The University of Hull

# U-SAFT$^{90}$ simulates the internal and external loads of University-level soccer match-play

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**by**

## Andrew Guard

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# Table of contents

**Acknowledgements ........................................................................................... iv**
**List of Figures ........................................................................................................ v**
**List of Tables ......................................................................................................... vi**
**Abbreviations and Symbols ................................................................................ vii**
**Abstract ...............................................................................................................viii**

**Chapter 1. General Introduction ........................................................................ 1**
Overview.....................................................................................................................2

**Chapter 2. Literature Review .............................................................................. ..9**
2.1. Introduction.........................................................................................................10
2.2. Fitness and Physical Demands of Soccer...........................................................10
2.3. Aerobic Energy System.......................................................................................12
2.4. Anaerobic Energy System....................................................................................16
2.5. Heart Rate............................................................................................................19
2.6. Fatigue.................................................................................................................21
2.6.1. Temporary Fatigue............................................................................................22
2.6.2. Cumulative Fatigue...........................................................................................24
2.7. Match Analysis.....................................................................................................26
2.7.1. Methods of Match Analysis...............................................................................27
2.7.2. Global Positioning System (GPS).....................................................................31
2.7.3. Accelerometry...................................................................................................35
2.7.4. Total Distance....................................................................................................36
2.7.5. High-Intensity Activity........................................................................................41
2.7.6. Within Match Variation.....................................................................................45
2.7.7. Utility Movements.............................................................................................46
2.8. Soccer-Specific Exercise Protocols......................................................................49

**Chapter 3. Motion Analysis of Competitive Amateur Soccer..............................55**
3.1. Introduction.........................................................................................................56
3.2. Methods...............................................................................................................58
3.3. Results.................................................................................................................65
3.4. Discussion............................................................................................................72
3.5. Conclusion...........................................................................................................76

**Chapter 4. Soccer-Specific Simulation (USAFT$^{90}$)……………………………………………………......77**

4.1. Introduction…………………………………………………………………………………………………..........78

4.2. Pilot Testing……………………………………………………………………………………………..........80

4.3. Methods……………………………………………………………………………………………………...........83

4.4. Results……………………………………………………………………………………………………………87

4.5. Discussion………..………………………………………………………………………………………….89

4.6. Conclusion…………………………………………………………………………………………………….91

**Chapter 5. General Discussion……………………………………………………………………………..........92**

5.1. General Discussion………………………………………………………………………………….........93

5.2. Future Research…………………………………………………………………………………….........95

Chapter 6. References…………………………………………………………………………………………..96

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# List of Figures

## Chapter 2: Literature Review

2.1. Match analysis-based techno-tactical representation of positional roles (reproduced from Di Salvo et al. 2007)
2.2. Match heart rate for University soccer player (Reilly, 2003)
Effect of pre-match muscle fibre glycogen content (Saltin, 1973)
2.3. High-intensity activity across 5 minute periods of a soccer match (Bradley et al. 2009).
2.4. Distances covered per game by different locomotor activities, adapted from Reilly and Thomas (1976)
2.5. Relationship of distance covered and maximal oxygen uptake by position (Bangsbo, Norregaard and Thorsoe, 1991)
2.6. Comparison of distances covered in old First Division and modern Premier League (Strudwick and Reilly, 2001)
2.7. Percentage Time spent in locomotor categories; Elite and Amateur (O'Donoghue et al. 2001)
2.8. Percentage time high-intensity activity between halves in elite and amateur soccer (O'Donoghue et al. 2001)

## Chapter 3: Motion Analysis of Competitive Amateur Soccer

3.1. Calculation equation of accelerometer Accumulated Player Load
3.2. Percentage of time spent in different locomotor categories
3.3. Average peak, subsequent, final and mean distance covered at high-intensity in a 5 minute period
3.4. Example heart rate trace of a central defender during match-play.

## Chapter 4: Soccer-Specific Simulation (USAFT$^{90}$)

4.1. Representation of 15 minute cycle of USAFT$^{90}$ velocities and activities
4.2. Schematic representation of USAFT$^{90}$ course (reproduced from Lovell, Knapper and Small, 2008)
4.3. USAFT$^{90}$ field-testing set up
4.4. Example heart rate curve of central defender for the USAFT$^{90}$
4.5. Mean heart rate of USAFT$^{90}$ and match-play
4.6. Mean player load of USAFT$^{90}$ and match-play

## Chapter 5: General Discussion

# List of tables

## Chapter 2: Literature Review

2.1. Maximal oxygen uptake by position, data from Bangsbo, Norregaard and Thorsoe (1991)
2.2. Reported match heart rates
2.3. Methods of match analysis in recording distances covered
2.4. Effect of opposition quality on total distance and high-intensity distance (Rampinini et al. 2007)

## Chapter 3: Motion Analysis of Competitive Amateur Soccer

3.1. Subject characteristics
3.2. Match-day testing protocol
3.3. Speed thresholds employed for post-match analysis of GPS data
3.4. Classification of high-intensity running activities
3.5. Percentage of time spent exercising at low and high intensities
3.6. Match performance parameters
3.7. Total distance and distances covered at high and very high-intensity and sprinting and peak velocity achieved by each positional group

## Chapter 4: Soccer-Specific Simulation (USAFT$^{90}$)

4.1. USAFT$^{90}$ activities and velocities
4.2. Frequencies, durations and distances of USAFT$^{90}$ activities
4.3. Match activities of USAFT$^{90}$ and competitive match-play
4.5. Comparison of heart rate and player load in match-play and USAFT$^{90}$

