expenditure; this information could then be compared to the estimations provided by the DLW method. The camera was positioned in a stand overlooking the pitch and close to the half-way line. Videotapes were replayed on a television monitor and video (Sony Trinitron, Panasonic NV-F77) and analysed using a personal computer (Amstrad PC7486). Full details of the procedures for analysis of the videotapes were described in Chapter 4.1.

4.2.2.2.2. Doubly-labelled water

Both subjects were provided with the isotopically enriched solution and a full list of instructions (see Appendix 2) two days before the designated game. The dose equated to 0.3 $g.kg^{-1}$ body weight of ^{18}O (at 99 % atom excess) and 0.12 $g.kg^{-1}$ of D (at 10 % atom excess). Prior to administration each subject provided a small urine sample to enable the calculation of the background levels of the isotopes. This was necessary as both isotopes are naturally occurring in the body.

The enriched drink was consumed approximately 4 hours prior to kick off. This allowed the dose of isotopically labelled water to equilibrate with the subjects' body water pools before the match commenced. It was emphasised that the isotope should be drunk immediately and completely finished since a reduction in the volume of the solution due either to evaporation of the fluid or not drinking all of it would lead to errors in the final analysis. Two 1 ml venous blood samples were taken from an antecubital vein by an experienced phlebotomist. An initial sample was taken before the players ran onto the pitch prior to kick-off with the second being obtained after the players came back into the changing rooms after the game. The difference in the rate of loss of the two isotopes provided an indication of carbon dioxide production and hence energy expenditure over the game. One of the two players provided a urine sample at the aforementioned times as he did not wish to provide a blood sample. The DLW analysis was carried out by an expert in the School of Biological and Earth Sciences at Liverpool John Moores University. The procedure followed is outlined in Appendix 3.

4.2.3. Results

The total distances covered for the first and second halves for the two players are shown in Table 4.2.1. Player 1 (midfield player) covered 5498 m for the first 45 min period compared to 4842 m for the second half. Player 2 covered a total distance 5071 m and 4503 m in the first and second half, respectively. Mean ± s.d. total distance covered was 9957 ± 541 m.

Table 4.2.1. Total distance covered (m) for the 2 players during the 90 min of soccer play (player 1 = midfield player, player 2 = defender)

	First	Second	Total
Player 1	5498	4842	10340
Player 2	5071	4503	9574

Table 4.2.2 shows the total distance covered in each activity classification for both players. Player 1 covered a greater percentage of the total distance jogging than player 2 (59 % compared to 52 %), this difference probably being the result of a lower percentage of the total distance covered walking (player 1, 17 %; player 2, 26 %). Differences were also observed in the percentage of the total distance covered in utility movements (backwards and sideways movements) (player 1, 12 %; player 2, 17 %) and the distance covered at a high intensity. Player 1 covered 13 % of the total distance covered either cruising or sprinting with player 2 covering 4 % of his total distance at a high intensity.

Table 4.2.2. Total distance covered (m) in each activity classification for the 2 players analysed (player 1 = midfield, player 2 = defender)

Activity	Player 1	Player 2
Walking	1729	2484
Walking backwards	686	566
Jogging	6098	5008
Jogging backwards	1531	420
Jogging sideways	374	683
Cruising	974	374
Sprinting	324	36

The energy demands placed on players have also been shown to be increased by the frequent changes in activity observed during match-play. The mean ± s.d. total number of activities performed during the game was 1382 ± 102. Table 4.2.3 shows the frequency counts for the total number of activities performed and the number of discrete bouts of each activity.

Table 4.2.3. Frequency counts for the 2 players analysed during the 90 min of match-play (player 1 = midfield, player 2 = defender)

	Player 1	Player 2
Total	1455	1310
Static	233	299
Walk	296	277
Walk back	149	124
Jog	561	394
Jog backwards	35	70
Jog sideways	109	130
Cruise	55	15
Sprint	17	1

The calculated energy expenditure according to the DLW method was 11.3 $kJ.min^{-1}$ for player 1 and 12.1 $kJ.min^{-1}$ for player 2. For accurate results a minimum rate of isotope turnover is required. With the analysis used in the current investigation a minimum rate of isotope turnover of 35-40 % is required for accuracy of calculation to overcome the errors inherent in analysis. Isotope turnover was found to be 15.5 % and 13.2 % for player 1 and player 2 respectively. Neither of these figures reached the critical turnover rate required for analysis. The figures provided therefore should not be utilised as they include analytical error as well as an indication of match-play energy expenditure.

4.2.4. Discussion

The aim of the present investigation was to evaluate the usefulness of the DLW technique as an indicator of the energy expenditure during elite soccer match-play. The energy expenditure calculated according to the DLW method was around 12 $kJ.min^{-1}$. This value possibly underestimates the energy cost of match-play as it includes the rate of resting metabolism and the half time period when the player's activity will be low. If a value of 5 $kJ.min^{-1}$ is assumed for resting metabolism (Reilly, 1990) the rate of energy expenditure during the 90 min of play, based on the DLW method, would be around 17 $kJ.min^{-1}$. The mean relative work-rate in soccer is around 70 % $\dot{V}O_2$ max. The energy expenditure, projected from heart rate data, at such work-rates is around 70 $kJ.min^{-1}$ (Reilly (1979). The figures produced in the current investigation therefore represent a substantial underestimation of the likely energy costs of soccer.

The results obtained in the current study are affected by the analytical error associated with the level of turnover of the isotopes. It is, therefore suggested that the DLW technique cannot be used to estimate short term energy expenditure during a soccer match. Large variations have been noted in individual work-rate profiles during soccer match-play. Differences have been observed between individuals within a team, for players between games and between teams (Ekblom, 1986). A possible consideration is that the failure to provide an adequate minimum rate of isotope turnover is the result of the players selected for analyses and their respective work-rates. Both the total distance covered during the game and the activity profile of the two players during the game are similar to those reported elsewhere within this thesis (see Chapter 4.1) and the previous literature (see Chapter 2.1). This would seem to indicate that the level of turnover would be inadequate for a 90 min match irrespective of individual differences within the work-rate profiles of players. The DLW technique has been shown previously to be unsuitable for the accurate assessment of short term energy expenditure unless it is used in combination with other methods and the sampling period is extended over whole days (Creagh, 1996). Creagh (1996) had attempted to use DLW to evaluate the energy expenditure of a 100 min treadmill run at 13 $km.h^{-1}$. The level of isotope turnover was found to be outside acceptable limits thus rendering the approach unacceptable for the assessment of short term energy expenditure.

The two players were also filmed during the game to provide an indication of each individual's work-rate profile during the game, as the total distance covered has been employed as a index of energy expenditure. It was envisaged that the work-rate profiles produced could then be compared with the estimation of energy expenditure from the DLW technique. This was, however, impossible due to the problems inherent in the DLW data. As has already been stated, both the total distance covered during the game and the activity profile for the two players were similar to those reported within this thesis and the previous literature. The total distance covered was 9957 ± 541 m. When this total distance was divided into its component parts with respect to intensity, it was found that the two different playing positions adhered to some of the positional trends discussed in Chapter 2.1.6.1. The midfield player was observed to cover a greater distance than the defensive player with a larger proportion of this total distance being covered jogging forwards (6098 m compared to 5008 m). A larger distance was also covered by the midfield player at a high intensity. Cruising and sprinting accounted for 1319 m for the midfield player compared to 402 m for the defender. These differences are probably the result of the positional requirements of the players.

It seems, on the basis of the presents results, that the DLW technique cannot be used to determine short term energy expenditure during a soccer match. The technique has been shown to be of use over a period that allows adequate isotope turnover (between 0.5 and 3 biological half-lives, Schoeller et al., 1995) and energy expenditures. Values in the literature would suggest that such energy expenditures needed for soccer would only be obtained after a period of days (Creagh, 1996). The technique may prove useful in the determination of the energy expenditure of soccer players during training camps as these are often used in the build up to important matches or international tournaments. It is unlikely that the technique will be widely applied in sports physiology despite the potential for its use, due to the financial cost of the isotopes and the specialised analysis tools required.

CHAPTER 5

METABOLIC RESPONSES TO SOCCER-SPECIFIC INTERMITTENT EXERCISE

5. METABOLIC RESPONSES TO SOCCER-SPECIFIC INTERMITTENT EXERCISE

This chapter contains two studies that consist of attempts to quantify the physiological and metabolic responses to laboratory based soccer-specific intermittent exercise. In the first study the physiological costs of soccer-specific intermittent exercise and steady-rate work at the same average intensity are examined. The effects of high ambient temperatures and whole-body pre-cooling on soccer-specific intermittent exercise performance are examined in the second study.

5.1. COMPARISON OF THE PHYSIOLOGICAL RESPONSES TO SOCCER-SPECIFIC INTERMITTENT EXERCISE AND CONTINUOUS EXERCISE AT THE SAME AVERAGE INTENSITY

5.1.1. Introduction

Invasive field games, such as soccer, are characterised by activity profiles that are intermittent in nature. High intensity periods of anaerobic exercise are superimposed on a background of endurance running. Around 1400 changes in the activity profile are observed during match-play (see Chapter 4.1). Such alterations embrace not only changes in pace and direction but also the performance of crucial match actions. This separates soccer from sports that exhibit a more continuous exercise profile (such as cycling, running and swimming) and as a consequence results in the physiological demands being more complex.

Various researchers have examined the physiological responses to intermittent exercise and compared them to continuous work at the same average intensity in an attempt to evaluate differences between the exercise patterns (Astrand et al., 1960; Christensen et al., 1960; Edwards et al., 1973; Essen, 1978). Intermittent exercise has been associated with higher oxygen uptake, heart rate, ventilation, respiratory exchange ratios and blood and muscle lactate concentrations than observed for continuous exercise at the same average intensity

(Edwards et al., 1973). A greater proportion of the increased oxygen consumption occurred in the recovery periods during intermittent exercise. Differences have also been observed between continuous and intermittent exercise in terms of high energy phosphate use (Chasiotis et al., 1987). Other researchers have failed to note changes in the energy cost associated with intermittent exercise compared to continuous exercise (Christensen et al., 1960; Astrand et al., 1960). For example, Essen (1978) noted a similar metabolic response between intense intermittent exercise (100 % $\dot{V}O_2$ max with 15 s exercise and rest periods) and continuous exercise performed for a 60 min period on a cycle ergometer. Oxygen uptake, heart rate and arterial lactate, glucose and free fatty acid concentration were not significantly different between the intermittent exercise session and continuous exercise after 5 min or upon cessation of exercise.

Discrepancies in the previous research may be partly explained by the experimental protocols employed in the studies that have been used to compare intermittent to continuous exercise. Christensen et al. (1960b) argued that the durations of the exercise and rest periods are of critical importance in the physiological responses to intermittent work. Oxygen consumption, ventilation and blood lactate have all been shown to be sensitive to changes in exercise:rest ratios (Christensen et al., 1960b; Ballor and Volovsek, 1992). The intensity of activity performed in the recovery periods may also lead to changes in the responses to subsequent exercise. A variety of factors relating to the intensity and duration of intermittent exercise and rest can, therefore, affect the results obtained from studies. Findings may be only applicable to the combination of variables studied in each experimental protocol (Ballor and Volovsek, 1992).

The available data regarding the relative metabolic and physiological responses to intermittent compared to continuous exercise are based largely on experimental protocols with regular variations in intensity and duration of exercise:rest periods. The recovery periods are also restricted to static pauses between intense exercise bouts. Such restrictions limit the application of the findings to the specific physiological demands of soccer where activity bouts are separated by recovery periods at a lower intensity as well as static pauses and the changes in pattern are irregular. Attempts have been made to develop protocols that in some way replicate the activity patterns observed in the multiple sprint sports (e.g.

soccer, hockey, basketball). Nevill et al. (1994) used a cycle ergometer in investigating thermal strain during intermittent and continuous exercise. The intermittent protocol consisted of 30 min of repeating cycles of 90 s activity at 40 % $\dot{V}O_2$ max followed by a 6 s sprint and 24 s passive rest. Mean heart rate, oxygen consumption blood lactate and ammonia were all significantly increased during intermittent exercise over the continuous exercise response. Significantly greater increases in tympanic and rectal temperature were also observed in the intermittent exercise period compared to continuous exercise.

Intermittent exercise has been shown to result in an increased physiological strain being placed on the body (e.g. increased oxygen consumption, increased heart rate) compared to continuous work at the same average intensity. Other researchers have failed to find such differences in the physiological cost between the two forms of exercise. Differences that exist in the data comparing the two forms of exercise may only apply to the specific testing conditions under which they are examined. Changes in the frequency and duration of exercise:rest pauses or the activity performed in recovery bouts may therefore affect the observations. Few research groups have examined the physiological demands of intermittent activity patterns representative of soccer. No data are available regarding the relative physiological costs of such activity compared to continuous exercise at the same average intensity. The aim of this study is to compare the physiological responses to a soccer-specific intermittent exercise protocol to steady-rate work at the same average intensity.

Hypothesis 2 : The physiological strain associated with soccer-specific intermittent exercise performance is not different from the physiological strain (e.g. similar oxygen consumption, heart rates) imposed on individuals from that of steady-rate exercise performed at the same average intensity.

5.1.2. Methods

5.1.2.1. Subjects

Seven male university soccer players were studied. Subject characteristics are shown in Table 5.1.1. All subjects gave their written informed consent in accordance with university ethical procedures. These were tested in the post-absorptive state between 10:00 and 12:00 hours, having performed no vigorous exercise or consumed any alcohol for 24 hours prior to testing. Each subject performed all the exercise periods at the same time of day to remove the effects of any circadian variation on the variables measured (Reilly and Brooks, 1986).

Table 5.1.1. Mean ± s.d. characteristics of the subjects (n = 7).

	Age (years)	Height (m)	Mass (kg)	Maximal oxygen consumption ($ml.kg^{-1}.min^{-1}$)
Mean	24	1.78	72.2	57.8
s.d.	± 2	± 0.5	± 5	± 4

5.1.2.2. Procedure

Each subject visited the laboratory on three separate occasions. Each visit was separated by approximately six days. The first visit entailed the assessment of the individual's maximal oxygen consumption ($\dot{V}O_2$ max). The intermittent and continuous exercise protocols were completed during the second and third sessions. The order of completion of the exercise protocols was determined by a random numbers table (see Appendix 4).

5.1.2.3. Pre-test assessment

Maximal oxygen consumption ($\dot{V}O_2$ max) was assessed on a motorised treadmill (Quinton, Washington, USA). Subjects performed a standardised warm-up before the maximal test. This consisited of 3 min submaximal exercise at 11 km.h^{-1}. The exercise intensity during the maximal test was raised by 2 km.h^{-1} every 2 min from a starting speed of 11 km.h^{-1}. Once the subject reached 17 km.h^{-1} the exercise intensity was increased until the subjects reached voluntary exhaustion by inclining the treadmill belt by 2.5 % every 2 min. Expired air was collected continuously and analysed using a Sensormedics 2900 metabolic cart (Yorba Linda, California, USA). Heart rate was measured continuously (5 s intervals) using short range radio telemetry (Sports Tester, Polar Electro, Kempele, Finland). The British Association of Sport and Exercise Sciences' (BASES) criteria were employed to check that maximal oxygen consumption had being reached. These included a respiratory exchange ratio of 1.15 or above and a increase in $\dot{V}O_2$ of less than 2 ml.kg^{-1}.min^{-1} with each new work-load. Subjects were verbally encouraged throughout the final stages of the exercise period.

5.1.2.4. Intermittent and steady-rate protocols

Each subject completed two experimental protocols. Mean ± s.d. laboratory temperature and relative humidity were 18 ± 3.3 ^{o}C and 54 ± 12 %, respectively. On one occasion a soccer-specific intermittent protocol was completed, on the other a steady-rate exercise session was completed at the same average intensity. Figure 5.1.1 shows a diagrammatic representation of the intermittent protocol. The soccer-specific intermittent protocol devised for the study consisted of activities (e.g. walking, jogging, etc.) as observed during soccer match-play. Details of the soccer-specific intermittent exercise protocol and its development were given in Chapter 3.1. The protocol was arranged around two identical 22.5 min periods separated by a 71 s static recovery period. This figure was based on half of the total time players stood still during a 90 min game (Reilly and Thomas, 1976). This gave a total test duration of 46 min 11 s. The use of two identical periods thus allowed comparisons to be made between the physiological responses to the two periods of activity.

The steady-rate exercise was performed for an identical time period at 12 km.h^{-1}. This was the same average intensity as that of the intermittent protocol.

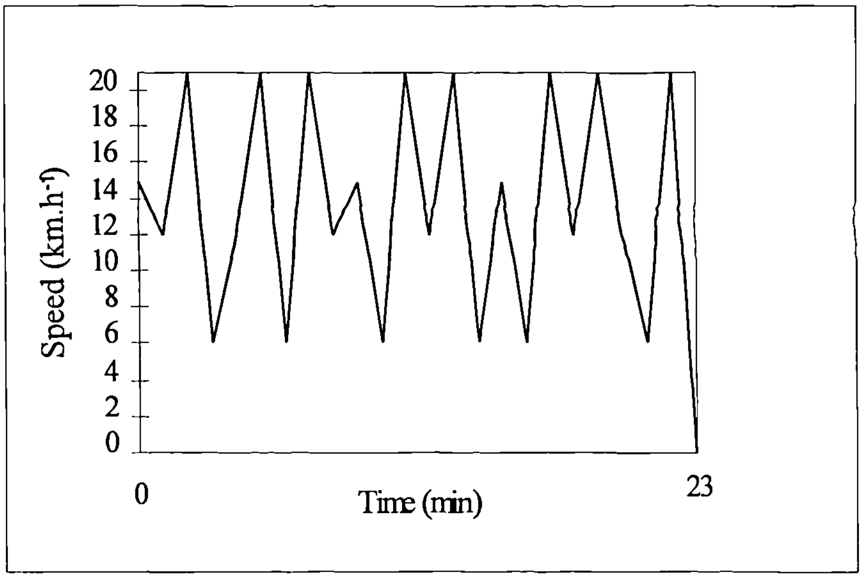


Figure 5.1.1. Diagrammatic representation of one half of the soccer specific intermittent protocol.

Prior to completion of the exercise bout each subject's height and body mass were determined using a stadiometer and calibrated precision weighing scales. Nude body mass was also evaluated before and after the exercise period to provide an indication of sweat production rate. This permits an estimation of the fluid loss during exercise. Care was taken to make sure all the sweat on the subject at the time of assessment was towelled off. Sweat production values were also corrected for evaporative water loss from the respiratory tract (Mitchell et al., 1972).

Expired air was collected continuously and analysed as before throughout the exercise period for the determination of the oxygen consumption during the exercise trial. Response times for oxygen and carbon dioxide analysers were 200 ms for 90 % at 300 ml.min^{-1} flow and 100 ms for 10-90 % at 250 $ml.min^{-1}$ flow, respectively. Measurements were integrated and recorded by means of an on-line system every 20 s. Ventilation rate was also assessed by a unidirectional anemometer. Mean values for oxygen consumption and minute ventilation (VE) were calulated for each minute for each subject. Heart rate was monitored continously (5 s intervals) to provide an indication of the circulatory strain. Mean heart rates for each minute were calculated for each subject. Finger prick blood samples were taken before, during (at 23 min) and upon completion of the protocols. No data from these samples were available due to a breakdown in the freezer in which they were stored in. Changes in core temperature were measured by use of a rectal temperature probe and thermometer (Light Laboratories, Brighton, England). The rectal probe was positioned 10 cm beyond the external anal sphincter. Rectal temperature was recorded before, during the exercise period (5 min intervals) and immediately after the cessation of exercise. Upon removal the rectal probe was placed in a sterilising solution (Sterilising Liquid, Boots, Nottingham, England) for approximately 2 hours. Borg's scale (1970) was used to produce a rating of perceived exertion (RPE) for the session as a whole.

5.1.2.5. Statistical Analysis

A two-way analysis of variance (ANOVA) was performed to compare differences in oxygen consumption, heart rate, minute ventilation and rectal temperature over time and between the two exercise conditions. A paired sample t-test was employed to examine differences between sweat production and RPE between the steady-rate and intermittent protocols. The probability level for statistical significance was set at $P < 0.05$.