## Chapter 5: General Discussion

5.1. Comparison of heart rate and player load in match-play and USAFT$^{90}$ (Mean ± Standard Deviation)

# Abbreviations and Symbols

| | |
|---|---|
| ATP | adenosine-triphosphate |
| AU | arbitrary units |
| $\text{bpm}^{-1}$ | beats per minute |
| cm | centimetres |
| FIFA | Fédération International de Football Association |
| GPS | global positioning system |
| HID | High-intensity Distance |
| HIR | High-intensity Running |
| $\text{HR}_{\text{max}}$ | Maximum heart rate |
| Hz | Hertz |
| kg | kilograms |
| $\text{kJ/min}^{-1}$ | kilojoules per minute |
| km | kilometres |
| L | litres |
| LIST | Loughborough Intermittent Shuttle Test |
| m | metres |
| m/s | metres per second |
| min | minutes |
| ml | millilitres |
| $\text{mmol.L}^{-1}$ | millimoles per litre |
| $n$ | number of subjects |
| ºC | degrees Celsius |
| $P$ | Statistical figure |
| PCr | Phosphocreatine |
| Q | Cardiac output |
| s | seconds |
| $\text{SAFT}^{90}$ | Soccer-Specific Aerobic Field Test |
| SD | standard deviation |
| SSEP | Soccer-Specific Exercise Protocol |
| $\text{USAFT}^{90}$ | University Soccer-Specific Aerobic Field Test |
| VHIR | Very High-intensity Running |
| $\text{VO}_2$ | Oxygen consumption |
| $\text{VO}_{2\text{max}}$ | Maximum oxygen consumption |
| *vs* | versus |
| yrs | years |

# Abstract

Motion analysis has become more prevalent in contemporary soccer research, particularly within the elite sector. The study of motion-profiles can be used for identifying patterns in soccer match performance regarding both physical and technical elements. Deducing movement patterns and internal and external loading through in-depth study, it may then be possible to simulate competitive match-play specific to squad or individual needs. Modern technology allows match performance to be broken down into specific periods that subsequently enables the examination of work rate. Changes in work-rate may indicate fluctuations in performance which can also heighten the risk of injury and susceptibility to conceding to opponents. As a result, preparatory, conditioning and nutritional interventions can be employed directed towards sustaining performance levels.

This thesis will firstly look at motion profiles of competitive soccer in an amateur population in order to quantify the internal and external physical demands and variation in work-rate compared to those previously scrutinised in elite soccer.

The following experimental chapter utilises motion analysis data to create and validate a squad soccer-specific exercise protocol (SSEP) to use as a simulation of soccer match-play in both rehabilitation and laboratory settings

Motion analysis was determined with a 5Hz Global Positioning System to analyse total, high-intensity and sprint distance as well as producing mechanical ‘Accumulated Player Load’ values through an in-built accelerometer. This data was combined with concurrent heart rate data during matches to provide a measure of internal physiological load. Total distance was found to range between 7223-12158m, with an average of 9423m for the squad, declining 6% between halves ($P < 0.01$) with a coefficient of variation of 12% between matches. High-intensity distance was 1593m on average, declining 14% between halves ($P < 0.01$), with a 24.9% between-match variation. The average peak HID covered in a 5 minute period was 142m, with the subsequent period 46% lower (76m), 18% lower than the match 5 minute mean ($P < 0.05$). The final 5 minute period in a match averaged 66m at high-intensity. Mean sprint distance was 137m, varying 44% between matches. Heart rate was 164bpm$^{-1}$ on average (86%HR$_{max}$) while Accumulated Player Load was 994AU on average. The motion analysis found similar patterns of physical demands (in terms of fluctuations in intensity) to those found in elite studies, although total, high-intensity and sprint distances were not as high in university players.

The second study sought to simulate the internal and external loads of competitive amateur soccer match in a controlled environment by developing a population-specific laboratory simulation, University Soccer Aerobic Field Test$^{90}$. The test comprised of a 15 minute CD repeated 6 times to produce a 90 minute simulation of a competitive match. The CD gave audio commands to the subjects completing the USAFT$^{90}$ course of multilateral soccer-specific movements. The CD was created by using average velocities from discreet movement categories, together with the average distances covered in each zone, using the data from the first study. Validation of USAFT$^{90}$ was done by monitoring the same internal and external load measures in the same population for both motion analysis and laboratory simulation. Using the same population meant greater ecological validity of the subsequent findings. The USAFT$^{90}$ showed a degree of cardiovascular strain through measurement of heart rate for internal physiological load, averaging 162 bpm$^{-1}$ (85% $HR_{max}$). The external load measured by accelerometer 'accumulated player load' was 1067 AU on average. Statistical comparisons of heart rate and accumulated player load between competitive match-play and USAFT$^{90}$ showed no significant differences in the internal and external loading ($P > 0.05$).

The findings in this thesis suggest patterns of physical demands in competitive amateur match play are similar to those of elite soccer, in terms of total, high-intensity and sprint distances but fall in the lower part of the range previously reported in motion-analysis studies. Changes in work-rate possibly due to fatigue are evident in motion profiles of amateur soccer players, similar to those observed in professionals. Furthermore heart rate analysis suggested cardiovascular strain is also high.

Competitive amateur match-play can be simulated effectively with respect to inducing the same internal and external loads associated with a 90 minute soccer match. The implications of such findings are that the USAFT$^{90}$ can be used to simulate the locomotor, physiological and mechanical demands of amateur soccer matches in controlled environments. This may be useful for rehabilitation purposes and testing intervention strategies to gauge effect on performance. Future research should address positional differences and examine the effect of fatigue on work-rate in more detail for university-level soccer. This would accommodate individual and positional capabilities that were not simulated in USAFT$^{90}$.