5.1.3. Results

No significant difference was observed between the oxygen consumption (Figure 5.1.2) for the two exercise patterns (intermittent 2.8 ± 0.3 $l.min^{-1}$; steady state 2.8 ± 0.2 $l.min^{-1}$). The steady-rate data were split into two 23 min sections to enable comparisons to be made with respect to time (Table 5.1.2). Oxygen consumption was significantly greater ($P < 0.05$) in the second period of both the intermittent (first period 2.8 ± 0.2 $l.min^{-1}$; second period 2.9 ± 0.2 $l.min^{-1}$) and steady-rate protocols (first period 2.7 ± 0.3 $l.min^{-1}$; second period 2.8 ± 0.3 $l.min^{-1}$). No significant difference was found in terms of this increase between protocols. Calculated energy expenditure was similar between the intermittent and steady-rate exercise periods (intermittent 57.9 $kJ.min^{-1}$; steady rate 57.2 $kJ.min^{-1}$).

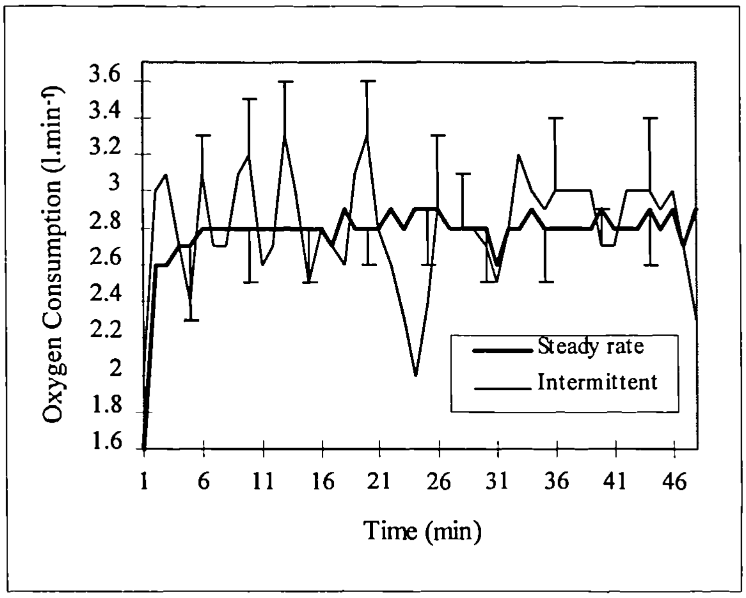


Figure 5.1.2. Mean ± s.d. oxygen consumption for the soccer-specific intermittent and steady rate protocols.

Heart rate for the intermittent protocol was 168 ± 10 $beats.min^{-1}$ (Figure 5.1.3). This figure was not significantly different from the value of 162 ± 1 $beats.min^{-1}$ for the steady-rate session. An F test for dependent samples was performed on the data to examine the variability between the intermittent and steady-rate exercise response. A significant difference ($F_{6,6} = 100$, $P < 0.01$) was found between protocols.

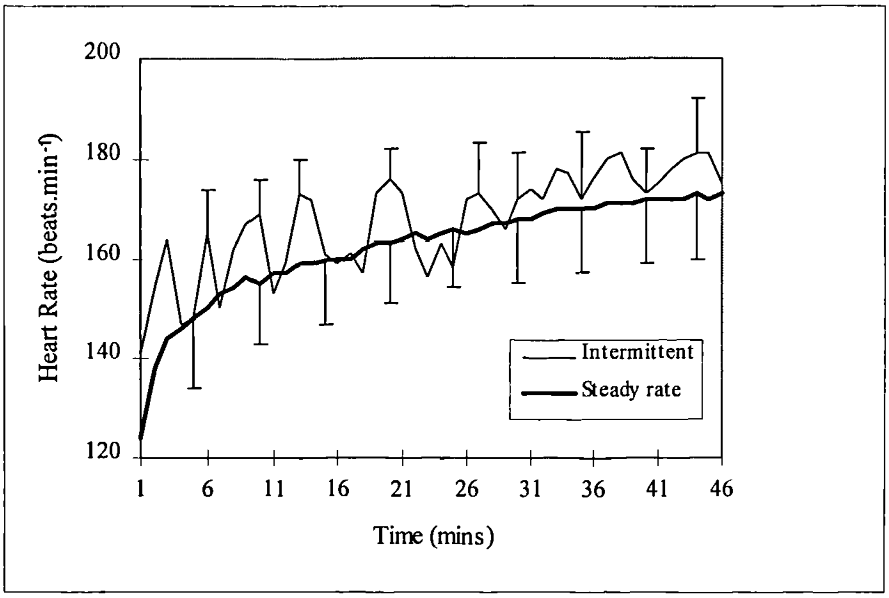


Figure 5.1.3. Mean ± s.d. heart rate response for the soccer-specific intermittent and steady state protocols.

Heart rate was significantly higher ($P < 0.05$) during the second period for both the intermittent (first period 161 ± 8 beats.min^{-1}; second period 174 ± 7 beats.min^{-1}) and steady-rate protocols (first period 155 ± 12 beats.min^{-1}; second period 170 ± 13 beats.min^{-1}). The increase in heart rate as a function of time did not differ significantly between the protocols.

The intermittent exercise test elicited a significantly greater ($P < 0.05$) mean VE response (81.3 ± 10 l.min^{-1}) than the steady-rate protocol (72.4 ± 11 l.min^{-1}) (Figure 5.1.4). Ventilation was also significantly greater ($P < 0.05$) for the second period of both protocols than the first (intermittent first period 75.9 ± 9.2 l.min^{-1}; second period 87 ± 13 l.min^{-1}; steady-rate first period 67.8 ± 9.7 l.min^{-1}; second period 76.6 ± 13.1 l.min^{-1}). No significant difference between the protocols was found for the observed increase from the first to the second period of exercise.

Table 5.1.2. Table showing mean ± s.d. values for the first and second periods of the soccer-specific and steady-rate protocols.

Variable	Intermittent		Steady-rate	
	1	2	1	2
Oxygen Consumption ($l.min^{-1}$)	2.8 ± 0.2	2.9 ± 0.2	2.7 ± 0.3	2.8 ± 0.3
Heart Rate ($beats.min^{-1}$)	161 ± 8	174 ± 7	155 ± 12	170 ± 13
Ventilation ($l.min^{-1}$)	75.9 ± 9.2	87 ± 13	67.8 ± 9.7	76.6 ± 13.1
Core Temperature (°C)	37.8 ± 0.3	39 ± 0.7	37.7 ± 0.3	38.7 ± 0.4

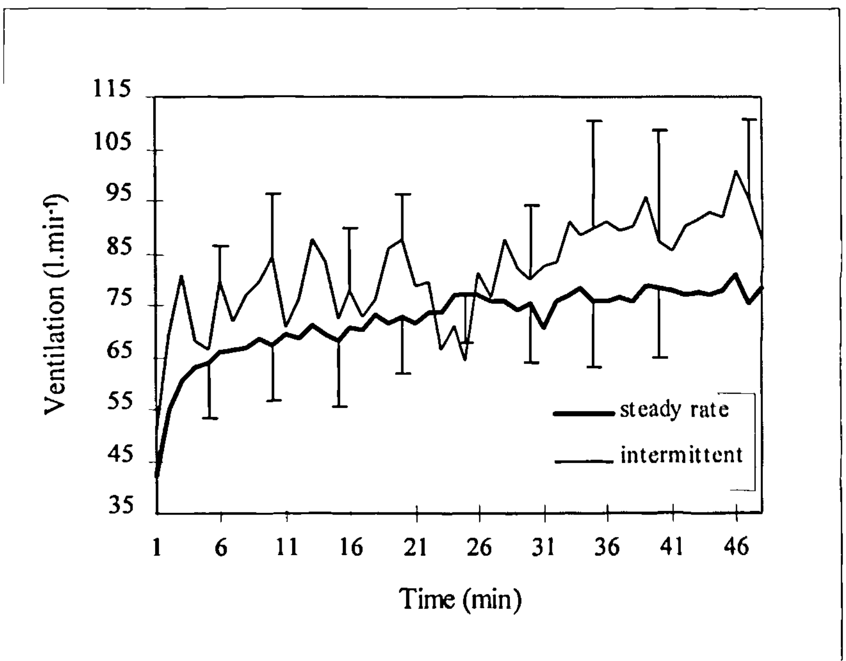


Figure 5.1.4. Mean ± s.d. ventilatory response for the soccer-specific intermittent and steady-rate protocols.

Core temperature was significantly higher (P < 0.05) in the second period of both protocols compared to the first (intermittent first period 37.8 ± 0.3 °C; second period 39.7 ± 0.7 °C; steady-rate first period 37.7 ± 0.3 °C; second period 38.7 ± 0.4 °C). The soccer-specific intermittent exercise protocols elicited a significantly greater (P < 0.05) rise in core temperature than the steady-rate period (Figure 5.1.5). No significant difference was observed, however, between the protocols for the mean ± s.d. rectal temperature during exercise (intermittent 38.4 ± 0.2 °C; steady-rate 38.3 ± 0.6 °C). Sweat production values were 0.97 ± 0.6 kg for the intermittent exercise period and 1.0 ± 0.5 kg for steady-rate. These values were not significantly different between the intermittent and steady-rate protocols.

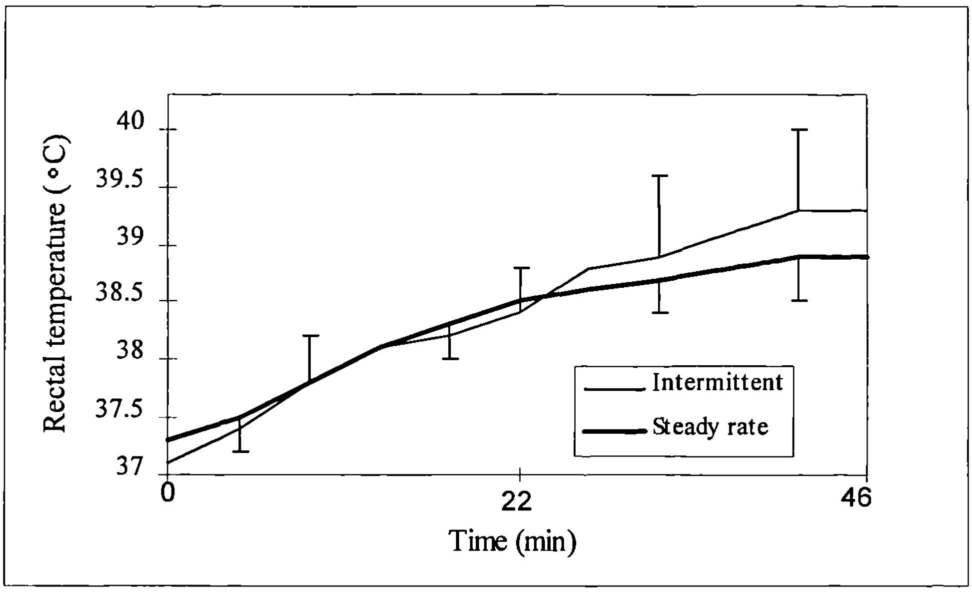


Figure 5.1.5. Mean ± s.d. core temperature response to the soccer-specific intermittent and steady state protocols.

Ratings of perceived exertion were recorded at the end of each session. Ratings of perceived exertion for the intermittent session was 15 ± 2 and 12 ± 1 for the steady-rate session. This difference between the two protocols was significant (P < 0.05).

5.1.4. Discussion

The aim of the present investigation was to compare the physiological responses to a soccer-specific intermittent exercise protocol and to continuous exercise performed at the same average exercise intensity for a comparative time period . Differences were also examined between the two identical periods of activity that made up the total protocol duration. No significant difference was observed between the mean oxygen consumption for the intermittent and steady-rate protocols (intermittent 2.8 ± 0.1 $l.min^{-1}$, steady-rate 2.8 ± 0.1 $l.min^{-1}$). Oxygen consumption during the soccer-specific intermittent protocol, which included a static recovery period, was approximately 68 % of maximal oxygen uptake. This is comparable to the estimated values for match-play (Bangsbo, 1994). The oxygen consumption followed changes in exercise intensity in the first half of the intermittent protocol while steady-rate oxygen consumption remained relatively stable.

Bangsbo (1994) examined the $\dot{V}O_2$ for continuous and intermittent treadmill running. The intermittent protocol consisted of alternating between running for 10 s at 8 $km.h^{-1}$ and running at a higher intensity for 15 s. No significant difference between $\dot{V}O_2$ in continuous and intermittent running was observed when running at 8 $km.h^{-1}$ was alternated with running at treadmill speeds up to 18 $km.h^{-1}$. Significant differences in $\dot{V}O_2$ were found, however, when the treadmill speeds for the high intensity work were increased above 18 $km.h^{-1}$. Results from previous studies have proved inconclusive regarding the differences in physiological strain imposed by intermittent and continuous exercise performed at the same average intensity. One possible explanation for the failure of previous researchers to find consistent differences between the physiological responses to intermittent and continuous exercise is the variety of exercise:rest protocols that have been used. Protocols have ranged from 12 min exercise periods with 10 or 30 s maximal exercise sessions interspersed with 30 s recovery periods to 1 min exercise bouts separated by 5 min recovery intervals. Discrepancies in the data provided by the current investigation and that of the past literature may therefore be the result of the different work loads and rest periods employed in the investigations. Changes in the exercise:rest pattern may reflect the dominant energy systems used during exercise and the physiological costs during recovery as opposed to differences in the physiological strain placed on individuals.

Comparisons with the current investigation are further complicated by the differences in exercise pattern employed. Previous researchers used intermittent models and a cycle ergometer with periods of intense activity being separated by periods of passive rest. The current investigation utilised work periods of high intensity running separated by low intensity recovery periods with running as a mode of exercise. It is highly likely that such a protocol would alter the kinetics of the physiological responses to exercise as active recovery has been shown to affect such parameters as blood lacate and heart rate (Hermansen and Stensvold, 1972; Saltin et al., 1976). The energy demand of exercise is lowered when periods of intense exercise are repeated (Gaitanos et al., 1993). The energy expenditure was, however, similar in both the intermittent and steady-rate exercise periods in the current investigation (intermittent 57.9 $kJ.min^{-1}$; steady rate 57.2 $kJ.min^{-1}$). Decreases in the utilization of adenosine triphosphate when high intensity intermittent activity is repeated may reflect an improvement in the efficiency of muscular contraction or an altered recruitment pattern of muscle fibres (Bangsbo, 1994). Such changes that lower the energy demand do not seem to take place when the exercise pattern incorporates periods of lower intensity activity as in soccer.

Increases in ventilation have been related to increased lactic acid production (Loat and Rhodes, 1993). Changes in the chemical status of arterial blood as a result of increased lactic acid production are detected by the chemoreceptors. These stimulate the body's inspiratory centres, resulting in a increase in the rate and depth of pulmonary ventilation. This suggests that the intermittent protocol placed a greater stress on the anaerobic energy systems than the steady-rate exercise period. No blood lactate values are available to confirm these assumptions though some evidence for the increased contribution of anaerobic metabolism comes from the findings of Medbo and Tabata (1989). They attempted to quantify the relative contributions of aerobic and anaerobic metabolism to short-term exhaustive cycling. The contribution from anaerobic and aerobic processes was approximately equal for exhausting exercise lasting 60 s. This exercise duration is similar to the high intensity periods employed in the current investigation when the time to increase the treadmill speed to the required level is added to the time performed at a constant speed.

The mean heart rate response to the intermittent protocol demonstrated rhythmic fluctuations corresponding to changes in activity level. This variability of the heart rate response was demonstrated by the significantly greater variance in the intermittent exercise session. The heart rate for the intermittent session of 168 ± 4 beats. min^{-1} was not significantly different ($P = 0.35$) from the 162 ± 1 beats. min^{-1} for the steady-rate session. The heart rate for the soccer-specific intermittent protocol is similar to first half match-play heart rates observed for professional players (Bangsbo, 1994). Such similarities indicate the relevance of the intermittent protocol as a model of match-play work-rates. High heart rates were preserved in the intermittent protocol as a result of the short recovery periods between the high intensity bouts as observed in match-play.

Mean oxygen consumption, heart rate and ventilation were all significantly elevated during the second period compared to the first half of both protocols. The increase in mean oxygen consumption during the second period of the intermittent protocol does not reflect a decrease in carbohydrate oxidation as the respiratory exchange ratio was similar for the two periods (first period 0.93 ± 0.04; second period 0.91 ± 0.02). The observed increases are probably the result of increases in recovery oxygen uptake in the low intensity recovery periods arising from increased anaerobic metabolism during the high intensity bouts. Such increases are thought to be the result of repletion of the oxygen stores bound to myohaemoglobin and haemoglobin in muscles and blood (Astrand et al., 1960), repletion of phosphagen stores (Edwards et al., 1973) or the oxidation of lactate. Subsequent increases in heart rate and ventilation would be in keeping with this argument. A component of the increase in oxygen consumption during intermittent work may also be a consequence of an increase in free fatty acid utilization as the protocol progressed since muscle glycogen utilization has been shown to be reduced when intense exercise is repeated (McCartney et al., 1986). Increases in heart rate in both intermittent and steady-rate protocols would also be due to a progressive decrease in stroke volume throughout the exercise periods as a result of the redistribution of blood to the skin to aid heat dissipation (Rowell, 1993).

Steady-rate oxygen consumption exhibited a gradual increase throughout the protocol. Such increases have been shown to be the result of an increase in body temperature (see Figure 5.1.5) and an increased utilization of free fatty acids as a substrate for energy provision (Newsholme, 1986). A steady-rate conditions denote a work situation where oxygen uptake equals the requirements of tissues and therefore no consequent lactate accumulation. Ventilation also significantly increased as a result of the increase in oxygen consumption during the second period.

Mean rectal temperature did not differ significantly between the intermittent and steady-rate exercise periods (Intermittent 38.4 ± 0.1 °C; Steady-rate 38.3 ± 0.2 °C). Previous data comparing the core temperature response to intermittent work indicated increased rectal temperatures in intermittent sessions when compared to continuous exercise at the same average intensity (Ekblom et al., 1971; Nevill et al., 1994). Other research has indicated no difference between the two exercise modes (Nielsen, 1968). Thermal strain is a function of the relative exercise intensity as opposed to absolute work-load (Saltin and Hermansen, 1966). No significant differences were observed in oxygen consumption and heart rate in the current study, signifying similar rates of metabolic heat production prevailed. The relative physiological strain for the two exercise protocols is similar thus suggesting a comparable thermal load.

The mean core temperature responses to the intermittent and steady-rate procedures indicate a rise throughout the exercise period with a levelling off being visible towards the end of the protocols (Figure 5.1.5). The increase in rectal temperature is illustrated by the significantly higher temperature in the second period of both protocols compared to the first (intermittent first period 37.8 ± 0.1 °C, second period 39.7 ± 0.3 °C; steady-rate first period 37.7 ± 0.1 °C, second period 38.7 ± 0.1 °C). The intermittent protocol elicited a significantly higher rise in core temperature than the steady-rate exercise protocol in the second period. This is similar to the data of Kraning and Gonzalez (1991) and Ekblom et al. (1971), both groups noting greater increases in core temperature during intermittent exercise compared to continuous exercise. Mechanisms of heat loss such as evaporation and convection are altered in intermittent exercise (Kraning and Gonzalez, 1991), heat balance residing in these heat dissipating mechanisms. These elements are influenced by peripheral blood flow and skin temperature. Core temperatures above 38 ^{o} C, as observed in the current study, have been associated with attenuated increases in skin blood flow during prolonged exercise (Kenney and Johnson,1992) while decreased skin temperature has been asociated with intermittent exercise (Ekblom et al. 1971).

The curent study provides some findings that are contradictory to past literature as sweat production was not significantly different between protocols in the current study. These findings are, however, in agreement with the work of Astrand et al. (1960). Core temperature is the primary stimulus to the sudomotor centre with skin temperature and rate of change of skin temperature providing a secondary influence (Wyss et al., 1974). Similar mean core temperatures in the two exercise protocols could therefore explain the similar sweat production rates. Saltin and Hermansen (1966) concluded that sweat rate during exercise is not dependent on core temperature per se. They argued that sweat rate was dependent upon absolute work-rate and therefore absolute heat production which was the same in both present protocols.

Ratings of perceived exertion were significantly higher at the end of the intermittent session than in the steady-rate trial. Higher ratings of perceived exertion were also reported for intermittent work by Edwards et al. (1972b). Astrand et al. (1960) linked subjective strain in intermittent exercise to the duration of the exercise period. The relatively long duration of the high intensity exercise periods employed in the study may therefore lead to a high RPE rating.

The oxygen uptake, heart rate and ventilatory responses observed in the intermittent protocol fluctuated in harmony with the alterations in exercise intensity. Intermittent exercise elicited a significantly greater rise in rectal temperature during the second exercise period than continuous exercise. It thus seems that a higher increase in body temperature is associated with intermittent work, thus indicating a decrease in the efficiency of the thermoregulatory system. The exercise pattern employed in the current protocol was regular. Soccer, however, involves random activity periods of irregular activity. Future work may therefore be more applicable if activity profiles more representative of soccer are utilised.

In conclusion, there was some evidence for an increased physiological strain being imposed on individuals when performing a soccer-specfic intermittent exercise protocol compared to steady-rate exercise at the same average exercise intensity. The protocol utilised in the current investigation is, however, only a model of the intermittent pattern associated with soccer. More realistic representations (e.g. more frequent changes in activity, performance of match actions) may further alter the physiological responses observed. A decrease in the efficiency of the thermoregulatory system may be associated with intermittent work. This has implications for the performance of soccer players at high ambient temperatures.

5.2. THE EFFECTS OF AMBIENT TEMPERATURE AND WHOLE BODY PRE-COOLING ON SOCCER-SPECIFIC INTERMITTENT EXERCISE PERFORMANCE

5.2.1. Introduction

The lack of adequate experimental models that can be used to study the demands of soccer match-play has promoted attempts to develop laboratory based soccer-specific intermittent protocols. One example of such a model was discussed in Chapter 3.1. The protocol described in Chapter 3.1 has been used in comparing the physiological responses to soccer-specific intermittent exercise and continuous exercise at the same average intensity (see Chapter 5.1). The aforementioned model, however, provides only a representation of the overall pattern of work-rate observed in soccer. This is primarily due to the restrictions placed on the pattern of activity by the equipment used for the performance in the test. These restrictions relate to the intensity of performance of some of the categories of activities (i.e. high intensity bouts cannot be performed maximally on the motorised treadmill) and the duration of each discrete bout of activity which exceeds that observed during match-play as alterations during the protocol are restricted by the time needed for the treadmill to alternate between intensities.

Such problems involved in the modelling of soccer-specific protocols in laboratory settings have limited the application of such protocols. The development of the non-motorised treadmill by Woodway has helped to overcome some of the problems associated with devising laboratory based intermittent exercise protocols. The non-motorised treadmill was modified for the measurement of power during sprinting (Lakomy, 1987), since near maximal sprinting speeds can be attained. This has led to the employment of the non-motorised treadmill in determining the metabolic responses to both 30 s maximal sprints (Cheetham et al., 1985) and repeated sprint protocols (Hamilton et al., 1990).

As well as facilitating the attainment of near maximal sprinting speeds, the non-motorised treadmill also permits almost instantaneous changes in the intensity of exercise. Such rapid changes in the intensity of action are characteristic of soccer match-play. This has encouraged researchers to use the ergometer to simulate match-play physiological stresses. Fallowfield et al. (1997) and Wilkinson et al. (1997) developed a 90 min soccer-specific intemittent protocol using a non-motorised treadmill to determine the effects of water ingestion and carbohydrate ingestion respectively on repeated sprint performance. The simulation was based on the observations of Yamanka et al. (1988). The experimental protocol consisted of 30 maximal sprints contained within a 3 min repeating cycle of activity. Each sprint was preceded by 45 s walking, 30 s jogging and 15 s running at 55 % of pre-determined maximal sprint speed and was followed by a further 30 s of jogging, 45 s of walking and 9 s rest. The total distance covered during the simulation was reported to be around 9 to 10 km. This is in agreement with previously published data on players during match-play (Ekblom, 1986). The physiological responses to the simulation were also similar in nature and magnitude to those reported during match-play for heart rate, blood lactate and blood glucose concentrations (Smith et al., 1993; Leatt and Jacobs, 1989). Such protocols provide useful models for the examination of the physiological and metabolic responses to match-play, despite not incorporating the game activities such as ball skills and tackling that increase the demands of the game placed upon the individual (Bangsbo, 1994a).

Previous studies have utilised a non-motorised treadmill to re-create activity patterns representative of soccer. The use of such apparatus allows a better approximation of the activity pattern of soccer to be made since frequent changes in the intensity of exercise are possible as well as maximal performance during high intensity bouts. These re-creations have, however, been concentrated on the effects of fluid supplementation on repeated sprint performance as opposed to the physiological and metabolic responses that accompany soccer-specific intermittent exercise performance. The aim of this study is to determine the physiological and metabolic responses to soccer-specific intermittent exercise protocols representative of work-rates observed during international match-play on a non-motorised treadmill.

The demands placed on the human body as a result of exercise are often complicated by environmental thermal conditions. Performing in extremes of heat and cold places a heavy burden on the mechanisms that regulate body temperature. The problems for the cardiovascular system in this situation stem from the need for the delivery of adequate amounts of blood flow to both the cutaneous circulation and to the exercising muscles (Johnson, 1992). Any large shift of blood away from the contracting muscle has implications for the energy provision to support the exercise. The metabolic response to exercise is also affected under hyperthermic conditions (Fink et al.,1975) with higher glycolytic rates and an increased anaerobic contribution to energy provision. The effects of high humidity and high ambient temperatures on performance are especially relevant in the sport of soccer as major competitions are often played under such conditions. For example, the last two F.I.F.A World Cup competitions have taken place in the U.S.A (1994) and Italy (1990) at times of the year and starting at mid-day when high temperatures are observed.

The vast majority of the available literature on the effects of high ambient temperatures relates to the body's thermoregulatory adjustments to submaximal continuous exercise with only a small amount being concerned with anaerobic exercise and intermittent patterns. The thermal response to exercise can be influenced by the intensity and type of exercise (Smolander et al., 1991). The performance of intermittent exercise also affects the human thermoregulatory response (Kraning and Gonzalez, 1991). Higher rectal temperatures have been associated with intermittent exercise when compared with continuous exercise at the samc average intensity (Ekblom et al., 1971; Cable and Bullock, 1996). Higher rectal temperatures in intermittent exercise were accounted for by changes in the body's heat dissipation mechanisms. Decreases in sweat loss coupled with lower mean skin temperatures, due to noradrenaline decreasing skin blood flow, will affect the body's ability to lose heat and result in higher levels of core temperature being reached. There may also be a role in these changes for non-thermal inputs associated with postural or work changes (Kraning and Gonzalez, 1991).

The research reviewed above has employed intermittent patterns of exercise that are interspersed with static recovery periods. Recovery periods during intermittent exercise are not restricted to static pauses and can involve exercise at a reduced intensity. Such exercise patterns are characteristic of soccer match-play and have been associated with significantly greater increases in rectal temperature compared to continuous exercise (see

Chapter 5.1). Laboratory based intermittent exercise patterns that incorporate changes in exercise intensity as opposed to exercise:static rest protocols have been investigated with respect to the thermoregulatory strain they place on individuals (Nevill et al., 1994). Garrett and Boyd (1995) found higher values for rectal temperature, oxygen consumption, heart rate, blood lactate concentration and RPE as a result of intermittent cycling compared to continuous exercise at the same average intensity. No statistical analysis was performed on the data. The 45 min intermittent exercise bout was made up of 15 identical 3 min exercise bouts that involved 90 s cycling at 40 % $\dot{V}O_2$ max, 60 s cycling at 60 % $\dot{V}O_2$ max followed by a 5 s rest and a constant work sprint (high intensity exercise bout of a constant work-load). Time to perform a constant work sprint (time to complete a set work-load) was recorded to provide an indication of performance. The decrease in performance was positively correlated (0.96) with the increase in rectal temperature, suggesting that overheating was linked with performance decrements.

Little information is available regarding the thermoregulatory, cardiovascular and metabolic responses and the effects of performing in the heat with respect to intermittent exercise patterns that have a specific relevance to soccer. The effects of moderate heat stress on intermittent exercise performance will be examined as these are more representative of the thermal strain imposed on players than the high temperatures observed during some international tournaments. The aim of the current investigation is to examine the physiological and metabolic responses to soccer-specific intermittent exercise in moderate heat and to compare these responses to an identical exercise period in thermoneutral conditions.

Hypothesis 3: The physiological strain associated with soccer-specific intermittent exercise performance at elevated environmental temperatures (26 ^{o} C) is no different than soccer-specific intermittent exercise performance under normal laboratory conditions (20 ^{o} C)

Increasing body temperature is one of the factors that has been shown to limit endurance performance (Adams et al., 1975). It has therefore been suggested by some researchers that a reduction in body temperature at the start of exercise may influence exercise performance. Schmidt and Bruck (1981) argued that by decreasing the starting temperature at the onset of exercise the margin to the attainment of a critical limiting body temperature is increased. This may result in improvements in performance in both terms of endurance time (Olschewski and Bruck, 1988) and increased work-rate (Hessemer et al., 1984). Limited data are available on the effects of whole body pre-cooling on the body's physiological responses to exercise. Oesophageal temperature was decreased by 0.6 ^{o} C during short duration sub-maximal exercise (16 min) on a cycle ergometer (Lewke et al.,1995). This decrease in core temperature has been shown to lower both heart rate and sweat production rate (Schmidt and Bruck, 1981; Lewke et al., 1995; Olschewski and Bruck, 1988). This results in higher work-rates being chosen, with a consequent decrease in the thermoregulatory strain associated with the exercise (Hessemer et al., 1984). With more prolonged sub-maximal exercise, differences in tympanic and oesophageal temperature gradually diminish, with only tympanic temperature still being lower than control conditions upon completion of 60 min of exercise (Hessemer et al., 1984).

Some evidence does exist in the literature to support the notion of a decreased physiological strain and a consequent increase in exercise performance as a result of a pre-cooling manoeuvre prior to exercise. The data are, however, limited and relate almost exclusively to short duration submaximal continuous exercise. No data are available on the effects of pre-cooling on intermittent performance especially with reference to the exercise pattern observed in soccer. A pre-cooling strategy is a very simple manoeuvre and could be used by soccer players prior to match performance. The aim of the current investigation is to compare the physiological and metabolic responses to a soccer-specific intermittent exercise protocol performed on a non-motorised treadmill following a whole body pre-cooling manouvre with those produced without pre-cooling under thermoneutral and hyperthermic conditions.

Hypothesis 4: The physiological strain associated with soccer-specific intermittent exercise performance after a whole body pre-cooling manoeuvre is no different from that experienced during soccer-specific intermittent exercise performance under normal and heated laboratory conditions.

5.2.2. Method

5.2.2.1. Subjects

Six male university soccer players were studied. Subject characteristics are shown in Table 5.2.1. All subjects gave their written informed consent in accordance with university ethical procedures. These were tested in a post-absorptive state having performed no vigorous exercise or consumed any alcohol for 24 hours prior to testing. Each subject performed all the exercise periods at the same time of day to remove the effects of any circadian variation on the variables measured (Reilly and Brooks, 1986).

Table 5.2.1. Mean ± s.d. characteristics of subjects (n = 6)

	Age (years)	Height (m)	Mass (kg)	Maximal oxygen consumption ($ml.kg^{-1}.min^{-1}$)
Mean	27	1.77	72.2	58.9
s.d.	± 2	± 0.3	± 1.5	± 3.5

5.2.2.2. Procedure

Each subject visited the laboratory on four separate occassions. The first visit entailed the assessment of the individual's $\dot{V}O_2$ max. The soccer-specific intermittent exercise protocol was completed on the second, third and fourth session. The intermittent exercise protocol was completed in a laboratory under normal temperature (20 ^{o} C) with and without prior pre-cooling and in the heated laboratory (26 ^{o} C). The order of completion of the exercise protocols was determined by a random numbers table (see Appendix 5). Approximately 7 days separated each subject's visit to the laboratory for the pre-test assessment of his $\dot{V}O_2$ max and the completion of the first intermittent exercise protocol. Each of the two remaining visits was separated by approximately four days.

5.2.2.3. Pre-test assessment

Maximal oxygen consumption was assessed on a motorised treadmill (Quinton, Washington, USA). Details of the protocol are provided in Chapter 5.1. Expired air was collected continuously using a computerised gas analysis system (Sensormedics 2900 meatbolic cart, Yorba Linda, California, USA). Heart rate was continuously measured (5 s intervals) using short range radio telemetry (Sports tester, Polar Electro, Kempele, Finland). The British Association of Sport and Exercise Sciences' (BASES) criteria were employed to check that $\dot{V}O_2$ max had being reached. These included a respiratory exchange ratio of 1.15 or above and an increase in oxygen consumption of less than 2 $ml.kg^{-1}.min^{-1}$ with each new work-load. Subjects were verbally encouraged throughout the final stages of the exercise test.

5.2.2.4. Pre-cooling

Whole-body pre-cooling strategies attempt to lower the internal temperature of an individual; such manoeuvres may not only improve performance but also allow the physiological responses to the exercise period to be examined. The pre-cooling strategies employed in past research have been composed of 2 intermittent cold stimuli of 5 to 10 ^{o}C in a climatic chamber (Hessemer et al., 1984; Schmidt and Bruck, 1981). Intermittent cold exposures have been utilised as the period of re-warming in between exposures leads to a decrease in short term threshold for shivering. This in turn leads to small changes in the body's metabolic responses in relation to the decrease in body temperature (Hessemer et al., 1984). Such procedures have resulted in decreases of oesophageal temperature of around 1 ^{o}C. These protocols were impossible to adopt in the current investigation as the institution did not posess a climatic chamber. An alternative approach to whole-body pre-cooling has been demonstrated by Blomstrand et al. (1984). They used a water bath to pre-cool the legs to investigate the effects of muscle glycogen availablity on the body's cooling responses. It was decided therefore to attempt to lower individuals' internal temperature by using cool water. As facilities for the total immersion of subjects in cold water were unavailable, a cold shower was used for the completion of the pre-cooling manoeuvre. The use of the shower had a number of advantages over the use of a bath as a pre-cooling stimulus. The temperature of the water could be easily adjusted and controlled via a thermostat. This prevented large variations existing in the cold stimulus between trials. It was also thought that it would be less uncomfortable for the subject to endure a prolonged exposure to a cold shower than to immersion in cold water.

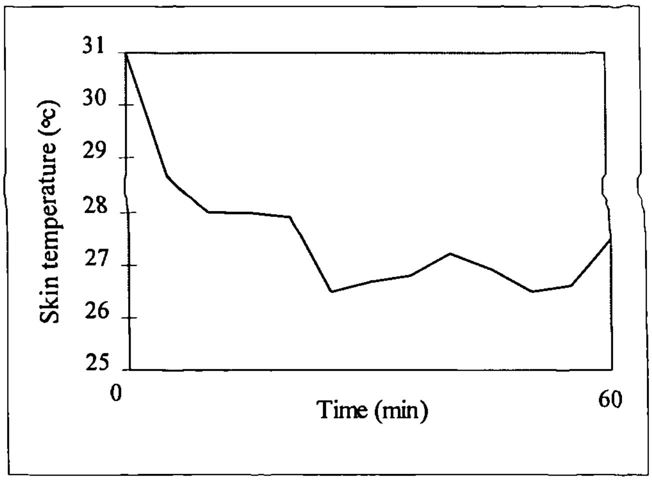
5.2.2.5. Pilot study

A pilot study was completed in order to evaluate the extent to which the core temperature could be altered by the shower and also to see how the thermoregulatory response was altered during exercise performed immediately afterwards. Two subjects were tested. Mean and range height (m), body mass (kg), age (years) and VO_2 max ($ml.kg^{-1}.min^{-1}$) were 1.79 (177-181) m, 73.1 (72-76) kg, 25 (24-26) years and 62.2 (61-63) $ml.kg^{-1}.min^{-1}$, respectively. Each subject visited the laboratory on two separate occasions. They were in a post-absorptive state having performed no vigorous exercise or consumed any alcohol for 24 hours prior to testing. Each subject performed all the exercise periods at the same time of day to remove the effects of any circadian variation on the variables measured (Reilly and Brooks, 1986). On each visit the subjects were required to exercise for 30 min at a constant work-rate of 200 W on an isokinetic cycle ergometer (Cybex MT100, Cybex Metabolic Systems, Ronkonoma, NY, USA). On one occassion the exercise protocol was completed immediately following the pre-cooling manoeuvre with the other session acting as a control. The pre-cooling strategy involved standing under a cold shower for 60 min. Water temperature was reduced by 2 ^{o} C every 20 min from an initial starting temperature of 28 ^{o}C to 24 ^{o} C. Water temperature was recorded every 5 min using a thermistor placed in the centre of the stream of water and a thermometer (Squirrel meter 1250, Grant Instruments, Cambridge, UK). Rectal temperature and skin temperature (assessed at the chest) were also recorded at 5 min intervals throughout the period in the shower and during the subsequent exercise period as well as before and immediately upon cessation of the shower and following exercise. Changes in rectal temperature were measured using a rectal probe and thermometer (Squirrel meter 1250, Grant Instruments, Cambridge, UK). The rectal probe was positioned 10 cm beyond the external anal sphincter. Skin temperatures (chest, forearm, calf and thigh) were also determined by using skin thermistors and a thermometer (Squirrel meter 1250, Grant Instruments, Cambridge, UK). The contact area of the skin thermistors was stainless steel.

Figure 5.2.1 shows the mean rectal and skin temperature changes in response to the pre-cooling stimulus. The range is presented as opposed to the s.d. as n = 2. Mean and range skin temperature for the 60 min pre-cooling period was 27.6 (24.2- 31) $^{\circ}$ C. Mean and range rectal temperature was demonstrated a slight increase during the shower. Mean and range rectal temperature was observed to be 36.6 (36.1-37.1) $^{\circ}$ C at the start of the pre-cooling stimulus and 36.9 (36.4 - 37.4) $^{\circ}$ C upon completion of the shower. Figure 5.2.2 shows the responses to the 30 min exercise session performed immediately after the cold shower. Both skin and rectal temperature showed a different response to the exercise session after the pre-cooling period compared to the control condition. Mean and range skin temperature was lower during exercise after pre-cooling than control (pre-cooling 31.4, range 25.3 - 37.5 $^{\circ}$ C; control 32.9, range 29.7 - 36.2 $^{\circ}$ C). A similar observation was also made for rectal temperature. Mean and range rectal temperature was 37 $^{\circ}$ C (36.3 - 37.7) after pre-cooling compared to 37.3 (36 - 38.6) $^{\circ}$ C in the control condition. Rectal temperature was lower at every point after pre-cooling than in the control condition.

The effects of the pre-cooling strategy on the rectal temperature response to the exercise period can be further examined by looking at the change in rectal temperature throughout the protocol. The mean change in rectal temperature is shown in Figure 5.2.3. The mean ± range rectal temperature was observed to fall at the onset of exercise before increasing steadily throughout the protocol. This pattern is in agreement with the work of Schmidt and Bruck (1981) who also observed the greatest drop in oesophageal temperature after the first 5 to 10 min of exercise. In the control condition mean and range rectal temperature was increased steadily throughout the exercise period. The lower rectal temperature during exercise would suggest that the pre-cooling strategy employed was successful in altering the response of rectal temperature during exercise despite the failure to find a reduction in rectal temperature during the shower. Large variability has been noted in individuals' responses to pre-cooling manoeuvres (Young et al., 1989). This variability has been explained by differences in body composition and muscle glycogen availability (Martineau and Jacobs, 1981). Individual differences between subjects during the cold stimulus may then have been responsible for the failure to find a mean decrease during pre-cooling.

The differences in the rectal temperature response to an exercise session at an identical absolute work-rate would seem to indicate that the body's thermoregulatory responses can be altered with the pre-cooling startegy adopoted in the current investigation. This is despite the failure to find a decrease in the rectal temperature during the cold stimulus. This is probably due to the inter-individual variation in the subject's response to the shower.