**Key words**: soccer, motion analysis, physical demands, global positioning system

# Chapter 1

# General Introduction

## 1.1 Overview

For many years soccer has been the most popular sport in the world. Its universal appeal is reflected by the 260 million men, women and children of all abilities, who participate globally (Junge and Dvorak, 2004). As a result, soccer is a game that is internationally recognised in many different cultures and social standings.

Over the last thirty years or so a relationship has grown between soccer and sports science and the various fields that fall within it, namely; physiology, biomechanics, psychology, nutrition and performance analysis. Consequently, such a rise in prevalence has led to professional soccer embracing scientific applications with specific reference to training, preparation and performance in the sport. By obtaining a greater level of precision in their analysis of data, coaches and scientists then benefit in terms of their ability to present more informed reports to modify tactics and training approaches for both the squad and indeed the individual player. The implementation of sports science theory and protocols are seen as key tools in achieving the ultimate goal of optimising performance (Reilly and Williams, 2003).

An open-field team sport, soccer has been described by Stolen *et al.* (2005) to be impacted upon by numerous factors dictating performance outcomes; physiological, physical, technical, tactical and cognitive. From a physical perspective, soccer is termed an intermittent team sport that comprises efforts of high and low intensity exercise derived from contributions of both aerobic and anaerobic energy sources, fluctuating over the course of a 90 minute match. Interspersed with the variation in exercise intensity is the inclusion of soccer utility movements (with or without the ball), unorthodox gait movements that are discretely masked within the traditional locomotor activities. Key to decisive movements during a match, such soccer-specific skills form the basis of the 1400 changes in activity an individual player may undertake during a game (Mohr, Krustrup and Bangsbo, 2003), equating to a change every 4-6 seconds (Reilly and Thomas, 1976). This rapid change in intensity and skill execution augments the subsequent metabolic work rate and energy cost placed upon the player and it is these that make soccer motion profiles hard to quantify (Bangsbo, 1994a; Reilly, 1997). Nonetheless, the available data signifies that over a 90 minute period a player will perform at 70-75% of maximal oxygen consumption. Work rate in soccer, thereafter, is expressed as a percentage of maximal cardiac frequency (*fc*max) with heart rates during match play (85% $HR_{max.}$) equating to an intensity approaching the lactate threshold (Reilly, 1994). The total amount of work done during a match may then be deduced by the total distance covered per player, typically agreed to be between 8-12 kilometres (Reilly and Doran 2003). However, given its inability to account for the utility movements and their associated energy cost, total distance is not considered to be a valid measure of overall match performance, with the proportion of high-speed running regarded as a more representative measure due to it discriminating more between training status and positional differences (Mohr, Krustrup and Bangsbo, 2003; Krustrup *et al.* 2003). The comparison by Mohr, Krustrup and Bangsbo (2003) of match performance between top class and moderate professional soccer players saw both groups covering a similar total distance but with the top class completing a greater proportion of high intensity running and sprinting activities. This therefore reinforces the importance of intermittent activity in top level soccer, characterized by one's ability to repeatedly perform bouts of exercise at such high intensities (Reilly and Thomas, 1976; Bangsbo, Norregaard and Thorsoe, 1991).

As a sport that is typified by its intermittent nature, the variation in exercise intensity and execution of the specific skills and utility movements dictated by the pattern of play serves to elevate physiological demands and energy costs in excess of those induced by steady state exercise (Drust, Atkinson and Reilly, 2007; Greig, McNaughton and Lovell, 2006). The cost of such utility movements integral to soccer has been shown by Reilly and Ball (1984) who suggested an 8% added energy expenditure of dribbling a ball. The nature of accelerations, decelerations and changes in direction also influence energy expenditure in a disproportionate fashion through engaging in game-related activities (Reilly and Bowen, 1984). The importance of such actions has been highlighted in studies comparing elite, semi-professional, amateur (Van Gool, Van Gervan and Boutmans, 1988; O'Donoghue *et al.* 2001) and international players (Rienzi *et al.* 2000). The total distance covered comprised of 7.9% backwards, 3% sideways and 89% forwards movement for South American Internationals, with similar figures reported by Bloomfield, Polman and O'Donoghue (2007a) for the amount of time travelled in each direction in English Premier League players. Using video recording observation and computer-programmed motion-analysis, O'Donoghue *et al.* (2001) demonstrated the quantity of utility movements that exist in matches and how they may discriminate between levels of play. Semi-professional players were found to perform 1400 'discrete' movements, such as shuffling, more than elite and amateur players in match-play. Bloomfield, Polman and O'Donoghue (2007a) emphasised the importance of unorthodox movements underpinning physical demands in soccer to exaggerate metabolic demand and are important determinants in key match events. These then add to the complete representation of the requirements of contemporary soccer in sport-specific simulations.

The development of soccer-specific exercise protocols (SSEP's) has several useful purposes. Firstly, it is possible to determine the influence of intervention strategies in a simulated match environment. Also, an accurate representation of the match-play demands may aid rehabilitation from injury where similar demands to competition can be experienced in a non-contact, controlled setting (Rahnama, Reilly, Lees, and Graham-Smith, 2002). Bangsbo (1994a) suggested how there is a high variability in physiological responses between matches and although physiological and skill simulations in soccer are reliable, Currell and Jeukendrup (2008) advised more research to be focused on skill performance through a physiological simulation where the reliability has been thoroughly tested. Furthermore Drust, Atkinson and Reilly (2007) suggested that the development of more refined protocols to increase their ecological validity and enhance soccer-specificity by including more soccer activities, based upon individual work rates, will be greatly advocated. The ability to use an appropriate soccer-specific simulation, in a closed environment would prove greatly beneficial to evaluating the progress of rehabilitation, preparatory and half-time intervention strategies. Evaluating nutritional (Nicholas *et al.* 1997), hydration (Clarke, *et al.* 2005; Bishop *et al.* 1999) and thermoregulatory (Lovell *et al.* 2007; Gregson *et al.* 2005; Gregson *et al.* 2002) intervention strategies could provide key insights into their effect on subsequent match performance, especially if experimental designs use a reliable and ecologically valid simulation of match physical demands.