(a)

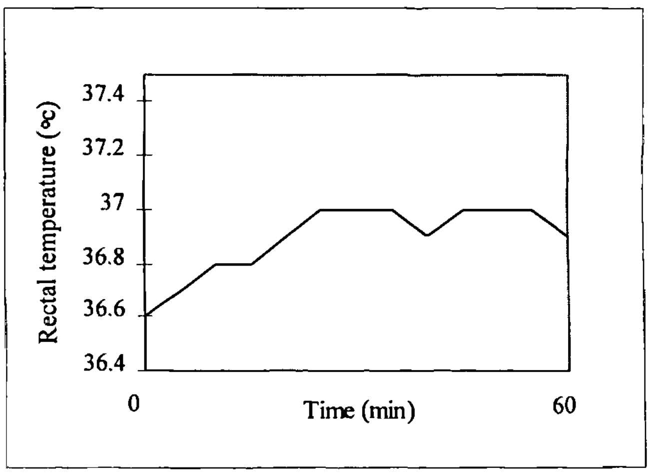
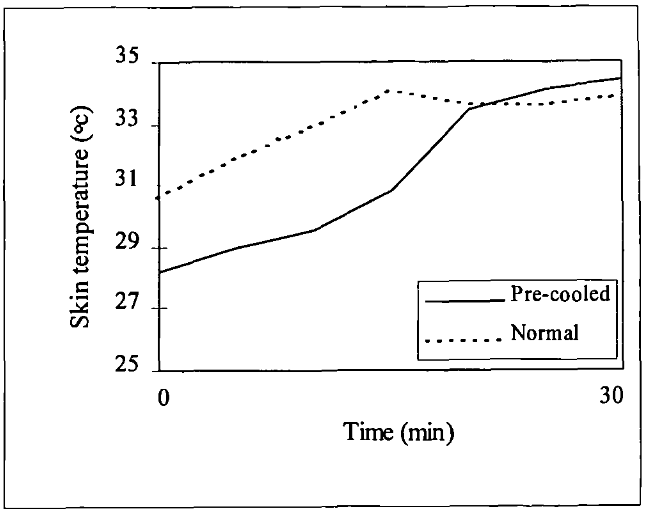


Figure 5.2.1. Mean skin temperature (a) and rectal temperature response to the pre-cooling strategy (n = 2)



(a)

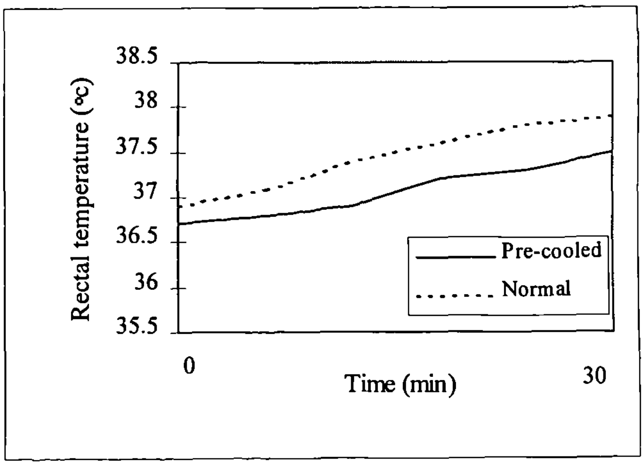


Figure 5.2.2. Mean skin temperature (a) and rectal temperature response to the pre-cooling strategy (n = 2)

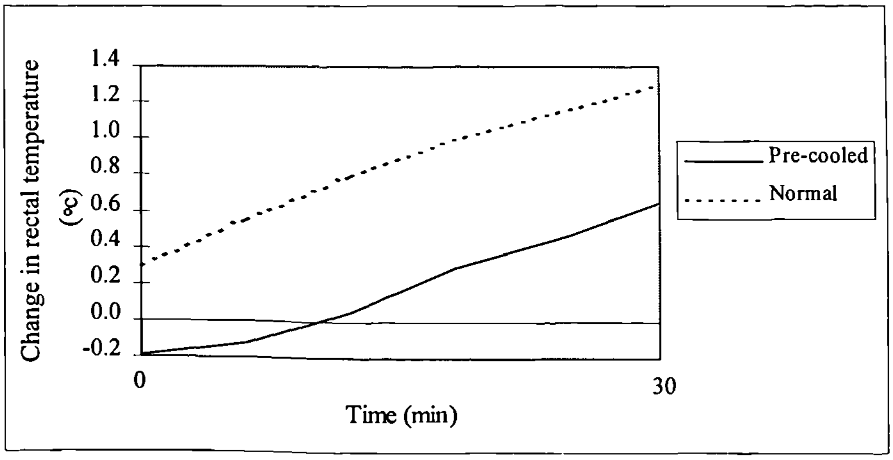
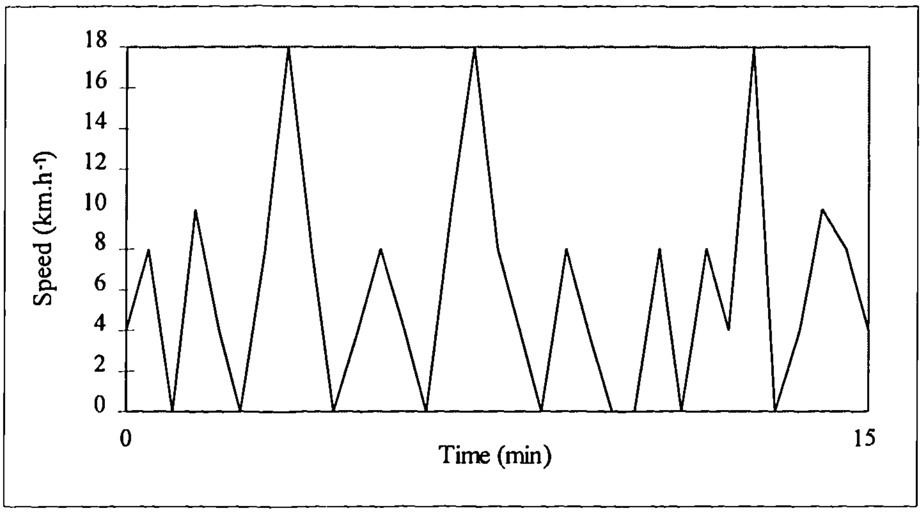


Figure 5.2.3. Mean change in rectal temperature during 30 min of exercise for the pre-cooled and control condition (n = 2)

5.2.2.6. Intermittent protocol

The intermittent protocol devised for the study was performed on a modified non-motorised treadmill (Woodway, Vor Dem, Auf Schrauben, Germany) and consisted of different exercise intensities that are observed during match-play (e.g. walking, jogging, sprinting). The protocol was performed on a non-motorised treadmill as the apparatus has the benefits of almost instantaneous acceleration and deceleration. This allows frequent changes in activity to be made as observed during soccer match-play. The proportions of activities incorporated in the protocol were based upon the data obtained for the international players in Chapter 4.1. Four movement categories were incorporated: walking, jogging cruising and sprinting. Static periods were also included in the protocol in which the subject was stationary on the treadmill. Utility movements (backwards and sideways) were not included in the protocol as a result of the technical limitations of the equipment used. The percentage time spent in these two activity categories during match-play was divided between the walking and jogging categories. This allowed the calculation of the percentage time that each activity category would make up in the final protocol. The non-motorised treadmill is a subject-propelled device. This makes it difficult to control the intensity of exercise during performance. It was, nevertheless, deemed important that each subject performed each different activity pattern at the same exercise intensity. This would ensure that the absolute physiological load remained constant across subjects. This was accomplished by designating treadmill speeds to each of the four types of activity incorporated in the protocol. The intensity of the performance could then be monitored by the speed gauge on the treadmill with the subject being given constant feedback to maintain the required intensity. Treadmill speeds for each activity were based upon those used in Chapter 4.1 from the data of Van Gool et al. (1988). Running on a non-motorised treadmill differs from free running (Lakomy, 1987), the major difference between the two modes of running being due to the intrinsic resistance of the treadmill although the tethering of the subject may also play a role. The resistance has been shown to be related to the body mass of the runner and resulted in maximal velocities of approximately 20 % lower than those achieved by non-tethered runners (Lakomy, 1987). It was decided on the basis of the above findings to decrease the speed for each of the activity patterns was performed. The respective speeds chosen at which each activity pattern were :- walking 4 $km.h^{-1}$, jogging 8 $km.h^{-1}$ and cruising 12 $km.h^{-1}$. No speed restrictions were placed on the sprinting category as subjects were instructed to produce a maximum effort.

The protocol was arranged around a 15 min activity cycle (see Figure 5.2.4). This was performed 6 times in all to make up the 90 min protocol duration. This 15 min cycle was further sub-divided into 3 separate 5 min cycles. The order of presentation of the activities was determined by the researcher. High intensity bouts were separated by low intensity recovery periods and static pauses in an attempt to replicate the acyclical nature of the exercise pattern in soccer. The duration of each bout of activity was determined by dividing the percentage time of each activity category observed during match-play by the time for one activity cycle in the intermittent protocol (i.e. 5 min). Once the total time for each activity category was established, it was possible to determine the time for each discrete bout of activity within each category by dividing the total time for each category by the number of bouts required (see Appendix 5 for full calculations). Each 5 min cycle consisted of 11 bouts of activity. The 11 bouts of activity were comprised of 3 static pauses, 3 walking bouts, 3 jogging bouts, 1 cruise and 1 sprint. These activities were ordered differently within each 5 min cycle though the duration of each bout remained constant.



(a)

walk	jog	static	cruise	walk	static	jog	sprint
4	8	0	10	4	0	8	max
jog	static	walk	jog	walk	static	cruise	sprint
8	0	4	8	4	0	10	max
jog	walk	static	jog	walk	static	static	jog
8	4	0	8	4	0	0	8
static	jog	walk	sprint	static	walk	cruise	jog
0	8	4	max	0	4	10	8
walk							
4							

(b)

Figure 5.2.4. Representation of the soccer-specific intermittent protocol developed for the non-motorised treadmill. Section a shows a graphical representation of the 15 min activity cycle (NB. The treadmill speed for the three sprinting bouts is arbitary and represents a maximal effort). Section b shows details of the activities included in the 3 x 5 min cycles and the treadmill speeds that they are performed at.

Each subject completed three experimental trials. The soccer-specific intermittent protocol consisted of 90 min of activity. This 90 min period was divided into 2 x 45 min identical exercise periods separated by a 15 min recovery period. This protocol corresponds to that observed during professional soccer match-play. On one occasion the soccer-specific intermittent exercise protocol was performed under normal laboratory conditions (mean ± s.d. temperature 20.5 ± 0.8 °C, mean ± s.d relative humidity 71.6 ± 8.4 %) and following whole-body pre-cooling. The pre-cooling strategy involved standing under a cold shower for 60 min. Water temperature was reduced by 2 °C every 20 min from an initial starting temperature of 28 °C to 24 °C. Water temperature was recorded every 5 min using a thermistor placed in the centre of the stream of water and a thermometer (Squirrel meter 1250, Grant Instruments, Cambridge, UK). Rectal temperature and skin temperature (chest, thigh, calf and thigh) were also assessed and recorded at 5 min intervals throughout the period in the shower. A 15 min intermission separated the completion of the cold shower and the onset of exercise. This permitted resting blood samples to be taken prior to exercise. Laboratory temperature and relative humidity were 20.5 ± 0.6 °C and 68.3 ± 6.2 %, respectively. The temperature chosen for the heated condition was based upon the average temperature calculated for the venues of the last four F.I.F.A World Cup finals as this provides a better representation of the average thermal stress imposed on players. Laboratory temperature was 26 ± 0.2 °C while the mean ± relative humidity was 61.5 ± 9 %.

Prior to the completion of each exercise bout, each subject's height and body mass were determined using a stadiometer and calibrated precision weighing scale. Nude body mass was also evaluated before and after the exercise period to provide an indication of sweat production rate. Sweat production rate permits an estimation of the fluid loss during exercise. Care was taken that all sweat on the subject at the time of assessment was towelled off. Sweat production values were also corrected for evaporative water loss from the respiratory tract as in Chapter 5.1 (Mitchell et al., 1972).

Expired air was collected continuously and analysed throughout the exercise period for the determination of the oxygen consumption associated with the exercise trial. A Medgraphics Cardi0_2 system (Minnesota, USA) was utilised. Response times for the oxygen and carbon dioxide analysers were < 80 ms and < 130 ms respectively. Due to technical failure a Sensormedics 2900 metabolic cart (Yorba Linda, California, USA) was used for determination of oxygen consumption during the intermittent protocol in all conditions for two subjects. Both computerised gas analysis systems used similar methods for the analysis of oxygen (paramagnetic) and carbon dioxide (infra-red) and were therefore deemed to be compatible. For details of the response time for the oxygen and carbon dioxide analysers of this system, see Chapter 5.1. Ventilation rate was also assessed by a unidirectional anemometer (Sensormedics 2900) and a bi-directional differential pressure preVent pneumotachograph (Medgraphics Cardi0_2 system). The calibration were identical for the two methods, being checked with room air and gases of a known concentration (British Oxygen, Manchester, UK) whilst ventilation was calibrated by means of a 3 l syringe. Mean values for oxygen consumption and minute ventilation (VE) were calculated for each minute for each subject. Heart rate was continuously monitored using short range radio telemetry (Sports Tester, Polar Electro, Kempele, Finland) during exercise and half time recovery periods (15 s intervals) to provide an indication of circulatory strain. Mean heart rates for every 3 min were calculated for each subject. Changes in core temperature were measured by use of a rectal probe and thermometer (Squirrel meter 1250 series, Grant instruments, Cambridge, UK). The rectal probe was positioned 10 cm beyond the external anal sphincter. Four skin temperatures were also recorded using skin thermistors (stainless steel) and a thermometer (Squirrel meter 1250 series, Grant Instruments, Cambridge, UK). Skin thermistors were placed on the chest, forearm, thigh and calf of the subject and secured using micropore tape. Mean skin temperature was calculated using the equation of Burton (1935). Rectal and skin temperatures were recorded before, during the exercise and half-time recovery periods (5 min intervals) and immediately after the cessation of exercise. Borg's (1970) RPE scale was used to produce a rating of perceived exertion (RPE) for the session as a whole.

Venous blood samples (< 10 ml) were taken from an antecubital vein by a experienced phlebotomist for the analysis of blood-borne substrates. Blood samples were taken approximately 5 min prior to exercise, during the half time recovery period and upon cessation of exercise. The two samples taken after completion of the first and second halves were obtained approximately 5 min after leaving the treadmill. Blood samples were immediately centrifuged (ALC PM180R, high speed refrigerated centrifuge, Camlab, Cambridge, UK) and the plasma removed and frozen at -83 $^{\circ}$ C for analysis. Plasma samples were analysed for glucose, free fatty acids, glycerol and lactate using a centrigugal analyser (Monarch Chemistry System, Instrumentation laboratory, Lexington, USA).

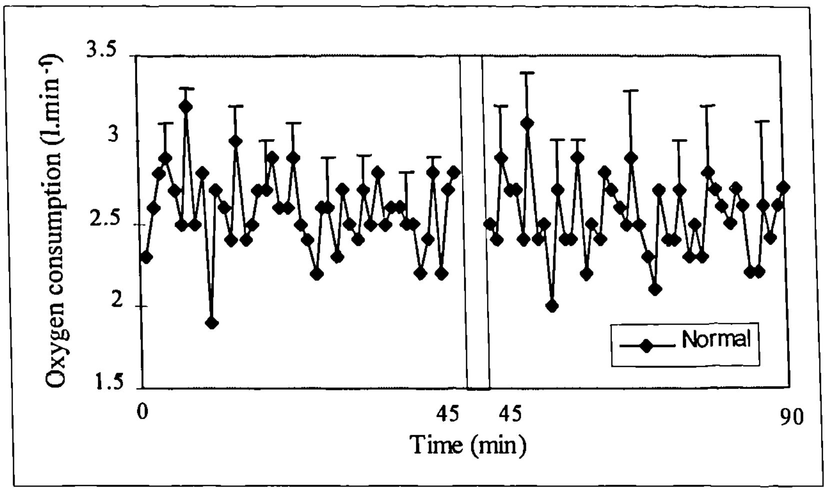
5.2.2.7. Statistical Analysis

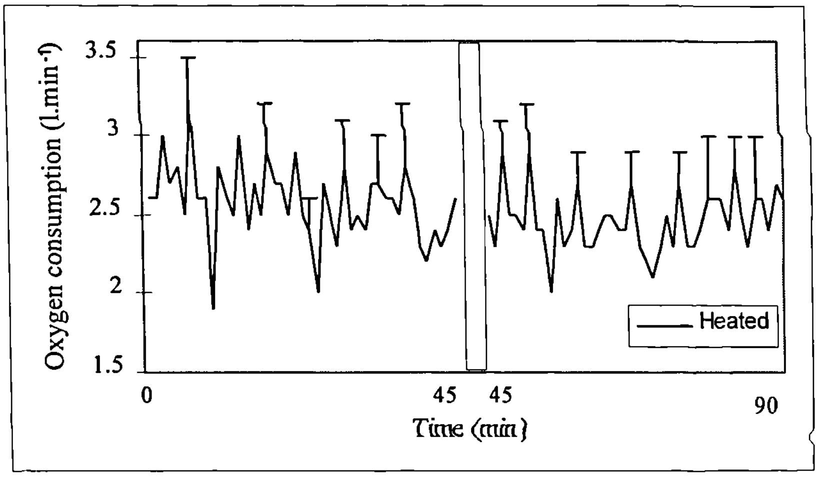
A two-way analysis of variance (ANOVA) was performed to compare differences in oxygen consumption, heart rate, minute ventilation, rectal temperature, change in rectal temperature and energy expenditure over time and between the environmental condition. A one-way analysis of variance was employed to examine differences in sweat production and RPE between the normal, hot and pre-cooled condition. The probability level for statistical significance was set at $P < 0.05$.

5.2.3. Results

No significant difference was observed between the mean ± s.d. oxygen consumption associated with the exercise for any condition (normal 2.5 ± 0.3 $l.min^{-1}$, heated 2.5 ± 0.3 $l.min^{-1}$, pre-cooled 2.7 ± 0.3 $l.min^{-1}$) (Figure 5.2.5). Oxygen consumption was not significantly different between halves for any condition (Table 5.2.2). Calculated energy expenditure was similar between the normal, heated and pre-cooled conditions. Energy expenditure for the 90 min exercise period was 106.1 ± 7.7 $kJ.min^{-1}$ for the normal condition and 111.1 ± 7.1 $kJ.min^{-1}$ and 105.5 ± 6.3 $kJ.min^{-1}$ for the pre-cooled and heated conditions, respectively. No significant difference was found for the energy expenditure for the protocol between the three environmental conditions.

Heart rate was 160 ± 6 $beats.min^{-1}$ for the soccer-specific intermittent protocol in the normal condition (Figure 5.2.6). This figure was not significantly different from the 153 ± 6 $beats.min^{-1}$ observed for the pre-cooled condition or the 160 ± 6 $beats.min^{-1}$ for the heated condition. Heart rate was not significantly different during the second 45 min period compared to the first in any condition (normal, first half 156 ± 10 $beats.min^{-1}$, second half 164 ± 8 $beats.min^{-1}$; pre-cooled first half 148 ± 12 $beats.min^{-1}$, second half 157 + 9 $beats.min^{-1}$; heated first half 156 ± 11 $beats.min^{-1}$, second half 164 ± 8 $beats.min^{-1}$) (Table 5.2.2).





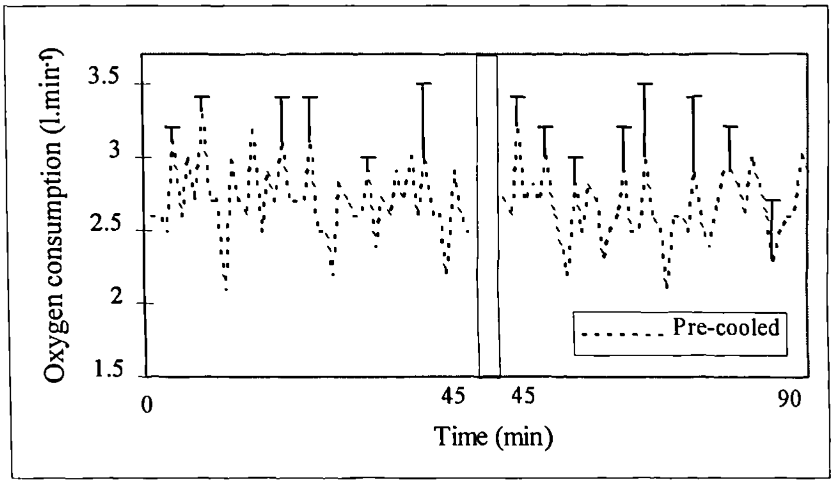


Figure 5.2.5. Mean ± s.d. oxygen consumption in the soccer-specific intermittent protocol in the normal, heated and pre-cooled condition

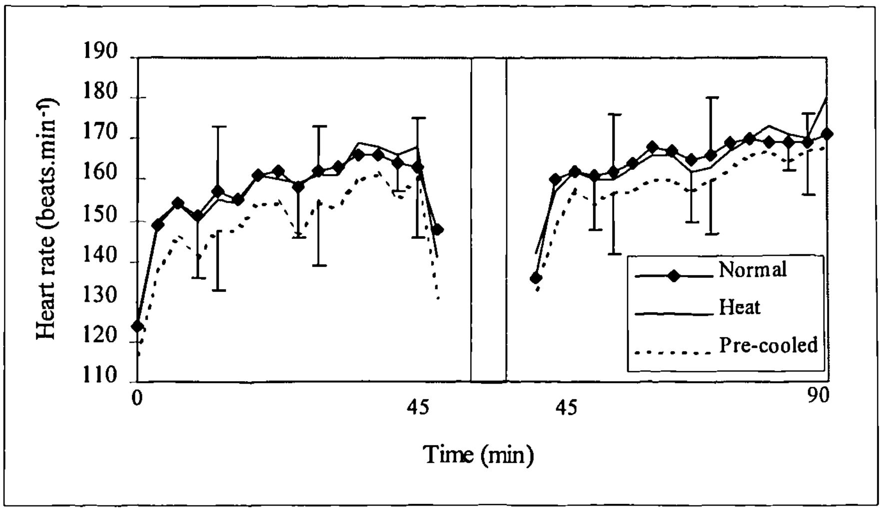


Figure 5.2.6. Mean ± s.d. heart rate response to the soccer-specific intermittent protocol in the normal, pre-cooled and heated condition.

No significant difference was observed for the ventilatory response between the normal, pre-cooled or heated condition (normal 87.7 ± 11.5 $l.min^{-1}$, pre-cooled 84.3 ± 10.7 $l.min^{-1}$, heated 82.4 ± 10 $l.min^{-1}$) (Figure5.2.7). Ventilation did not significantly differ between the first and second halves in either the heated, pre-cooled or normal condition (normal, first half 87.7 ± 11.8 $l.min^{-1}$, second half 87.7 ± 11.4 $l.min^{-1}$; pre-cooled, first half 87.4 ± 12 $l.min^{-1}$, second half 87.4 ± 9 $l.min^{-1}$; heated, first half 83.5 ± 10 $l.min^{-1}$, second half 81.4 ± 9.8 $l.min^{-1}$).

Rectal temperature fell from 37.5 ± 0.3 ^{o} C to 37.2 ± 0.4 ^{o} C during the shower (Figure 5.2.8). Rectal temperature continued to fall during the 15 min period between completing the pre-cooling period and the onset of exercise reaching a level of 36.9 ± 0.6 ^{o} C. Rectal temperature showed a small increase as a result of the pre-cooling strategy initially before declining gradually throughout the remaining 15 min time period prior to exercise (Figure 5.2.9). A one sample t-test was used to determine the consistency of the rectal temperature response to the pre-cooling strategy. The change in rectal temperature was almost significantly different (P = 0.057) from zero for the sample of 6 subjects tested. The change in rectal temperature was -0.3 ± 0.3 ^{o}C. When a one sample t-test was used to evaluate the change in rectal temperature from the start of the pre-cooling strategy to the onset of exercise, a significant difference ($P < 0.05$) was found. Change in rectal temperature, when the time period from the completion of the shower to the start of exercise was included was - 0.6 ± 0.6 °C (Figure 5.2.10). Mean skin temperature fell from an initial level of 28.2 ± 1.3 °C to a value of 24.4 ± 1.3 °C at the end of the shower. Mean skin temperature was increased in the 10 min after leaving the shower before falling again in the 5 min immediately prior to exercise.

Table 5.2.2. Mean ± s.d. for the first and second halves of the soccer-specific intermittent protocol

	Normal		Heated		Pre-cooled	
	First	Second	First	Second	First	Second
Ventilation ($l.min^{-1}$)	87.7 ± 11.8	87.7 ± 11.4	83.5 ± 10	81.4 ± 9.8	87.4 ± 10	82.4 ± 9
Oxygen consumption ($l.min^{-1}$)	2.5 ± 0.3	2.5 ± 0.3	2.5 ± 0.3	2.5 ± 0.2	2.7 ± 0.3	2.6 ± 0.2
Heart rate ($beats.min^{-1}$)	156 ± 11	164 ± 8	156 ± 10	164 ± 8	148 ± 12	157± 9
Rectal temperature (°C)	38.1 ± 0.5	38.6 ± 0.2	38.4 ± 0.5	38.8 ± 0.2	37.7 ± 0.6	38.5 ± 0.3
Mean skin temperature (°C)	31.1 ± 0.4	30.2 ± 0.6	32.5 ± 1.2	32.1 ± 0.7	28.7 ± 1.6	30.2 ± 0.3
Energy expenditure ($kJ.min^{-1}$)	53.5 ± 4	52.6 ± 4	53.5 ± 2	52.1 ± 5	56.3 ± 3	54.9 ± 4

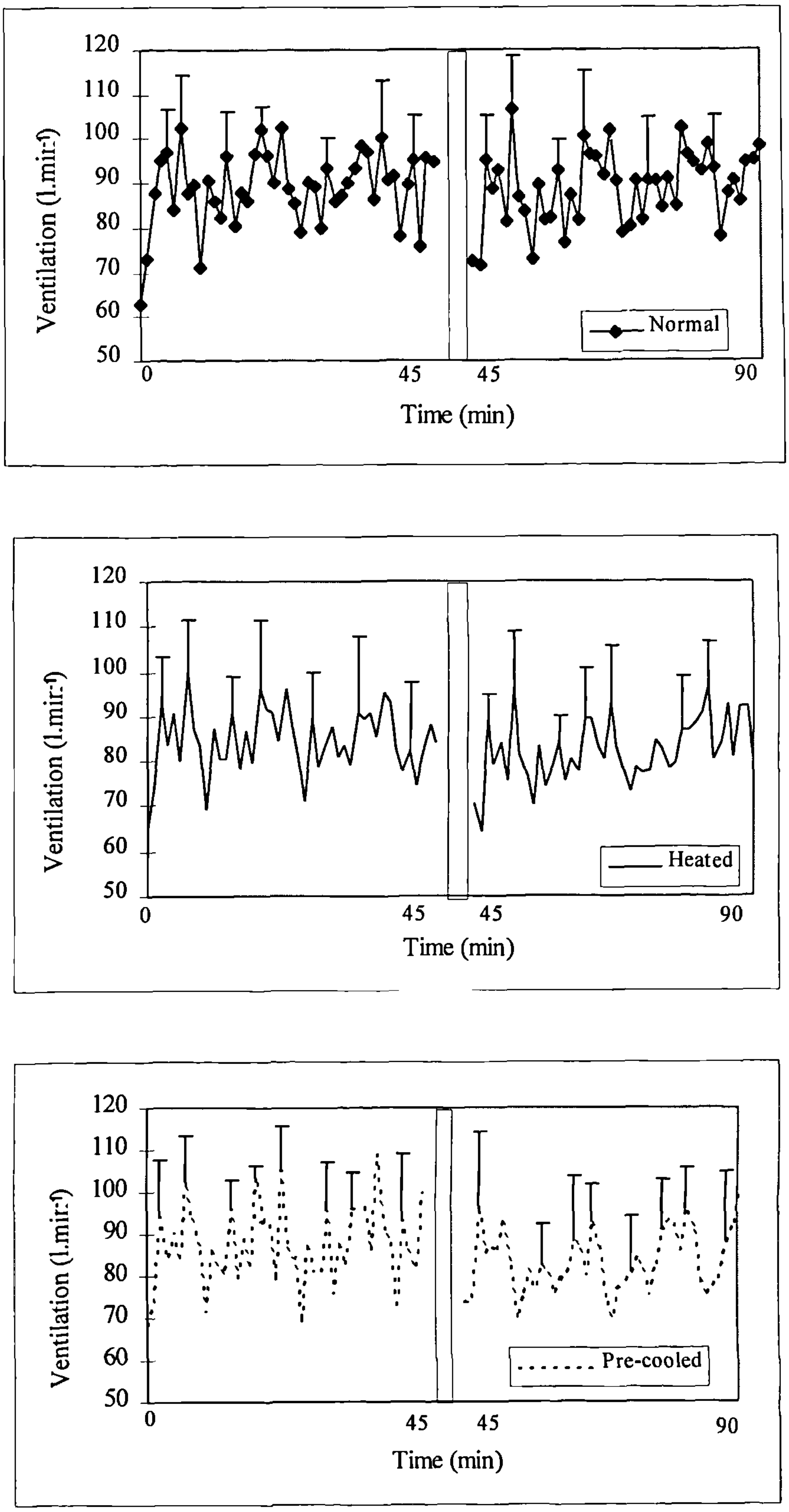


Figure 5.2.7. Mean ± s.d. ventilatory response to the soccer-specific intermittent protocol in the normal, heated and pre-cooled condition

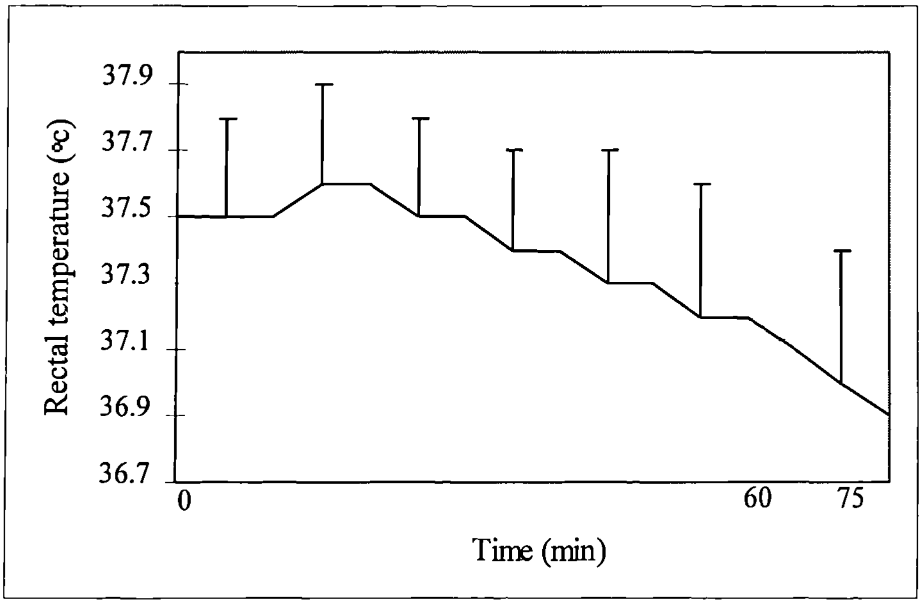


Figure 5.2.8. Mean ± s.d. rectal temperature response to the pre-cooling strategy

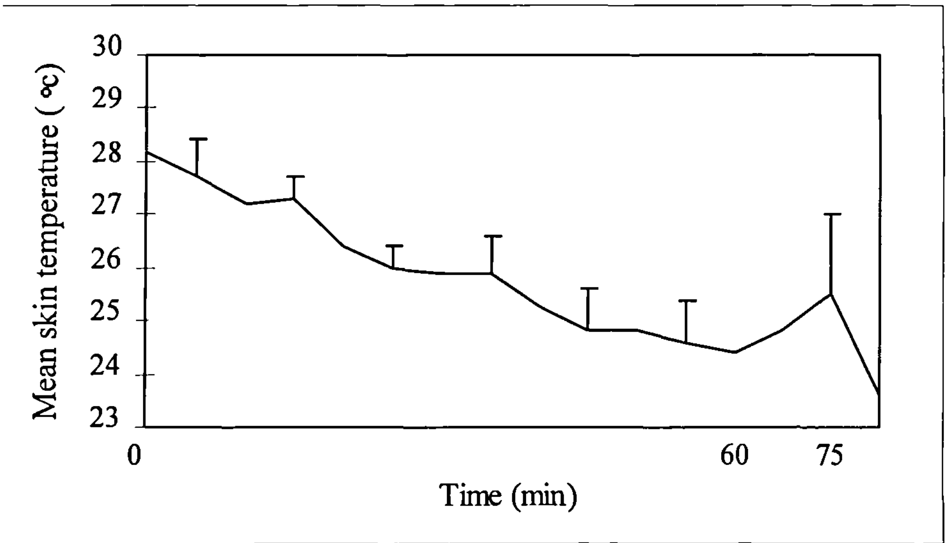


Figure 5.2.10. Mean ± s.d. mean skin temperature response to the pre-cooling stimulus

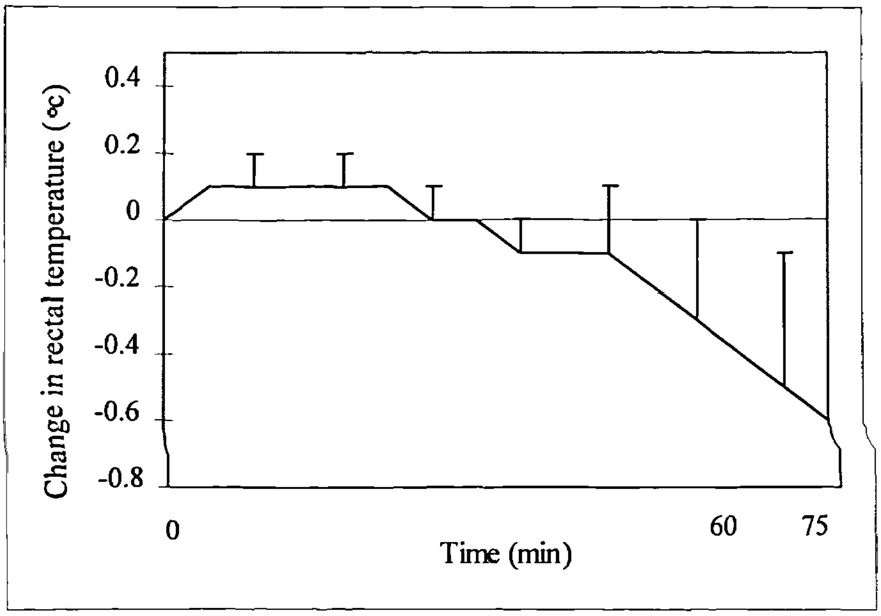


Figure 5.2.9. Mean ± s.d. change in rectal temperature as a result of the pre-cooling stimulus

Rectal temperature (Figure 5.2.11) was significantly lower during exercise ($P < 0.05$) in the pre-cooled condition compared to heated condition (pre-cooled 38.1 ± 0.6 ° C, heated 38.6 ± 0.3 ° C). No significant differences were observed between the rectal temperature values between the normal and the heated condition. The rectal temperature in the normal condition was 38.4 ± 0.4 ° C. Rectal temperature was significantly higher ($P < 0.05$) in the second half of the intermittent protocol for all 3 environmental conditions (normal, first half 38.1 ± 0.5 ° C, second half 38.6 ± 0.2 ° C, pre-cooled, first half 37.7 ± 0.6 ° C, second half 38.5 ± 0.3 ° C, heated, first half 38.4 ± 0.5 ° C, second half 38.8 ± 0.2 ° C). Rectal temperature was found to exhibit a significantly greater increase in the second half of the protocol after pre-cooling than the other conditions ($P < 0.05$).

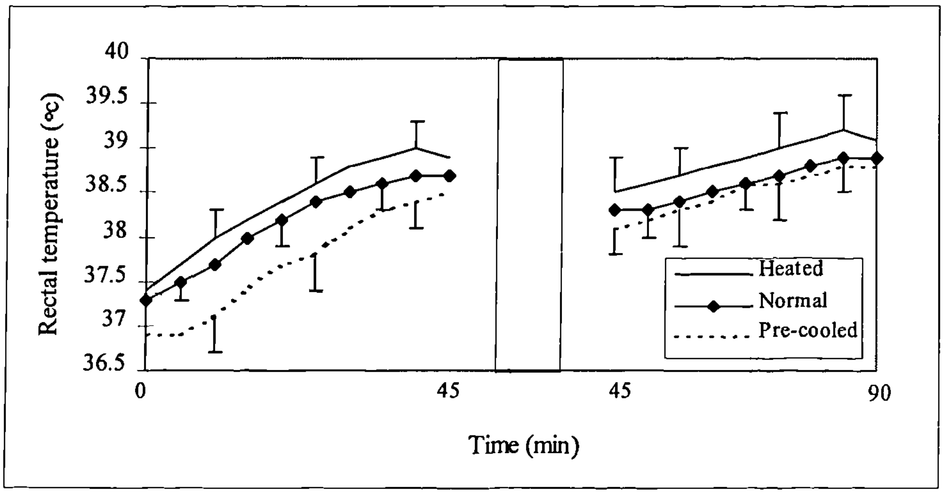


Figure 5.2.11. Mean ± s.d. rectal temperature response to the soccer-specific intermittent prototcol in normal, pre-cooled and heated conditions

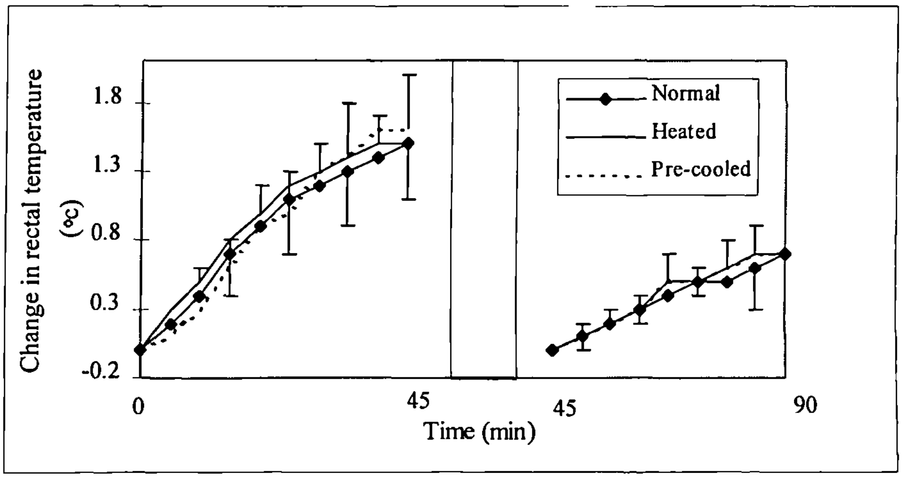


Figure 5.2.12. Mean ± s.d. change in rectal temperature in the soccer-specific intermittent protocol in the normal, pre-cooled and heated conditions

The change in rectal temperature was also calculated for the normal, heated and pre-cooled condition (Figure 5.2.12). No significant difference was observed for the change in rectal temperature in the normal, heated or pre-cooled condition. The change in rectal temperature was found to be significantly lower ($P < 0.05$) in the second half when compared with the first.

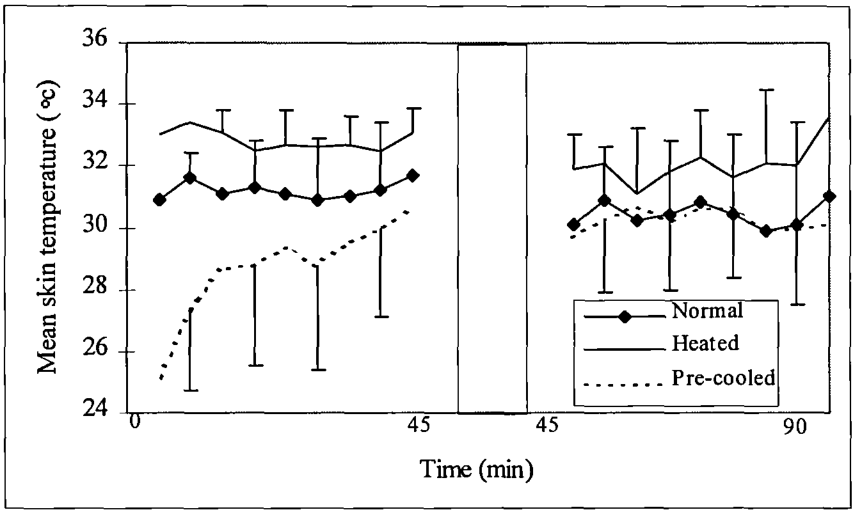


Figure 5.2.13. Mean ± s.d. mean skin temperature for the soccer-specific intermittent protocol in the normal, pre-cooled and heated conditions

Mean skin temperature was 30.6 ± 0.2 ^{o} C for the normal condition compared to 29.5 ± 1.4 ^{o} C for the pre-cooled condition and 32.2 ± 0.9 ^{o} C for the heated condition during the exercise period (Figure 5.2.13). No statistical analysis was performed on the skin tempearture data due to incomplete data sets reducing the sample size of the subjects to below that which is acceptable for statistical analysis (n = 3). This was a consequence of methodological problems in the collection procedures during the investigation. Mean skin temperature remained relatively constant between the first and second halves of the protocol in the normal and heated conditions (heated, first half, 32.5 ± 1.2 ^{o} C, second half 32.1 ± 0.7 ^{o} C; normal, first half, 31.1 ± 0.4 ^{o} C, second half 30.2 ± 0.6 ^{o} C). An increase in mean skin temperature was observed between halves in the pre-cooled condition. Skin temperature was 28.7 ± 1.6 ^{o} C in the first half compared to 30.2 ± 0.3 ^{O} C in the second.