However, the numerous attempts to accurately simulate competitive soccer matches with the use of motorised treadmills have presented some methodological issues. Fundamentally, such studies have failed to reproduce both the physiological responses and mechanical demands of match play simultaneously. This may be due to an inaccurate simulation of soccer activity profiles administered with regards to the variations in intensity and duration of exercise. Many SSEP's have overestimated the intensity and/or duration of match activities engaged in, and are often based on single match observations and of different populations (Drust, Reilly and Cable, 2000). For example, Nicholas, Nuttall and Williams (2000) implemented bouts of 60m exercising at 95%$VO_{2max}$ whereas Drust, Cable and Reilly (2000) utilised bouts of various activities far in excess of the normal time spent performing them in matches, such as 35.3 seconds for walking and 10.5 seconds for sprinting. Using such intensities serve to compensate for the absence of utility movements and multi-directional movements in the protocol, obtaining energy expenditure and physiological responses sufficiently similar to 90 minute intermittent exercise in a competitive match. However sprints in soccer usually last for less time (about 2 seconds in top-class players according to Mohr, Krustrup and Bangsbo, 2003). The same study found each high-intensity and sprinting bout on average to be distances of 12m and 17m of only short duration compared to those used by Drust, Cable and Reilly (2000).

The physiological cost of highly intermittent activity was outlined in the study of Greig, McNaughton and Lovell, (2006). Comparing the responses of intermittent and steady state treadmill protocols, physiological values were higher following intermittent exercise, yet still 'consistently lower' than data previously collected from competitive matches. Heart rate and blood lactate were found to peak at 135$bpm^{-1}$ and

1.4mmol.L$^{-1}$ respectively compared to 171bpm$^{-1}$ (Bangsbo, 1994a) and 4.4mmol.L$^{-1}$ (Bangsbo, Norregaard and Thorsoe 1991), with a subjective Rate of Perceived Exertion of 15 on the Borg Scale (Borg, 1973) at the highest, indicating lowered physical strain.

The majority of studies detailing soccer motion analysis and simulations stem from the classical study of Reilly and Thomas (1976) of elite soccer. However it is semi-professional and amateur players who make up 86% of the total 260 million soccer players worldwide (Junge and Dvorak, 2004). Existing studies of motion analysis on amateur players (O'Donoghue *et al.* 2001) have limitations through the use of unreliable video analysis that has been shown to underestimate distances covered (Randers *et al.* 2010). Furthermore, the smaller number of observations used in O'Donoghue's study also compromise the coefficient of variation illustrating changes in parameters match-to-match. This is because high-intensity running for example was shown by Gregson *et al.* (2010) to vary as much as 30% between matches, therefore requiring a larger, more representative pool of data to be collected. As a result it is difficult to confidently suggest average distances covered per player per match from analysis of a low number of matches with seasonal observations more appropriate for a more informed understanding of locomotor activity.

Several limitations with regards to previous studies of motion-analysis have been described above. Drawbacks of certain methodologies can make drawing comparisons between previous literature difficult, particularly with limited match observations and differing intensities employed. The reliability of some methods may be questioned as matches' energetic conditions are not effectively simulated and cannot be applied to players of varying ages and abilities. Furthermore more frequent observations would help account for large variation in high-speed running activities between matches (Gregson *et al.* 2010) that may be affected by quality and training status of opponents (Di Salvo *et al.* 2009; Mohr, Krustrup and Bangsbo, 2003) and formations employed (Bradley *et al.* 2011).

# Chapter 2

# Literature Review

## 2.1 Introduction

The amount of research concerning soccer and science has grown rapidly over the last thirty years or so and has focused predominantly on three populations; elite (Di Salvo *et al.* 2009; Di Salvo *et al.* 2007; Abt and Lovell, 2009; Bradley *et al.* 2009; Rampinini *et al.* 2009, Rampinini *et al.* 2007; Impellizzeri *et al.* 2006; Rienzi *et al.* 2000; Mohr , Krustrup and Bangsbo, 2003; Bangsbo, Norregaard and Thorsoe, 1991; Bangsbo 1994a; Reilly and Thomas, 1976; Van Gool, Van Gervan and Boutmans, 1988), youth (Stroyer, Hansen and Klausen, 2004; Chamari *et al.* 2004; Helgerud *et al.* 2001; Impellizzeri *et al.* 2006; McMillan *et al.* 2005; Harley *et al.* 2010; Thatcher and Batterham, 2004), and female (Krustrup *et al.* 2005; Kirkendall, Leonard and Garrett Jr, 2003).

The purpose of such research is directed towards generating a greater, more comprehensive understanding and explanation of the physical demands and physiological responses that make-up performance at these levels. This literature review will detail factors of fitness and performance that are most important in influencing changes in soccer performance across matches and population groups. Previous and recently emerging methods of analysis will also be presented to demonstrate the transition in methodological approaches to scientific soccer studies.