No significant difference was observed between the different environmental conditions for the sweat production rate estimated from loss of body mass. Sweat production was 1.7 ± 0.3 kg for the normal condition compared to 1.9 ± 0.6 kg in the pre-cooled condition and the 2.0 ± 0.8 kg in the heated condition. Ratings of perceived exertion were also obtained at the end of each session. Ratings of perceived exertion for the normal, heated and pre-cooled were 15 ± 2, 16 ± 3 and 15 ± 2, respectively. These were not significantly different between the conditions. The distance covered during the intermittent protocol was also recorded in all three environmental conditions. Distance covered in the normal condition was 9.5 ± 0.4 km compared to 9.4 ± 0.6 km in the pre-cooled condition and 9.3 ± 0.5 km in the heated.

No significant differences were found between plasma lactate concentrations in the normal, heated or pre-cooled condition (Table 5.2.3). Plasma lactate concentration did not increase with time at any stage of the protocol (normal, pre-exercise 1.8 ± 1.4 $mmol.l^{-1}$, half time 3.4 ± 1.3 $mmol.l^{-1}$, completion 3.8 ± 1.9 $mmol.l^{-1}$; heated, pre-exercise 3.1 ± 2.5 $mmol.l^{-1}$, half-time 4.3 ± 2.2 $mmol.l^{-1}$, completion 4.7 ± 2.7 $mmol.l^{-1}$; pre-cooled, pre-exercise 3.8 ± 1.9 $mmol.l^{-1}$, half-time 3.5 ± 1.3 $mmol.l^{-1}$, completion 3.8 ± 1.9 $mmol.l^{-1}$). Plasma glucose levels were not significantly different between conditions. Plasma glucose concentrations were elevated significantly after 45 min of the intermittent protocol in the normal and heated condition (normal pre-exercise 5.0 ± 0.6 $mmol.l^{-1}$, half-time 5.7 ± 0.5 $mmol.l^{-1}$; heated pre-exercise 4.9 ± 0.6 $mmol.l^{-1}$, half-time 6.0 ± 1.0 $mmol.l^{-1}$). Plasma glucose concentrations were then maintained for the remainder of the protocol (normal completion 5.5 ± 0.9 $mmol.l^{-1}$; heated completion 5.4 ± 0.8 $mmol.l^{-1}$). No significant differences were noted between sampling intervals for plasma glucose in the pre-cooled condition. Concentrations before, after 45 min and upon completion of exercise were 5.1 ± 0.5 $mmol.l^{-1}$, 5.2 ± 0.2 $mmol.l^{-1}$ and 5.1 ± 0.3 $mmol.l^{-1}$ respectively. Free fatty acids were elevated in all conditions after 45 min over resting values though this difference was not significant. Significant differences were found, for all experimental conditions, between the concentration at the end of the protocol and both pre-exercise and half-time concentrations (normal, pre-exercise 322.9 ± 265.6 $\mu mol.l^{-1}$, half-time 812.9 ± 526.5 $\mu mol.l^{-1}$, completion 1557.4 ± 667.7 $\mu mol.l^{-1}$; pre-cooled, pre-exercise 456.1 ± 137 μmol.l^{-1}, half-time 751.3 ± 267.2 μmol.l^{-1}, completion 1468.4 ± 617.1μmol.l^{-1}; heated, pre-exercise 348.7 ± 166.5 μmol.l^{-1}, half-time 732.2 ± 329.6 μmol.l^{-1}, completion 1561.3 ± 670.4 μmol.l^{-1}). No significant differences were observed between environmental conditions for the free fatty acid response.

Table 5.2.3. Mean ± s.d. plasma lactate, glucose, and free fatty acid response to the soccer-specific intermittent exercise protocol in the normal, heated and pre-cooled condition

	Normal			Pre-cooled			Heated		
	Pre-	45 min	Post-	Pre-	45 min	Post-	Pre-	45 min	Post-
Lactate (mmol.l^{-1})	1.8 ± 1.4	3.4 ± 1.3	3.8 ± 1.9	3.5 ± 1.3	3.8 ± 1.9	3.6 ± 1.3	3.1 ± 2.5	4.3 ± 2.2	4.7 ± 2.7
Glucose (mmol.l^{-1})	5.0 ± 0.6	5.7 ± 0.5	5.5 ± 0.9	5.1 ± 0.5	5.2 ± 0.2	5.1 ± 0.3	4.9 ± 0.6	6.0 ± 1	5.4 ± 0.8
Free fatty acids (μmol.l^{-1})	322.9 ± 265.6	812.9 ± 526.5	1557.4 ± 667.7	456.1 ± 137	751.3 ± 267.2	1486.4 ± 617.1	348.7 ± 166.5	732.2 ± 329.6	1561.3 ± 670.4

5.2.4. Discussion

The aim of the present investigation was to determine the physiological and metabolic responses to a soccer-specific intermittent protocol performed on a non-motorised treadmill. The effects of increased ambient temperature (26 ^{o} C) and whole-body pre-cooling on the physiological and metabolic responses to soccer-specific intermittent exercise performance were also investigated.

5.2.4.1. The use of a non-motorised treadmill for soccer-specific intermittent exercise

The use of a non-motorised treadmill as apparatus for the modelling of match-play work-rates provides the advantage of almost simultaneous acceleration and deceleration in mimicking activity changes. This allows a more accurate re-creation of the activity profile in soccer than is possible on a motorised treadmill. Maximal efforts during high intensity exercise are also possible using the non-motorised treadmill as the belt is self-propelled by the subject. Such advantages help overcome some of the problems associated with the soccer-specific protocol previously designed in Chapter 3.1. The total distance covered during the soccer-specific intermittent protocol was 9500 ± 400 m. This distance is similar to the total distance of 8638 ± 1158 m observed for South American international players in Chapter 4.1. It is also in the order of the 10 km total distance covered according to Bangsbo et al. (1991) for Danish players. Some differences, with respect to the activity profile, still exist between match-play and the soccer-specific intermittent protocol in the current investigation. The replication of utility movements (i.e. backing and sideways movements) is not possible as the non-motorised treadmill permits only forward motion at its current stage of development. The total number of activity changes in match-play cannot be modelled adequately either in an experimental laboratory simulation due to their frequency and irregular nature. Performance of game skills is also neglected in the laboratory simulation. The exclusion of these components will probably result in the energy demands being lowered in the soccer-specific intermittent protocol compared to match-play. However, their inclusion would make it more difficult to investigate the physiological responses. Despite these problems it should nevertheless be recognised that the locomotive pattern employed in the current investigation is an accurate a representation of match-play work-rates as can be achieved at the present moment with the available apparatus.

The physiological and metabolic responses to the soccer-specific intermittent protocol on the non-motorised treadmill still approximated the physiological strain associated with match-play despite these shortcomings. Oxygen consumption was 2.5 ± 0.3 $l.min^{-1}$ over the 90 min period of the protocol. Such values indicate a high aerobic contribution to energy provision as has been previously noted for match-play (Reilly, 1996). Few researchers have utilised direct assessment techniques for VO_2 during match-play. This makes quantitative comparisons with the current data difficult. Values of around 3.18 $l. min^{-1}$ have been reported for match-play (Seliger, 1968). These values are similar to those produced in the current investigation when the additional physiological strain associated with the performance of game skills is taken into consideration. The VO_2 associated with the soccer-specific intermittent protocol can be expressed as a percentage of maximum to enable comparisons to be drawn with values estimated during match-play. The oxygen consumption during the intermittent protocol was approximately 65-70 % VO_2 max. This is also similar to the mean relative oxygen consumption associated with soccer match-play (Bangsbo, 1994).

Heart rate was observed to be 160 ± 6 $beats.min^{-1}$ for the soccer-specific intermittent protocol. This compares well with the 157 $beats.min^{-1}$ obtained by Reilly (1986) for soccer match-play. Other studies have noted a slightly higher heart rate (approximately 10 $beats.min^{-1}$) during games (Bangsbo, 1994; Van Gool et al., 1988). These results indicate that the soccer-specific intermittent protocol in the current investigation provokes a good representation of the cardiovascular demands of match-play. The slightly lower heart rates are probably the result of the omission of game skills and a decrease in the number of activity changes in the protocol. The heart rate response was maintained, as in match-play, as a result of the short recovery periods between high intensity bouts. This response is also characteristic of intermittent exercise (Saltin et al., 1976).

The blood lactate concentration can be used as an indicator of the anaerobic energy provision. Plasma lactate concentration increased above pre-exercise values during the first half of the soccer-specific intermittent protocol though this difference was not significant. The data suggest that there is an anaerobic component to the energy demands of the intermittent protocol, as indicated by the increased plasma lactate levels, though this anaerobic contribution was not increased in the second half. These results may suggest an increased removal during the second half of the protocol as the exercise stimulus is identical in both periods. Plasma lactate concentrations during the soccer-specific intermittent protocol were lower than values at half and full time for soccer match-play (Ekblom, 1986; Rhodes and Espersen, 1988; Gerish et al., 1988). These differences could again be the result of the exclusion of activities that increase the physiological demands on players (e.g. match skills) or simply reflect the problems relating to sampling that have been already discussed.

The dominant substrates utilized in soccer are carbohydrate and fat stored within the exercising muscle or delivered via the blood stream (Bangsbo, 1994). Plasma glucose levels were significantly elevated upon completion of the first half of the soccer-specific intermittent protocol. Blood glucose levels are similarly elevated over resting values during competitive matches. Blood glucose levels are increased as a result of higher adrenaline and cortisol levels during exercise limiting uptake of glucose and stimulating hepatic gluconeogenesis respectively as well as a decrease in circulating insulin. Mean values of between 3.2 to 4.5 $mmol^{-1}$ have been observed for elite Swedish and Danish players during match-play (Ekblom, 1986; Bangsbo, 1994a). Plasma free fatty acid concentrations had not increased significantly during the first half of the soccer-specific intermittent protocol. Plasma free fatty acid concentration was, however, significantly elevated upon completion of the exercise session over values prior to exercise and after the first 45 min of the protocol. Bangsbo (1994) noted increases in free fatty acid concentration in the blood during a competitive soccer match, with the increase being more pronounced in the second half of the match. This trend is identical to that found for the simulation in the current investigation. The increase in free fatty acid concentrations are probably the result of elevated blood flows to the adipose tissue and changes in catecholamine concentrations, thus promoting a high free fatty acid release in the second half. The progressively increased free fatty acid concentrations during the protocol are probably associated with a lower uptake of glucose and oxidation of free fatty acids by the active muscles (Hargreaves et al., 1991).

The data provided by the soccer-specific intermittent protocol in the current investigation seem to indicate that the protocol replicates the overall energy demands of match-play as well as the physiological responses observed during the game. Such similarities make the current soccer-specific intermittent protocol suitable for the investigation of the metabolic and physiological responses to intermittent work despite its possible limitaions.

5.2.4.2. Effects of temperature on soccer-specific intermittent exercise performance

During heat stress an individual's capacity for exercise is reduced. Reductions in performance occur across a wide range of exercise types from isometric contractions (Edwards et al., 1972), prolonged sub-maximal exercise (MacDougall et al., 1974) and maximal tests (Sawka, 1972). Few data are available regarding the effects of temperature on intermittent exercise performance. The current investigation attempted to provide some information on the effects of an increased ambient temperature (26 ^{o} C) on the metabolic and physiological responses to the soccer-specific intermittent protocol. The effects of a whole-body pre-cooling manoeuvre on the physiological responses to soccer-specific intermittent exercise were also investigated.

No significant differences were observed for the oxygen consumption under normal, heated or pre-cooled conditions. Studies examining the $\dot{V}O_2$ changes during exercise after pre-cooling have shown that $\dot{V}O_2$ remains the same (Hessemer et al., 1984) or is decreased (Bergh and Ekblom, 1979). Oxygen consumption has been shown to be elevated over control values during exercise in the heat (Nevill et al., 1994). Their study is one of the few to have utilised an experimental protocol that goes some way to replicating the activity pattern of games such as soccer. They observed significant increases in heart rate and oxygen consumption when intermittent exercise was performed at laboratory temperatures of 10 ^{o} C and 30 ^{o} C. No data were presented on the ventilatory response, though research has shown that it is independent of increases in internal temperature (Bergh and Ekblom, 1979).

The discrepancies in the experimental findings of the current investigation and the previous literature with respect to the physiological responses to intermittent exercise at different ambient temperatures and after whole-body pre-cooling could be accounted for by differences between the methodologies employed in the studies. The effects of temperature on the physiological responses to exercise appear to be dependent upon the magnitude of the increase or decrease in core and muscle temperature (Young, 1990). The previous research that has demonstrated significant differences in the physiological responses to exercise sessions in normothermic and hyperthermic exercise has primarily compared normal ambient temperatures (approximately 20 ^{o} C) with extreme heat stress (approximately 40 ^{o} C). For example, Febbraio et al. (1994) found significantly higher heart rates and respiratory exchange ratio and increased muscle glycogenolysis and higher muscle lactate accumulation when exercise was performed on a cycle ergometer at 70 % of $\dot{V}O_2$ max at 40 ^{o} C compared to 20 ^{o} C. The failure to find changes in the physiological responses to the intermittent exercise protocol is therefore not surprising when the change in the ambient temperature is only around 6 ^{o} C. This would suggest that such moderate increases in ambient temperature, as in the current investigation, have no major physiological consequences for intermittent exercise performance. Similarly, the reduction in core temperature prior to the initiation of exercise in the pre-cooled condition is not of a sufficient magnitude to produce changes in $\dot{V}O_2$.

The $\dot{V}O_2$ values in the three experimental trials indicated that the exercise sessions imposed a similar physiological strain on subjects irrespective of environmental conditions. Subjective estimations of exercise performance support these physiological similarities. Rating of perceived exertion were not significantly different between conditions. The increase in ambient temperature in the current investigation did not affect the perception of the intensity of the exercise. No psychological advantage was gained by lowering rectal temperature prior to exercise. These findings are in agreement with those of Lee and Haymes (1995) with respect to whole-body pre-cooling.

Metabolism has also been shown to be affected during exercise under heat stress and in the cold (Young,1990). No significant differences in plasma glucose and free fatty acid concentration were observed between the experimental conditions. The failure to find significant differences in substrate utilization in the current investigation is again probably the result of the magnitude of heat stress not being sufficient to instigate changes in the metabolic response to exercise. Plasma glucose failed to exhibit a significant increase during the pre-cooled condition as was observed in both the heated and normal conditions. This pattern of glucose response may reflect the increased utilization of endogenous carbohydrate stores as an energy substrate for shivering (Blomstrand et al., 1984) or an increased insulin sensitivity of peripheral tissues enhancing glucose uptake (Vallerand et al., 1988).

Plasma lactate concentrations were not significantly different between the pre-cooled condition and the other environmental conditions in the current investigation. Plasma lactate concentratons tended to be higher in the second half of the intermittent protocol in the heated condition than the normal and pre-cooled condition though this difference was not significant. This may provide some evidence to support a change in fibre recruitment and increased anaerobic metabolism in the second half of the heated conditon. Fibre type recruitment has also been shown to be altered under increasing ambient temperatures with a greater proportion of fast twitch fibres being recruited (Young, 1990). Such changes in the recruitment pattern, or a Q_{10} effect on glycolytic enzymes, will result in an increased rate of glycolysis. An alternative explanation may be a limitation in aerobic metabolism via mechanisms associated with tissue hypoxia as a consequence of a reduction in blood flow to the active muscle under conditions of heat stress. This would also result in a decreased aerobic contribution to the energy demands and an increased glycolytic rate.

Plasma lactate values indicate that there was an anaerobic component to the energy demands of the intermittent protocol. This will have implications for the cardiovascular responses to the soccer-specific protocol. Heart rate was not significantly different between the normal, heated and pre-cooled trials though there was a tendency for heart rate to be lower during both halves of the intermittent protocol in the pre-cooling condition. Lower heart rates have been shown during exercise following pre-cooling (Schmidt and

Bruck, 1981; Olchewski and Bruck, 1988). Lewke et al. (1995) found the average heart rate to decrease by approximately 9 beats.min^{-1} during 16 min of cycle ergometry separated into 4 min workloads at 35, 45, 55, 65 % $\dot{V}O_2$ max, respectively. The decrease in heart rate during exercise is believed to be associated with a decrease in thermoregulatory strain. Cutaneous vasoconstriction as a result of the lower levels of internal temperature results in the displacement of blood centrally and lowers the circulatory stress associated with exercise as the need for skin blood flow is reduced (Rowell, 1974). Support for a reduction in circulatory strain is provided by the observed increase in heart rate in the second half of the protocol in the pre-cooled condition. The thermoregulatory advantage of the lowered rectal temperature is lost by half-time. The increased need for skin blood flow to aid heat dissipation results in increases in heart rate to maintain cardiac output as stroke volume is decreased due to peripheral pooling and dehydration. Increases in heart rate during the second half were also found for the heated condition as a consequence of cardiovascular drift. This should be even more prominent during the heated condition than the normal and pre-cooled condition as the cardiovascular responses to exercise have been shown to be elevated under hyperthermic conditions (Rowell, 1983).

Rectal temperature was not significantly different between the intermittent exercise sessions performed in the heated and the normal conditions. Nielsen (1969) demonstrated that increases in core temperature are proportional to work intensity and independent of environmental conditions when laboratory temperatures are in the range of 5-30 $^{\circ}$ C. Saltin and Hermansen (1966) further defined this relationship by demonstrating that thermal strain is a function of the relative exercise intensity as opposed to absolute work-load. Rectal temperature was not significantly different between the normal and heated conditions as laboratory temperatures for the nomal and heated condition were below the danger threshold of 28 $^{\circ}$ C WBGT index and the work completed was identical in terms of the work-load and the physiological strain induced.

The pre-cooling stimulus employed in the current investigation elicited a 0.3 $^{\circ}$ C mean fall in rectal temperature. The decreases observed are in the region of those reported by Lewke et al. (1995) and Schmidt and Bruck (1981). Despite the reduction in rectal temperature as a result of the pre-cooling strategy mean rectal temperature was only observed to be significantly reduced only during exercise in the pre-cooled condition compared to the heated condition. There was, however, a tendency for the rectal temperature to be lower in the pre-cooled condition than in the normal condition (see Figure 5.2.11). These differences in rectal temperature were observed only during the first half of the intermittent protocol. Rectal temperature in the second half of the soccer-specific intermittent protocol demonstrated a significantly greater increase after pre-cooling than it did in either the normal or the heated condition.

The results indicate that the reduction in internal temperature during exercise after pre-cooling was not maintained throughout exercise and that prolonged work can lead to increases in rectal temperature over those observed for the identical sessions without prior pre-cooling. This is in contrast to literature that has shown lower core temperatures maintained throughout exercise. Lee and Haymes (1995) stated that discrepancies in the literature with respect to the pre-cooling data are due to the procedure used to lower core temperature or the wide range of exercise intensities and durations employed. The vast majority of the research that has been conducted into the effects of prior pre-cooling on exercise performance has employed exercise sessions that are approximately 15 to 30 min in duration. If a similar duration was employed in the current investigation, pre-cooling would appear to be beneficial as rectal temperature has still decreased, though not significantly, compared to the other conditions. Hessemer et al. (1984) examined the effects of pre-cooling utilising prolonged exercise (60 min) at the highest work-rate subjects found possible. Maximum differences in oesophageal temperature were observed 5 to 10 min after the onset of exercise. The difference between oesophageal temperature with and without prior pre-cooling were then found to diminish gradually throughout the exercise protocol although a small difference was still found between oesophageal temperature measurements upon completion of exercise. Pre-cooling may only be of benefit if the exercise periods are relatively short (around 30 min) in duration and continuous in nature. Further research is needed to clarify the internal temperature response to pre-cooling in prolonged exercise.

A significant increase in mean rectal temperature was also observed in the second half of the heated and normal experimental protocols when compared to the first half values.

Increases in rectal temperature with prolonged exercise are thought to be due to the failure of rectal temperature to stabilize due to the high work-rate or the result of impaired thermoregulatory mechanisms. An attenuation in the increases in skin blood flow above core temperatures of 38 ^{o} C results in a decrease in the body's ability to lose heat when exercise is continued (Kenney and Johnson, 1992). This reduction in skin blood flow is a direct consequence of the need to maintain stroke volume and prevent cardiac output falling during exercise. The heat dissipation mechanisms are also affected by dehydration. A progressive decrease in sweat rate is observed when exercise is prolonged despite increases in core temperature, as this helps to avoid excess loss of body water (Fortney and Vroman, 1985). Decreases in plasma volume associated with exercise and increased osmolality are a result of the loss of hypotonic fluid through sweat glands (Harrison et al., 1975; Brandenberger et al., 1989). Decreases in plasma volume result in decreases in sweat rate at a given internal temperature, therefore reducing the heat loss due to evaporation and increasing heat storage (Fortney et al., 1981).

Skin temperature was higher throughout the 90 min intermittent exercise protocol in the heated condition than the normal exercise session. Skin temperature is increased as a result of increases in skin blood flow during exercise radiation (Gisolfi and Wenger, 1985). This helps to promote heat loss by conduction and convection. Mean skin temperature was elevated over ambient temperature for the entire duration of the protocol, thus permitting the maintenance of the thermal gradient for heat loss. Higher skin temperatures in the hot condition may suggest increased skin blood flow levels as a result of the need to increase heat loss. Core to skin temperatures gradients were also maintained as rectal temperature still increased. This increase may be the result of the high exercise intensity and metabolic rate associated with the intermittent protocol. Green (1990) stated that intermittent exercise performance does not allow a steady state internal temperature to be attained. Mechanisms of heat loss such as evaporation and convection are altered in intermittent exercise (Kraning and Gonzalez, 1991). Frequent alterations between exercise and rest result in oscillations in the vasoconstriction of peripheral vessels and sweat rate leading to heat storage.

Mean skin temperature was lower in the first half of the protocol after pre-cooling than in both normal and hot conditions. Similar mean skin temperature responses have been observed by Lee and Haymes (1995). They found mean skin temperature was significantly lower for the first 25 min of exercise performed at 82 % $\dot{V}O_2$ max. The low skin temperatures are probably due to the maintenance of vasoconstriction in response to exposure to the cold stimulus. The low skin temperatures after pre-cooling in the first half would help to maintain low rectal temperature levels by promoting heat dissipation to the environment through convection and radiation. The reduced rectal temperature in the pre-cooled condition would allow a greater heat storage before rectal temperature increased to a level sufficient to stimulate heat dissipation mechanisms, thus reducing the physiological strain imposed on the individual. An increase in skin temperature to a level similar to that obtained in the normal condition was found in the second half. This increase in skin temperature is associated with the need for an increased rate of heat dissipation due to increases in rectal temperature as exercise progresses. It seems likely that the increase in mean skin temperatures during the first half results in the decrease of the thermal gradients for heat transfer leading to a loss of the decrease in rectal temperature advantage gained during pre-cooling.

Sweat production rate was not significantly different between conditions. Core temperature is the primary stimulus to the sudomotor centre with skin temperature and rate of change of skin temperature being of secondary importance (Wyss et al., 1974). Similar mean core temperatures in both the heated and normal environmental conditions may therefore explain the similar sweat production rates. Sweat production rate was reduced as a result of prior whole body pre-cooling (Olschewski and Bruck, 1988; Lee and Haymes, 1995). This reduction is the result of both a decrease in mean sweat rate and a delayed onset of sweating (Lewke et al., 1995). Hessemer et al. (1984) found that sweat production rate was only significantly different after pre-cooling for the first 30 min during exercise with a similar rate being observed up to the completion of the exercise test. Sweat production rate was only calculated from changes in body mass corrected for respiratory losses for the entire 90 min period exercise period in the current investigation. It is therefore possible that differences in sweat production rate did exist between the experimental conditions for the initial stages of exercise though these were not detected due to the methodology employed.

In conclusion, the soccer-specific intermittent protocol employed in the current investigation resulted in a similar overall energy demand as soccer match-play. The physiological ($\dot{V}O_2$, heart rate, VE and rectal temperature) and metabolic responses (plasma free fatty acids, glucose and lactate) were also similar, thus indicating its usefulness as a laboratory simulation of match-play work-rates. Intermittent exercise performance at 26 ^{o}C did not result in significant increases in the physiological or thermoregulatory responses compared to intermittent exercise performance at 20 ^{o}C. The temperature chosen for the high temperature condition was based upon the average temperature for the last four venues of the FIFA World Cup finals. This gave the data a higher degree of validity for soccer than some arbitary temperature though it should be noted that it represents an average temperature and not the extremes of temperature observed at some tournaments. This makes it invalid to make firm conclusions regarding the effect of heat stress on intermittent exercise performance outside the thermal limits examined in the study. Whole-body pre-cooling resulted in significant decreases in rectal temperature prior to exercise though these reductions in rectal temperature disappeared gradually during exercise. No effect on the physiological or metabolic responses to intermittent exercise were found as a result of pre-cooling manoeuvre. It therefore seems possible that the lowering of core temperature prior to exercise does not benefit soccer-specific intermittent exercise performance within the ranges of temperature investigated in this study.

CHAPTER 6

SYNTHESIS OF FINDINGS

6. SYNTHESIS OF FINDINGS

The purpose in this chapter is to interpret and integrate the results obtained within this thesis. The possible applications and limitations will be discussed. The realisation of the aims of the thesis will be confirmed prior to reviewing the original hypotheses. Within the general discussion and conclusions which follow, the results of the separate studies will be interpreted with respect to the physiological demands of soccer-match play and laboratory based soccer-specific intermittent exercise protocols.

6.1. REALISATION OF AIMS

The experimental sections of this thesis have fulfilled all of the aims stated in Chapter 2. The demands of match-play were established by techniques of motion-analysis (Aim 1). The work-rate profiles of South American international soccer players and English Premier League players were analysed. The demands of soccer seem to be primarily aerobic in nature with critical match events calling for anaerobic efforts. No estimation of the energy cost of match-play was available from the doubly-labelled water study to supplement work-rate profiles as a result of the low turnover rates of the isotopes employed (Aim 2).

Intermittent exercise protocols based on match-play work-rates were developed to evaluate the physiological and metabolic responses to soccer-specific intermittent exercise (Aim 3). These protocols were employed on a motorised and non-motorised treadmill and elicited physiological responses similar to those produced during match-play (Aim 4). The physiological demands associated with soccer-specific intermittent exercise performance were not significantly different from steady-rate exercise performed at the same average intensity.

The effects of thermal strain on soccer-specific intermitent exercise were investigated for fulfilment of Aim 5. The effects of increased ambient temperature on the physiological responses to soccer-specific intermittent exercise were compared with the physiological responses to an identical exercise test after whole body pre-cooling and under normal environmental conditions. Physiological strain was equivalent between experimental conditions though some evidence was provided for an altered thermoregulatory response during exercise after pre-cooling though this was only transient in nature.

6.2. REVIEW OF HYPOTHESES

A series of hypotheses were formulated throughout the thesis. It is appropriate to examine whether the findings have lead to the accepting or rejecting of the hypotheses prorposed.

Hypothesis 1: *Elite South American international soccer players exhibit work-rate profiles that are no different to those observed elite professional players in the English league*

This hypothesis was rejected. English Premier League players covered a significantly greater total distance than South American players during match-play. No significant differences were observed between the two groups, with respect to the total distance covered in each activity classification except walking backwards.

Hypothesis 2: *The physiological strain associated with soccer-specific intermittent exercise performance is not different from the physiological strain (e.g. similar oxygen consumption, heart rates) imposed on individuals from that of steady-rate exercise performed at the same average intensity.*

This hypothesis was accepted. Oxygen consumption and heart rate during intermittent exercise performance were not significantly different from steady-rate exercise performed at the same average intensity. Intermittent exercise did, however, elicit a significantly greater rise in rectal temperature during the later stages of the exercise protocol.

Hypothesis 3: *The physiological strain associated with soccer-specific intermittent exercise performance at elevated environmental temperatures (26 ^{o} C) is no different than soccer-specifc intermittent exercise performance under normal laboratory conditions (20 ^{o} C.)*

This hypothsis was accepted. No significant differences were observed for the physiological demands (i.e. oxygen consumption, heart rate) or thermoregulatory response to intermittent exercise at 26 ^{o} C and 20 ^{o} C.

Hypothesis 4: *The physiological strain associated with soccer-specific intermittent exercise performance after a whole-body pre-cooling manoeuvre is no different from that experienced during soccer-specific intermittent exercise performance under normal and heated laboratory conditions*

No significant differences were observed between the physiological and thermoregulatory demands to intermittent exercise performance in the normal condition or after pre-cooling. Significant differences between the pre-cooled condition and the "heated" condition were restricted to differences in the core temperature response to exercise. No significant differences were found in the physiological demands associated with soccer-specific intermittent exercise performance in the heated or pre-cooled condition. This hypothesis was therefore accepted.

6.3 GENERAL DISCUSSION

A two-way approach was adopted to investigate the metabolic responses to soccer-specific intermittent exercise. Both the demands associated with match-play and the physiological responses to laboratory simulations of match-play work-rates will be discussed. The issues arising from this overview will then be considered with respect to the sport of soccer.

Chapter 4 of the current experimental work aimed to quantify the demands of soccer match-play. Motion-analysis techniques were employed as the physiological demands of soccer can be examined by making relevant observations during match-play. No data were previously available regarding the energy demands of international soccer or for South American players. The primary finding of the investigation was that the total distance covered during match-play was lower for South American international soccer players compared to elite players in the English Premier League. This would indicate differences in the overall severity of exercise and hence an individual contribution towards the total team effort with the different standards of play. Such discrepancies are probably the result of tactical differences between international and club level competition or cultural differences in the style of play between European and South American teams.

The activity in games is executed more or less continuously as the rest pauses were infrequent and low in duration. The total distance covered does not fully represent the demands of soccer as the exercise pattern constantly fluctuates giving the activity its characteristic intermittent pattern. These component parts need to be evaluated in order to provide a more complete picture of the physiological demands of match-play. Significant differences were not found in the distance covered in each separate activity categories, between the international and English Premier League players, except for walking backwards. This would seem to suggest that the pattern of exercise is similar despite changes in the overall severity of exercise. Around 11 % of the total distance was covered while performing backing or sideways movements. This total distance, although quantitatively small, will provide an increase in the energy demands placed on players.

The work-rate profiles of players are not stable and can be a consequence of a number of determining factors such as importance of the game, the opponents, environmental conditions, fatigue and tactical restraints. The work-rate is also determined to a large extent by the positional role of the player. Significant differences between defensive, midfield and forward players existed in the current investigation (see Chapter 4.1). These probably reflect the different tactical and technical requirements associated with each positional role. The exercise pattern during soccer match-play is still predominatly aerobic in nature with anaerobic periods superimposed on the background of endurance running irrespective of differences that are observed between levels of play or positions.

Prior to the current investigation no research group had attempted to examine the relationship between work-rate profile and anthropometric determinations. The relationships between the work-rate profile produced in a game and an individual's physical charateristics i.e. body mass, sum of skinfolds is difficult to evaluate in a sport such as soccer as an individual's performance is dependent upon a number of interdependent factors. Many variables will influence the relationship between work-rate and anthropometric profile. Technical and tactical restraints placed upon the players prevent them from maximally stressing their physical capacities. Further evidence of the complexity of the relationship is provided by the large variablity observed among the anthropometric characteristics of the players in the sample. Despite this variation some aspects i.e. low adiposity, high muscularity, will prove beneficial in all positions.

Methodological problems restrict the information that can be collected in competitive match situations as the changeable and irregular nature of the work-rate profile makes experimental control difficult. An emphasis must then be placed on laboratory simulations to supplement the data provided during games. Past research has suffered from the lack of experimental models for studying soccer- specific intermittent exercise in the laboratory. Laboratory based intermittent exercise protocols that replicated the work-rates of match-play were developed for a motorised and non-motorised treadmill. Both protocols were based around data obtained from motion-analysis studies in the current investigation and in previous research (Reilly and Thomas, 1976). The intermittent protocol performed on the motorised treadmill was developed as a model of match-play work-rates to enable comparisons to be made between soccer-specific intermittent exercise and steady-rate exercise performed at the same average intensity. It is of fundamental importance that any laboratory based simulation has a high degree of fidelity with what it is actually trying to re-create. Technical restrictions of the equipment utilised in the current investigation placed limitations on the re-creation of the activity profile observed in a soccer match. Utility movements cannot be performed within the context of an intermittent protocol on a treadmill. The frequency and irregularity of the activity changes are also compensated as a result of the need to provide some degree of control over the activity pattern. This specific problem was minimised by the implementation of a non-motorised treadmill in the final experimental investigation. Match activities cannot be performed so must be omitted.

These discrepancies with respect to the activity profile during match-play will probably result in the energy demands being decreased during laboratory simulations compared to match-play. Ball contacts and utility movements, however, make up only a small component of the total match demands, thus suggesting that laboratory simulations may be useful in the investigation of soccer-specific intermittent exercise performance. Despite these limitations the conclusions regarding the energy demands of soccer based upon work-rate profiles can be supported by the experimental findings in Chapter 5.

The overall severity of the physiological strain for the 90 min non-motorised treadmill simulation was similar to that of match-play. The total distance covered during the soccer-specific intermittent protocol was in the order of 10 km. This is equivalent to the total distance covered in match-play, according to the results in Chapter 4.1 and past research. Further support for the validity of the intermittent protocols devised can be obtained by relating the physiological and metabolic responses to the soccer-specific intermittent protocol to those obtained during competitive match-play. Comparisons between the data provided by the laboratory simulations and match-play in terms of the oxygen consumption and energy expenditure are difficult to interpret. Few researchers have attempted to quantify directly the oxygen cost of soccer performance. The values provided, by those studies that have, are likely to underestimate the energy costs due to the restrictions placed on performance by the collection procedure and the low abiltiy level of the subjects used.

Both soccer-specific intermittent protocols placed a large emphasis on the aerobic energy systems, resulting in a mean relative work-rate of approximately 70 % $\dot{V}O_2$ max for the exercise. A mean relative work-rate of 70 % of $\dot{V}O_2$ max corresponds to the mean relative work-rate in soccer despite the prolonged periods of activity performed at a low submaximal intensities during match-play. The main energy requirement is to support locomotion and the performance of match activities such as game skills, accelerations, changes in direction, jumps and static muscle contractions in addition to locomotion. A small component of the extra energy cost may also be due to the intermittent nature of the exercise. Significant increases in the physiological demands have been associated with intermittent exercise when compared to continuous exercise at the same mean work-rate.

This higher level of energy demand has been linked to increases in the $\dot{V}O_2$ during recovery periods due to the anaerobic energy production in the preceeding exercise bout. Oxygen consumption may also be increased as a result of increases in free fatty acid utilization in the later stages of exercise.

Mean heart rate responses to both soccer-specific intermittent protocols were in the order of 160-170 beats.min^{-1}. Such figures correspond well with values obtained by others during match-play. The pattern of the heart rate response was also duplicated in the intermittent protocols. Fluctuations in heart rate occurred as a result of changes in exercise intensity. Heart rate was, however, maintained at a high rate throughout exercise as a result of the short recovery periods associated with soccer-specific intermittent exercise.

The major inferences drawn from the preceeding discussion lead to the categorisation of soccer as primarily an endurance sport. The energy demands are placed mainly on the aerobic energy systems. The pattern of substrate utilization in the soccer-specific intermittent protocol also showed responses similar to those associated with match-play and indicate the high aerobic contribution to energy provision. Plasma glucose levels were maintained above resting concentrations throughout the 90 min simulation as is the case during match-play. Plasma free fatty acid response to the intermittent protocol was also comparable with respect to the pattern of response associated with match-play. Plasma free fatty acids concentrations were elevated in the first half compared to resting conditions, this elevation being increased further in the second half of the protocol.

The intermittent exercise pattern and the importance of an individual's ability to perform both high intensity exercise and match specific actions result in other physiological components being crucial to successful match-play. These include the ability to develop high power outputs (force) in single match situations and to perform repeated intense intermittent activity. Anaerobic energy systems are taxed largely by the high intensity bouts during matches. These were found to be infrequent and short in duration during games. The ability to perform at a high intensity is nevertheless important to match outcome as the incidence of high intensity exercise is confined to crucial match actions (e.g. sprinting to create space, to win a ball in a tackle). The high intensity performances in soccer will result in a major component of the energy demand being supplied by alactic sources. Glycolytic pathways are also important as blood lactate values have been shown to be elevated in the course of match-play.

Plasma lactate concentrations were elevated compared to resting values in the intermittent protocol performed on the motorised treadmill. This increase was of the same magnitude as that noted for match-play. The intermittent protocol on the non-motorised treadmill did not result in significantly increased plasma lactate concentrations compared to resting conditions. Discrepancies with the data produced on the motorised treadmill may indicate the problems associated with evaluating the blood lactate response to intermittent exercise as opposed to a change in the energy demands of the protocol. Single blood samples for determination of lactate concentrations are not appropriate for assessing the contribution of the anaerobic energy systems during soccer-specific intermittent exercise. Variations in the concentrations occur as a function of the activity performed prior to sampling in both games and simulations. The lactate concentration also underestimates the role of the anaerobic energy system in intermittent exercise as it provides no indication of the contribution of the alactic energy systems to the anaerobic energy demands. The short duration of the maximal bouts probably leads to a considerable contribution of the energy for the activity coming from phosphocreatine, and to a lesser extent stored adensine triphosphate. It therefore seems likely that both match performance and soccer-specific intermittent exercise require significant contributions from the anaerobic energy systems to support exercise at the required level.

The high energy expenditures associated with soccer-specific intermittent exercise are illustrated by the high rectal temperatures observed in the experimental investigations (see Chapter 5). This has important practical implications for soccer match-play under conditions of high thermal stress. Evaluation of the body's thermoregulatory responses to intermittent exercise patterns that are representative of soccer match-play is limited. It has therefore been difficult to produce firm conclusions regarding the effects of increased ambient temperature on the physiological responses to intermittent exercise.
Soccer-specific intermittent exercise performance was found to be associated with a decrease in efficiency of the thermoregulatory system and a consequent greater rise in

rectal temperature than during steady-rate exercise. These changes are associated with the alterations in the heat loss mechanisms of the body such as evaporation and convection during intermittent exercise. This response is probably mediated through the pulses of exercise and rest sessions causing transient changes in the body's sweating and vasoconstrictory responses.

In the present study core temperature was not significantly affected by intermittent exercise performance at an increased ambient temperature of 26 °C. This temperature represents an average indication of the thermal strain provided in the last four World Cup competitions though it does not reflect the extreme of temperatures (> 30 °C, Orlando, USA, 1994) that have been observed at some tournaments. The results suggest that intermittent exercise performance at such levels of ambient temperature does not increase the thermoregulatory or physiological strain associated with performance. Further work is probably needed to examine the effects of a wide range of ambient temperatures on performance before firm conclusions can be drawn regarding the effects of heat on performance.

Pre-cooling the body prior to exercise can result in improvements in exercise performance. No investigators have examined the effects of whole body pre-cooling on intermittent exercise performance. A whole body pre-cooling manoeuvre prior to exercise resulted in a lowering core temperature of around 0.5 °C. This was also manifested in a decrease in core temperature during exercise, though this difference was only significant between the pre-cooling condition and the intermittent exercise at 26 °C. The reduction in rectal temperature was transitory lasting until approximately half time at which point the change in rectal temperature approximated that in the other experimental conditions. The effects of pre-cooling manoeuvre were probably mediated through a delayed onset of the body's thermoregulatory responses. No significant differences were found with respect to the physiological demands associated with the exercise after pre-cooling. These results suggest that when exercise is prolonged in environmental temperatures up to 26 °C and is intermittent in nature, there is little or no thermoregulatory or physiological benefit provided by whole body pre-cooling.

Few studies, prior to the current work, have examined the physiological responses to continuous and intermittent exercise with intermittent protocols that attempt to replicate the activity pattern in soccer and have chosen instead to alternate between exercise and rest periods. The physiological reponses to the soccer-specific intermittent protocol were not significantly different from the responses to steady-rate exercise at the same average intensity (Chapter 5.1). No significant differences in terms of the magnitude of the responses were found for oxygen consumption and heart rate. The results from such investigations have implications for the testing and training of players. The stimulus for improvement in exercise performance is related to the magnitude and duration of the stress imposed during training. Training under anything but optimal conditions will decrease the efficiency of the training response. The lack of differences in the physiological stresses associated with intermittent and continuous exercise in the current investigation would seem to suggest that soccer players benefit equally from a training stimulus be it presented in a continuous format or intermittently. This situation, however, represents an over-simplification of the physiological processes associated with soccer-specific intermittent exercise and may just reflect the short recoveries. The physiological responses to intermittent exercise are linked to the duration of both exercise and recovery periods. The stress associated with intermittent exercise is therefore determined by the protocol employed. This makes it unwise to generalise the findings further than situations in which the exercise:rest ratios are similar. The impression that intermittent and continuous work are equivalent with respect to the energy demands required to support the effort may therefore be misleading.