## 2.2 Fitness and Physical demands of Soccer

Soccer is a dynamic game that has a complex structure, broadly based on its intermittent activity profile, which resultantly induces significant physical demands and stresses in soccer players. Over the course of a 90 minute game, dependent upon position, an outfield player typically covers 8-12 kilometres (Rampinini *et al.* 2007), 98% of which is covered without possession of the ball (Reilly and Thomas, 1976). Approximately 90% of energy metabolism is provided by aerobic energy pathways for locomotion (Bangsbo, 1994a), with 12 % of total distance requiring anaerobically sourced efforts for  approximately 220 high-speed runs,  11%  of which are sprinting activities (Mohr, Krustrup and Bangsbo, 2003; Mayhew and Wenger, 1985). The benefit of an efficient aerobic energy system and oxygen kinetics will subsequently benefit soccer player's performance by delaying effects of fatigue whilst improving their recovery between key high-intensity bouts, allowing them to be executed with greater frequency for the duration of the match (Balsom, Ekblom and Sjödin, 1994).

The need for low-intensity running is paramount to provide a means of sub-maximal aerobic recovery between intense periods of play. This is a necessity in soccer, in which an individual may perform up to 1400 changes in activity, equating to one every 6 seconds (Reilly and Thomas, 1976; Bangsbo, Norregaard and Thorsoe, 1991; Mohr, Krustrup and Bangsbo, 2003). Ekblom (1986) and Withers *et al.* (1982) suggested that, again depending on positional role, these include anaerobic, skilled actions of 14 tackles, 9 headers, 50 ball involvements and 30 passes, per game, in addition to the rapid accelerations, decelerations, changes in direction and external stressors such as the presence of opponents.

It is clear from existing literature that there is a need to possess physical proficiency in a myriad of fitness components is crucial in soccer. The ability to sustain aerobic, anaerobic, strength, power and agility aspects for the duration of a match, particularly in the second half and closing minutes, are vital to aid physical performance in soccer and determine a successful outcome. A greater understanding of such demands, particularly in the amateur game where literature is scarce, will play a role in underpinning individual training prescription to transfer onto the pitch.

## 2.3 Aerobic Energy System

According to Drust, Atkinson and Reilly, (2007) soccer is a sport mainly fuelled by aerobic energy sources that consists of frequent bouts of activity of varying intensities and durations. In addition, there are also vital high-intensity utility movements in soccer that serve to be pivotal to the final result, such as being in possession of the ball for example, which accounts for about 2% of the overall distance covered (Reilly and Thomas, 1976). However, these are superimposed on an activity background that is 90% aerobic, highlighting the importance of endurance capacity (Bangsbo, 1994a).

Perhaps the most important parameter surrounding the deduction of one’s aerobic capacity is maximal oxygen consumption ($VO_{2max}$). Defined as the maximum amount of oxygen that one can take in, transport and utilise during exercise (Astrand and Rodahl, 1986), $VO_{2max}$ is used heavily in determining aerobic power thus providing an idea of the ‘functional limit’ and efficiency of the oxygen transport system. Players of a higher standard (Mohr , Krustrup and Bangsbo, 2003) and those who have undergone aerobic training, improving $VO_{2max}$ (Helgerud *et al.* 2001; Impellizzeri *et al.* 2006), have been shown to contribute to larger total distances covered as well as the distances and number of high-intensity and sprinting efforts compared to players of lower standards and training status.

As well as $VO_{2max}$ being correlated to distance covered and work done at higher intensities (Krustrup *et al.* 2003), it is also positively correlated with numerous other factors that may all contribute to fluctuations in soccer match performance to varying degrees. These, for example, have been investigated to be factors such as team success and ranking (Wisloff, Helgerud and Hoff, 1998; Apor, 1988) and positional role (Rampinini *et al.* 2007; Di Salvo *et al.* 2007, Figure 2.1).

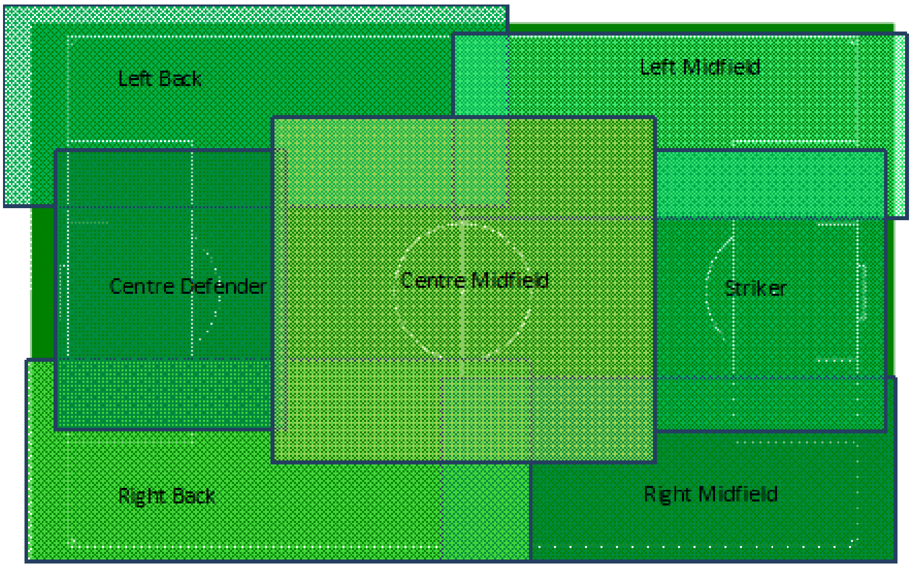

*Figure 2.1– Match analysis-based techno-tactical representation of positional roles (reproduced from Di Salvo et al. 2007).*

A higher $VO_{2max}$ has also been suggested to improve recovery between bursts of high-intensity running (HIR) (Balsom, Ekblom and Sjödin, 1994; Tomlin and Wenger, 2001). As the most highly taxed energy pathway during a match (with a low-to-high intensity exercise ratio of 7:1, Mayhew and Wenger, 1985), the aerobic system also plays a role in repaying oxygen debt and resynthesizing phosphocreatine (PCr) following intense periods of play. As much as 85-90% of activity in soccer is classified as low-intensity (Mohr, Krustrup and Bangsbo, 2003), and it is activity of this nature that plays a key role in removing accumulated metabolites in the blood and working muscles through engaging in active recovery enabling repeated high-intensity movements with greater force production (Gollnick and Hermansen, 1973). The consistently high oxygen consumption and heart rate during a match also depend on the individual's muscle oxygen kinetics and oxidative capacity to utilise the supply efficiently as exercise deviates between low and high-intensity efforts (Bangsbo *et al.* 2002). The continued ability to maintain an optimal work rate is typified by self-pacing strategies that may be employed by soccer players. As an unpredictable sport with an irregular, acyclical activity pattern, players may choose to regulate their direct involvement in match play by exercising at a lower intensity in order to 'spare' energy substrates and ensure minimal taxing of the anaerobic energy system (Edwards and Noakes, 2008). Such a self-chosen activity pattern would then spare glycogen stores for defining actions, aided further by a higher aerobic capacity in certain positions (Table 2.1) meaning they are better able to mobilize fat as an energy source instead (Bangsbo, 1994a; Krustrup *et al.* 2006). Accordingly, possessing the enhanced ability to retain the required work rate has been stated by Saltin (1973) to provide an advantage over 'equally skilled players' who may have further depleted energy stores at their disposal.

*Table 2.1 - Maximal oxygen uptake by position, data taken from Bangsbo, Norregaard and Thorsoe (1991)*

| Position | Maximal Oxygen Uptake ( $ml.kg.min^{-1}$) |
|---|---|
| Defenders (*n* = 4) | 58.9 ± 1.5 |
| Midfielders (*n* = 7) | 61.9 ± 1.8 |
| Forwards (*n* = 3) | 60.2 ± 1.7 |

Bangsbo, Mohr and Krustrup, (2006) concurred with previous findings regarding the importance of high aerobic proficiency. They suggested that effective oxygen consumption is crucial to coping with physical demands associated with soccer performance and should form the basis of training regimes, directed towards increasing aerobic capacity through training at a high intensity, simultaneously enhancing the ability to recover effectively. Training may be implemented through interval training or intermittent, soccer-specific small-sided games and skill circuits. This is beneficial as the external training load, if prescribed correctly, has been said by Impellizzeri, Rampinini and Marcora (2005) to induce the subsequent physiological responses (internal training load) that are more likely to be representative of matches.

Aerobic fitness and its development through different training stimuli is a significant determinant of performance and success in soccer. It has previously been shown to discriminate between players of different standards of play and indeed positional roles, although the author suggests an absence of literature surrounding amateur soccer match-play that should be investigated further.

## 2.4 Anaerobic Energy System

Although soccer is predominantly dependent on aerobic energy sources to sustain exercise and match performance, perhaps the most decisive moments are regulated by anaerobic energy metabolism (Reilly and Thomas, 1976). However, it is often the high velocity and multi-directional movements that are absent from SSEP's. Anaerobic energy sources are responsible for the energy provision to execute unorthodox and spontaneous utility movements synonymous with soccer, accounting for 16% of total distance and increasing energy expenditure in intermittent sports (Reilly, 1997). For example these might include; heading, tackling, cutting and sprinting requiring explosive acceleration that the anaerobic system serves to produce, enabling players to run faster, jump higher and recruit greater strength in key duals with opposition (Wragg, Maxwell and Doust, 2000).

During a match a player may perform 150-250 brief, intense actions (Mohr, Krustrup and Bangsbo, 2003) including 15 tackles, 10 headers, 30 passes and 50 direct ball involvements (Bangsbo, Norregaard and Thorsoe, 1991). Furthermore the frequency of efforts has been noted with sprints performed every 90 seconds, lasting 2-4 seconds, equating to 3% of total playing time, something that is often exaggerated in controlled environment match simulations. Similarly, high-intensity running (consisting of running, high-speed running and sprinting) is engaged in every 70 seconds, contributing to 11.2-18% of the total distance covered (Reilly and Thomas, 1976; Withers *et al.* 1982). Clearly these represent a number of key movements in soccer match-play and should therefore be accurately portrayed  in attempts to simulate competitive matches, where they can enhance the ecological validity of the process. Despite being performed frequently in matches, utility movements are often not included in subsequent analysis. Moreover, they are also excluded from methodologies looking to use match motion-analysis data to create SSEP's. The mechanical and internal load of the protocol is then underestimated, with a lowered energy cost produced, questioning the validity of the simulation. The significance of anaerobic 'non-locomotor' activities are also emphasised by Bloomfield, Polman and O'Donoghue (2007a). They suggest that energy expenditure should be deduced by determining exercise to rest ratios, fluctuation in intensities and direct involvements in play, or 'purposeful movements' (PM's) such as accelerations, decelerations, cutting and jockeying. Although different depending on positional role and tactical restraints, it is thought that purposeful movements and utilities are often ignored leading to consistent underestimations of energy expenditure in which anaerobic stressors contribute pivotal actions. The influence of cutting, accelerations and decelerations, however, can be measured with the use of accelerometry data to quantify external load and will be utilised in this thesis.