Differences in muscle fibre recruitment patterns between the two forms of exercise indicate that the training stimulus should be presented in the most sport specific context. Intermittent exercise performance has been associated with an altered fibre type recruitment pattern compared to continuous exercise. Performing exercise continuously may not lead to the recruitment of fast twitch fibres and may thus lead to changes in the muscle fibre recruitment pattern between match performance and training. Recruitment patterns will also be mediated further by the performance of match-specific actions. These will result in further increases in the energy requirements of the activities compared to similar patterns of exercise without the ball. The major training stimulus for soccer should therefore be as similar in nature to match performance as is possible to ensure an optimal training stimulus. This means the pattern of exercise should be intermittent, with frequent changes in activity and work with the ball being incorporated wherever possible.

Significant increases in rectal temperature in the second half of the soccer-specific intermittent protocol illustrates the need for fluid consumption during exercise to maintain hydration. This will help prevent decreases in performance capability and large increases in skin blood flow to aid heat dissipation. Whole-body pre-cooling seems to have little implications for soccer training or match-play as the benefits of a reduced core temperature are transient. It may be possible that pre-cooling manoeuvres may benefit performance at high ambient temperatures. More work is needed before the benefits of whole-body pre-cooling manoeuvres to intermittent exercise performance can be fully delimited.

6.4. CONCLUSIONS

The aims set out in Chapter 2 have been fulfilled, resulting in the quantification of the demands of soccer match-play and the subsequent development of laboratory protocols that have enabled the physiological and metabolic responses to soccer-specific intermittent exercise to be evaluated. The exercise pattern in soccer is intermittent with high intensity anaerobic periods superimposed on a background of endurance running. The demands of match-play are predominantly aerobic in nature with anaerobic periods probably being supported by alactic and lacatic energy systems in similar proportions. These demands are relatively consistent from game to game despite differences in the work-rate profile existing between positions and level of competition. Other factors, particularly psychological and tactical, also contribute to an individual's work-rate. An individual's anthropometric profile does not seem to be a crucial factor in the prediction of match-play work-rate in the current investigation. The failure to find significant relationships between work-rate in matches and anthropometric characteristics is probably a consequence of the multiplicity of factors that prevent players from taxing their physical capacities maximally during games.

Laboratory based simulations of soccer-specific intermittent exercise were devised based on match-play work-rates. These were found to elicit physiological responses that were similar in magnitude and pattern to those produced during match-play. This was despite the exclusion of utility movements and specific match activities. Physiological responses to 46 min of soccer-specific intermittent exercise equivalent to steady-rate response at the same average intensity. Differences in the pattern of responses were, however, observed with fluctuations in oxygen consumption, heart rate and ventilation being associated with changes in exercise intensity. Increased demands are also associated with recovery periods as execution of the protocol progressed, reflecting the need for the replenishment of phosphagen, after high intensity anaerobic periods. Intermittent exercise was also associated with a significant increase in rectal temperature over values for continuous exercise. This represents a decrease in efficiency of the body's thermoregulatory system as a result of an alteration in heat loss mechanisms in intermittent work.

No significant differences were observed in the physiological and metabolic responses to soccer-specific intermittent exercise at 20 ^{o} C and 26 ^{o} C and after a lowering of core temperature prior to exercise by whole-body cooling. This indicates that performance capabilities are not affected under such conditions of thermoregulatory strain. The thermoregulatory response was altered after pre-cooling with significantly lower rectal temperatures being observed in the pre-cooled condition when compared to exercise at 26 ^{o} C. The pattern of response was only transiently altered with increases in rectal temperature during the second half being signifcantly elevated over increases in 20 ^{o} C and 26 ^{o} C environmental temperatures. The lowering of rectal temperature prior to exercise seems to be of little benefit in prolonged intermittent exercise performance.

The implications arising from this thesis are related to the physiological demands of soccer-specific intermittent exercise. Soccer players should perform as much of their training as possible with an intermittent exercise pattern targeted at both aerobic and anaerobic energy systems. This will not only replicate the pattern and stresses placed upon the cardiovascular system but also will lead to the muscle recruitment patterns being reproduced. These sessions should where possible be built around the exercise to rest ratios associated with soccer match-play and incorporate activities with the ball. Despite the failure to find significant links between anthropometric profiles and work-rates, players should still possess a body composition that tends towards mesomorphy and has low adiposity. Laboratory based protocols can be developed that attempt to replicate the exercise pattern in soccer. Despite their limitations such procedures are useful for determining the physiological responses to match-play and providing a framework for fitness assessments.

In summary :-

1. The work-rate profile of players is a function of position of play and the type of competition. Despite these variations the energy demands are relatively constant with the major physiological demands of soccer being placed upon the aerobic energy systems. There are important periods of high intensity exercise, however, which call for anaerobic efforts.

2. Laboratory based simulations of soccer match-play work-rates elicited physiological responses that were similar in magnitude and pattern to those obtained as a result of match-play despite the limitations of the simulations. These findings confirm the benefits of the development of soccer-specific intermittent protocols in the investigation of the demands associated with match-play.

3. The physiological demands of the soccer-specific intermittent exercise protocol on the motorised treadmill were equivalent to continuous exercise at the same average intensity. The protocols devised did not, however, incorporate specific match activities (i.e. ball work, utility movements) that may further increase the demands associated with match-play. Intermittent exercise as employed in the investigation was associated with increased demands in recovery periods as the protocol progressed and a higher increase in rectal temperature.

4. The physiological and metabolic loads were similar between soccer-specific intermittent exercise at 20 ^{o}C, 26 ^{o}C and after a whole body pre-cooling manoeuvre. Whole-body pre-cooling resulted in significantly lower rectal temperatures compared to exercise at 26 ^{o}C

though this difference was only transiently maintained and is consequently of little benefit to prolonged intermittent exercise performance.

CHAPTER 7

RECOMMENDATIONS FOR FUTURE RESEARCH

7. RECOMMENDATIONS FOR FUTURE RESEARCH

The studies completed within this thesis provided an overview of the physiological demands of soccer. In achieving this some issues have arisen and certain findings have prompted the formulation of recommendations for further research.

Suggestions arising from Chapter 4:

(1) Significant differences were observed in the total distance covered during match-play. Further research would be useful in determining if such discrepancies are purely the result of the type of competition. Techniques of motion-analysis could be used to determine work-rate profiles amongst a wider population of soccer players, including recreational, old and females, as such data may provide further information on the demands of the game at these levels and hence implications for training and fitness evaluations that are specific to the populations.

(2) The validation of the doubly-labelled water technique for use with human subjects has allowed for the measurement of average daily energy expenditure in a range of subjects. This may prove valuable in the examination of the energy expenditure of soccer players over a number of days and may have implications for dietary advice or match-play and training.

Research proposals in response to the findings in Chapter 5:

(3) No significant differences were found between the physiological responses to soccer-specific intermittent exercise and steady-rate exercise at the same average intensity. Differences may, however, exist between the two modes of exercise as the protocol utilised did not incorporate specific match activities that may increase the physiological strain. The physiological response to intermittent exercise is related to the exercise:rest ratios utilised. It would therefore be of interest to develop this research by examining the impact of different intermittent protocols and their effects on the physiological responses to exercise.

This could be in comparison to continuous exercise or with respect to the subsequent in the protocol.

(4) The energetic consequences of accelerating, turning and decelerating in the game are likely to have accentuated the physiological responses to soccer. In order to quantify the extra energy costs, discrete movements should be isolated for studying metabolic reactions and also ground reaction forces.

(5)Methodological problems relating to blood sampling techniques form problems for the determination of the anaerobic contribution to the demands of soccer-specific intermittent exercise performance. More frequent blood samples (e.g. every 5 min) interspersed with control periods of activity both before and after sampling would allow investigation of the effects of prior exercise intensity as well as provide some indication of the alactic contribution to energy demands during intermittent exercise. Muscle biopsies obtained before, during and after exercise would also help to enhance the understanding of the demands of exercise.

(6) The inclusion of some of the specific match actions i.e. utility movements in the intermittent protocol, may lead to the laboratory based protocols possessing an even greater validity to soccer match-play, thus improving the relevance of the data to a practical setting.

(7) The physiological demands of field based soccer-specific intermittent protocols should also be investigated. Such information would lead to links between laboratory based research and field based research being established.

(8) Performance capabilities, especially with respect to high intensity bouts and specifc match actions, need to be maintained close to optimal levels throughout the duration of games. It would be of interest to evaluate the effects of soccer-specific intermittent exercise performance on the maintainence of such variables. Evaluation of sprinting performance, by monitoring the power produced, and its variation as a consequence of the

previously performed activity would also be of benefit in soccer-specific intermittent exercise performance.

(9) The kinetics of high energy phosphate recovery is important in intermittent exercise. Use of imaging techniques such as nuclear magnetic resonance may help provide data on the pattern of utilisation of such energy sources and lead to a better understanding of the energy utilization during intermittent exercise. Soccer is an intense activity that will result in a decrease in the body's energy stores : besides, it may lead to muscle soreness due to the engagement of eccentric contractions in kicking the ball and decelerating the body. Players are increasingly being required to compete in more matches. The pattern of recovery following games has not yet been evaluated. It would therefore be of interest to examine the recovery of players from games and explore recovery strategies that accelerate recuperation processes.

CHAPTER 8

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APPENDIX 1

Calculation of time (s) for each activity category

Percentages of total distance covered for each activity classification (Reilly and Thomas, 1976)

Walk	24.8 % + 3.35 % = 28.15 %
Jog	36.8 % + 3.35 % = 40.15 %
Cruise	20.5 %
Sprint	11.2 %
Other	6.7 % (÷2 = 3.35 %)

Speed Changes

Total speed = 598 s

Protocol duration

22.5 min (1350 s)

Test time

Test time = protocol duration - speed changes
Test time = 1350 - 598 = 752 s

Total time for each activity category (s)

Walk	28.15 ÷100 x 752 = 211.68
Jog	40.15 ÷100 x 752 = 301.92
Cruise	20.5 ÷100 x 752 = 154.16
Sprint	11.2 ÷100 x 752 = 84.22

Time for each discrete bout (s)

Walk	211.68 ÷ 6 = 35.3
Jog	301.92 ÷ 6 = 50.3
Cruise	154.16 ÷ 3 = 51.4
Sprint	84.22 ÷ 8 = 10.5

APPENDIX 2

Instructions for taking heavy isotope oxygen and hydrogen

1. Taking a sample of your body's background isotopic enrichment. As your body already contains heavy isotopes of hydrogen and oxygen (background levels), we need to know what these are prior to taking the enriched isotopes. To do this you will need to provide us with a small urine sample (no more than one eighth of a pint). We have provided a bottle labelled urine sample 1 which you can pee into. After you have peed in to the bottle the lid should be tightly screwed back on. Please bring the sample with you to the game. the urine sample can be taken any time before drinking the isotope but preferably the night before the match. If you have any problems giving a urine sample still drink the isotope, as it is possible to take a background sample at a later date.

2. Drinking the isotope. The isotope should be drunk over 4 hours before kick off. Once the lid is taken off the pots the isotope should be swallowed immediately as any evaporation will cause errors in the final experiment. Finally, please make sure you drink the total content of the pot, as the volume of isotope has been carefully measured.

Once the isotope has been swallowed, it will begin to mix with the water in your own body, after 4 hours it should be completely mixed allowing us to commence measurement of your energy consumption.

3. Measuring the initial isotopic enrichment of your body. At the beginning of the experiment we need to measure the concentration of the isotopes in your body. To do this we would like to take a small 1 ml blood sample (less than a 1000 th of a litre), we appreciate this may be unpleasant, but again I can guarantee it will not affect your performance on the pitch. The blood sample will be taken from your arm by a qualified practising medical doctor.

4. Measuring the final isotopic enrichment of your body. At the end of the game we will need to take a second blood sample to measure the change in ratios of the heavy isotopes. This will again be less than 1 ml and be more than a pin prick.

Summary

1. Provide a urine sample in urine bottle A, <u>before you drink the isotope.</u>
2. Drink the isotope <u>4 hours before kick off.</u>
3. Give a 1 ml sample of blood before going onto the pitch.
4. Give a second 1 ml of blood after the game.

APPENDIX 3

TECHNICAL BACKGROUND TO THE DOUBLY-LABELLED WATER TECHNIQUE

Introduction

The doubly-labelled water (DLW) technique is a non-invasive method of measuring energy expenditure in free-living humans, through the measurement of the rate of CO_2 production. Water is labelled with heavy isotopes of hydrogen (Deuterium, D) and oxygen (^{18}O), resulting in a non-toxic, non-radioactive label ($D_2{}^{18}O$). $D_2{}^{18}O$ equilibrates rapidly with the body water pool and reacts similarly metabolically.

Water is lost from the body through the gastrointestinal tract, respiratory tract, skin, and kidneys. Both the isotopically labelled oxygen (^{18}O) and hydrogen (D) exit the body as water through these processes. In addition to this, ^{18}O also exits the body as CO_2 during respiration. Thus, the ratio of ^{18}O and D will be affected by the disproportionate loss of ^{18}O through respiration and the difference will be proportional to the CO_2 production.

Net CO_2 production (rCO_2) is calculated using the turnover rates of ^{18}O and D. Three samples of body fluid (saliva, blood or urine) are extracted from subjects. The first sample, taken prior to administration of the DLW, is used to measure the background abundance of ^{18}O and D in body water. After a period of time (approximately 12 h), during which the isotope equilibrates with body water, a second sample is taken, referred to as the 'initial' sample. The 'final' sample is then taken after the required test period has elapsed. The difference in isotope content between the initial and final samples is then used to calculate the rate of CO_2 production (rCO_2) as follows:

$$rCO_2 = (N/2)\,(k_o - k_H)$$

where k_o and k_H are the apparent fractional turnover rates of ^{18}O and D, respectively. N is the body water content, which is divided by 2 - a constant equating two atoms of O_2 in each molecule of CO_2 with one atom in each molecule of water.

Analysis of ^{18}O and D abundance in the current research

The measurement of ^{18}O and D abundances, as in research on humans, is generally carried out using gas Isotope Ratio Mass Spectrometry (gIRMS). This requires prior conversion of water samples into CO_2 for ^{18}O analysis, and into hydrogen gas (H) for D analysis. The conversion of CO_2 is carried out using a technique of guanidine hydrochloride conversion, while H is produced by a zinc reduction technique.

^{18}O analysis

An ultra high vacuum manifold was utilised in the preparation of ^{18}O and D, to minimise contamination and fractionation of water samples. The urine samples were sealed into this manifold and frozen into a tube containing guanidine hydrochloride by liquid nitrogen distillation. This was then heated in a muffle furnace at 260°C for a period of 10 hours, and subsequently cooled resulting in the formation of ammonium carbamate. CO_2 was finally extracted from the ammonium carbamate by reaction with orthophosphoric acid. The CO_2 was then cryogenically purified before the final gIRMS analysis (using a VG SIRA 12 mass spectrometer) which was normalised against two international standards - V-SMOW (Vienna-Standard Mean Ocean Water) and SLAP (Standard Light Arctic Precipitation).

D analysis

The urine samples were distilled liquid nitrogen, as before, into a tube containing an experimental zinc reagent. This tube was then placed in a muffle furnace at 500°C for 30 minutes to catalyse the reduction process. On cooling, the sample was then transferred to a further tube to enable the gIRMS analysis to take place.

Results of both above analyses were expressed as delta (δ) per mil ($^{o}/_{oo}$). For the calculation of rCO_2 these values must be expressed as parts per million (ppm), using the following equations:-

$$^{18}O \text{ PPM} = 2.0052 \text{ x normalised } \delta(^{o}/_{oo}) + 2005.2$$

$$D \text{ PPM} = 0.15575 \text{ x normalised } \delta(^{o}/_{oo}) + 155.75$$

where 2005.2 = the ^{18}O abundance of V-SMOW and 155.75 = the D abundance of V-SMOW.

Reference:

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APPENDIX 4

TABLE B.41 Ten Thousand Random Digits

	00-04	05-09	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49
00	22808	04391	45529	53968	57136	98228	85485	13801	68194	56382
01	49305	36965	44849	64987	59501	35141	50159	57369	76913	75739
02	81934	19920	73316	69243	69605	17022	53264	83417	55193	92929
03	10840	13508	48120	22467	54505	70536	91206	81038	22418	34800
04	99555	73289	59605	37105	24621	44100	72832	12268	97089	68112
05	32677	45709	62337	35132	45128	96761	08745	53388	98353	46724
06	09401	75407	27704	11569	52842	83543	44750	03177	50511	15301
07	73424	31711	65519	74869	56744	40864	75315	89866	96563	75142
08	37075	81378	59472	71858	86903	66860	03757	32723	54273	45477
09	02060	37158	55244	44812	45369	78939	08048	28036	40946	03898
10	94719	43565	40028	79866	43137	28063	52513	66405	71511	66135
11	70234	48272	59621	88778	16536	36505	41724	24776	63971	01685
12	07972	71752	92745	86465	01845	27416	50519	48458	68460	63113
13	58521	64882	26993	48104	61307	73933	17214	44827	88306	78177
14	32580	45202	21148	09684	39411	04892	02055	75276	51831	85686
15	88796	30829	35009	22695	23694	11220	71006	26720	39476	60538
16	31525	82746	78935	82980	61236	28940	96341	13790	66247	33839
17	02747	35989	70387	89571	34570	17002	79223	96817	31681	15207
18	46651	28987	20625	61347	63981	41085	67412	29053	00724	14841
19	43598	14436	33521	55637	39789	26560	66404	71802	18763	80560
20	30596	92319	11474	64546	60030	73795	60809	24016	29166	36059
21	56198	64370	85771	62633	78240	05766	32419	35769	14057	80674
22	68266	67544	06464	84956	18431	04015	89049	15098	12018	89338
23	31107	28597	65102	75599	17496	87590	68848	33021	69855	54015
24	37555	05069	38680	87274	55152	21792	77219	48732	03377	01160
25	90463	27249	43845	94391	12145	36882	48906	52336	00780	74407
26	99189	88731	93531	52638	54989	04237	32978	59902	05463	09245
27	37631	74016	89072	59598	55356	27346	80856	80875	52850	36548
28	73829	21651	50141	76142	72303	06694	61697	76662	23745	96282
29	15634	89428	47090	12094	42134	62381	87236	90118	53463	46969
30	00571	45172	78532	63863	98597	15742	41967	11821	91389	07476
31	83374	10184	56384	27050	77700	13875	96607	76479	80535	17454
32	78666	85645	13181	08700	08289	62956	64439	39150	95690	18555
33	47890	88197	21368	65254	35917	54035	83028	84636	38186	50581
34	56238	13559	79344	83198	94642	35165	40188	21456	67024	62771
35	36369	32234	38129	59963	99237	72648	66504	99065	61161	16186
36	42934	34578	28968	74028	42164	56647	76806	61023	33099	48293
37	09010	15226	43474	30174	26727	39317	48508	55438	85336	40762
38	83897	90073	72941	85613	85569	24183	08247	15946	02957	68504
39	82206	01230	93252	89045	25141	91943	75531	87420	99012	80751
40	14175	32992	49046	41272	94040	44929	98531	27712	05106	35242
41	58968	88367	70927	74765	18635	85122	27722	95388	61523	91745
42	62601	04595	76926	11007	67631	64641	07994	04639	39314	83126
43	97030	71165	47032	85021	65554	66774	21560	04121	57297	85415
44	89074	31587	21360	41673	71192	85795	82757	52928	62586	02179
45	07806	81312	81215	99858	26762	28993	74951	64680	50934	32011
46	91540	86466	13229	76624	44092	96604	08590	89705	03424	48033
47	99279	27334	33804	77988	93592	90708	56780	70097	39907	51006
48	63224	05074	83941	25034	43516	22840	35230	66048	80754	46302
49	98361	97513	27529	66419	35328	19738	82366	38573	50967	72754

APPENDIX 5

Calculation of time (s) for each activity category

Percentage of the total time spent in each activity category (Chapter 5.1)

Static	15.2 %
Walk	40.9 % + 6.3 % = 47.2 %
Jog	26.7 % + 6.3 % = 33 %
Cruise	3.8 %
Sprint	1.1 %

Protocol duration

5 min (300 s)

Total time for each activity category (s)

Static	15.2/100 x 300 = 45.6
Walk	47.2/100 x 300 = 141.6
Jog	33/100 x 300 = 99
Cruise	3.8/100 x 300 = 11.4
Sprint	1.1/100 x 300 = 3.3

Time for each discrete bout (s)

Static	46/3 = 15.3
Walk	142/3 = 47.3
Jog	99/3 = 33
Cruise	11.4
Sprint	3.3