Heightened energy expenditure in match play attributable to soccer-specific skills, changes in direction and velocity, can in turn lead to blood lactate values of 5-12mmol.L$^{-1}$ that suggest anaerobic metabolism is apparent in soccer (Ekblom, 1986). Bangsbo *et al.* (1993) suggested how differences in metabolite accumulation may differ between modes of exercise, with steady state running provoking lower lactate levels than intermittent exercise due to the absence of rapid accelerations, decelerations and changes in direction. The intermittent nature of soccer may then influence periods of high anaerobic energy yield that are reflected by phosphocreatine degradation, elevated core temperature and  concentrations (Ekblom, 1986). Examples in soccer include movements involving forceful contractions to accelerate, decelerate and change direction.

The brief duration of soccer sprints means that 96% are less then 30m distance with 49% less than 10m (Valquer, 1998) and it is here that anaerobic sources with high energy phosphates are highly taxed. Other authors have expressed concern regarding anaerobic contribution in soccer. Stolen *et al.* (2005) considered that expressing exercise intensity of soccer as an average of the 90 minutes may also compound the loss of such crucial data with regards to changes in high and low-intensity periods where there are clear discrepancies in physical demands, in excess of the ‘match average’. This is also evident in heart rate (Balsom, Seger and Ekblom, 1991) and blood lactate (Bangsbo *et al.* 1993), for example, where values may be disproportionate as a result of the activity performed immediately prior to samples being observed. Predominant utilisation of aerobic metabolism throughout aids active recovery from HI bouts, with a higher $VO_{2max}$ and larger stroke volume aiding metabolite removal and ATP (Adenosine Triphosphate) and PCr regeneration (Balsom, Ekblom and Sjodin, 1994). More efficient usage of substrates will help to buffer onset of lactate accumulation, low blood and muscle pH and acidosis that could potentially impair oxidative enzyme function and repeated sprint ability (Sahlin, 1992). In their review, Stolen *et al.* (2005) described how elite players use anaerobic energy pathways to a greater extent than non-elite players as shown by blood lactate values 40-50% higher when samples were taken at the end of each half. Values for both however were significantly reduced in the second half, justifying previous literature regarding decrements in work rate encompassing distance covered, high-intensity running and sprinting efforts with prolonged periods of recovery (Randers *et al.* 2010; Bangsbo, 1994a; Bangsbo, Norregaard and Thorsoe, 1991; Bangsbo and

Mohr 2005, Di Salvo *et al.* 2007, Ekblom, 1986, Mohr, Krustrup and Bangsbo, 2003; Rampinini *et al.* 2007; Rampinini *et al.* 2009, Reilly and Thomas, 1976). These changes in performance may also be consequences of glycogen depletion, however. As a result there is greater employment of low-intensity running in the second half as a mechanism of active recovery to remove lactate. Mediated changes in work-rate patterns may be apparent for elite soccer, but there is little evidence to confirm that this is also the case in amateur soccer.

The following experimental chapter will look to examine this population and include specific actions of anaerobic metabolism in SSEP validation.

## 2.5 Heart Rate

Heart rate is often used in soccer to gauge exercise intensity, expressed as a percentage of maximal heart rate ($HR_{max}$) due to the large variations that occur over the course of a match (Stolen *et al.* 2005). Heart rate is often used to maintain and design aerobic training regimes through the setting of defined target intensities of heart rate ‘zones’, and has been found by Rampinini, Sassi and Impellizzeri (2004) and Sassi, Reilly, and Impellizzeri (1998) to be especially acceptable in optimising training of a soccer-specific nature compared to continuous training.

Although often limited to the non-competitive environment, measures of heart rate are still employed in training and friendly matches as an indicator of circulatory strain (Drust, Atkinson and Reilly, 2007). Bangsbo (1994a) and Reilly (2003) observed heart rates to be approximately 170$bpm^{-1}$ (80-90%$HR_{max}$) in match play. Heart rate in match-play, however, fluctuates frequently due to the intermittent nature of soccer and the movements the sport incorporates (Figure 2.2). Protocols of soccer-simulations must therefore must be valid in terms of including match movement demands in order to produce a reliable heart rate physiological load.

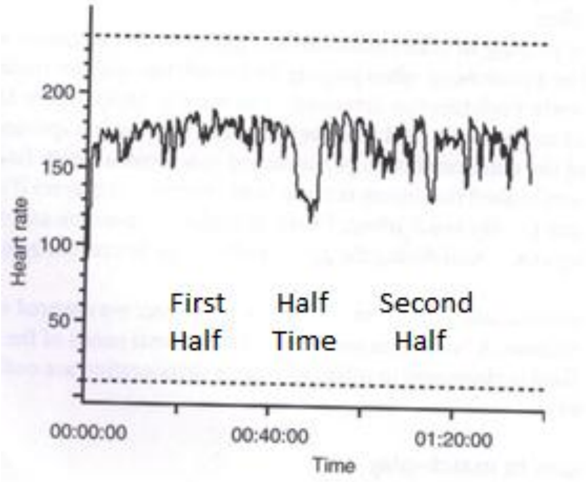

*Figure 2.2 – Match heart rate for University soccer player (Reilly, 2003)*

Advances in heart rate technology have seen the development of radio telemetry systems. These systems have the ability to record heart rate every 5 seconds of every player to understand the variation on cardiovascular strain in each position. More recent studies of amateur and elite heart rate responses to match play have been reported (Table 2.2), but it was Ali and Farrally (1991) who carried out one of the first investigations into heart rate during match play using such team systems. Based on players of a sub-elite level, heart rates of semi-professional-, university- and recreational-level players were recorded. Heart rates were found to range between 160-178 bpm$^{-1}$ in the first half and 159-174 bpm$^{-1}$ in the second half. All heart rates were reduced in the second half, regardless of position or level. University player’s heart rates averaged 166 bpm$^{-1}$, averaging 169 bpm$^{-1}$ in the first half and 164 bpm$^{-1}$ in the second. Semi-Professional players had an average of 169 bpm$^{-1}$,174 bpm$^{-1}$ in the first half and 168 bpm$^{-1}$ in the second. Finally, recreational players averaged heart rates of 167 bpm$^{-1}$ in the match and168 bpm$^{-1}$ and 165 bpm$^{-1}$ in respective halves.

*Table 2.2 – Reported Match Heart Rates*

| Author | Population | Mean Match HR (bpm) |
|---|---|---|
| Ali and Farrally, 1991 | University (English) | 166 |
| Esposito *et al.* 2004 | Amateur (Italian) | 173 |
| Bangsbo, 1994a | Elite (Danish) | 170 |

Heart rates in amateur and semi-professional soccer have rarely been recorded since this study and the fact that they were collected over a small number of matches is a limitation. This thesis will use a similar telemetry system to monitor heart rate in competitive play. Furthermore, this will be done over the course of an entire competitive season, and then used to directly validate a simulation of amateur soccer match-play. The simulation will seek to accurately produce the same heart rate response to matches through effective simulation of match motion-profiles and soccer-specific movements.

## 2.6 Fatigue

Due to the necessity of high physical effort during 90 minutes of intermittent exercise, soccer players may be susceptible to different types of fatigue. Reilly, Drust and Clarke (2008) define fatigue to entail the “inability to sustain the required work rate” and is also said to reduce physical capability as a result of inhibited potential for force generation (Hawley and Reilly, 1997). The self-chosen activity pattern and the presence of external factors (i.e. opposition players) have made the effect of fatigue in soccer a highly researched area with several specific factors suggested. Physical stress during soccer has been reported to be a consequence of aspects of thermoregulation, substrate depletion and metabolite accumulation. Disturbances in these may in turn influence work rate patterns in soccer and can dictate temporary and more sustained forms of fatigue. As a result of changes in work rate, various solutions have therefore been proposed to counteract the effect of fatigue in soccer to sustain 90 minute performance. For example, pre-cooling (Drust, Cable and Reilly, 2000), high-carbohydrate diets (Bangsbo, Mohr and Krustrup, 2006) and isotonic energy drink strategies (Nicolas, Williams and Phillips *et al.* 1995) may enhance energy stores and hydration status whilst limiting increases in core temperature to reduce thermal strain. Validated SSEP's are therefore warranted for research in order to provide effective simulations of match-play, in terms of mechanical and physiological stress. Subsequent results should be able to evaluate the success of interventions with regards to reducing loading of these parameters, allowing sustained performance.

### *2.6.1 Temporary Fatigue*

Numerous studies have illustrated the transient nature of fatigue and its temporary effects in soccer (Krustrup *et al.* (2006); Mohr, Krustrup and Bangsbo (2003) and Bradley *et al.* (2009). The latter two measured the extent of high-intensity activity in 5 minute periods, with the most intense period followed by an immediate drop in intensity in the next 5 minutes, found to be below that of the overall match average (Figure 2.3).

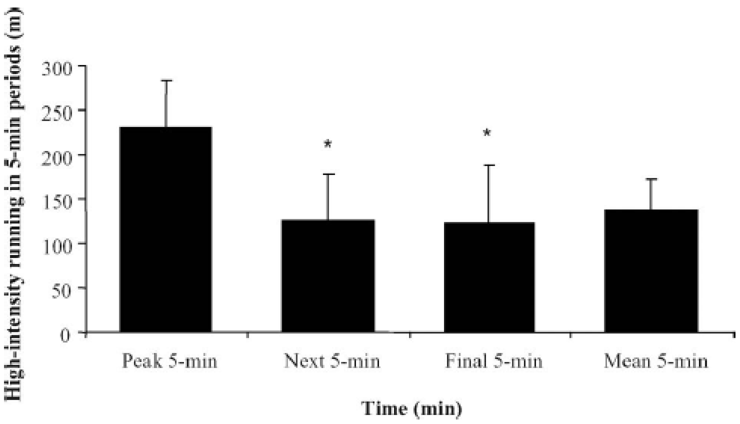

*Figure 2.3 – High-intensity activity across 5 minute periods of a soccer match (Bradley et al. 2009).*

Movement analysis could be improved by using more frequent time period observations to enhance detail of changes over time. In terms of HIR, Mohr, Krustrup and Bangsbo (2003) found that the peak distance covered in a 5 minute period was 219m (27% greater than players of a lower standard). Interestingly the 5 minutes following the most intense period consisted of 106m at high-intensity which corresponded to a level 12% lower than the 5 minute average for the whole game (121m, Figure 2.3). Bradley *et al.* (2009) also found a reduction in high-intensity activity immediately following the most intense period, although to a lesser extent (6% below the match average). Currently, there is no data with which to compare work rate in elite soccer with that of amateur soccer and any fluctuations in high-intensity running patterns and distances covered.

These above mentioned studies would suggest that scrutiny of data in 5 minute periods provides sufficient sensitivity with which to better dissect patterns of work rate in soccer (Drust, Atkinson and Reilly, 2007). Moreover, the results of such in-depth match analysis could aid perceptions of the extent of fatigue occurring transiently during a match as well as the ability to sustain high-intensity running and how it differs between individual positions and lower-level University or amateur players.

### *2.6.2 Cumulative Fatigue*

Although fatigue in soccer may occur temporarily during matches this effect may contribute to more cumulative fatigue towards the end of a match (Krustrup *et al.* 2006). Consequently, there are several factors in which changes are noticed in the second half. Heart rate is one factor that has been observed to decrease in the second half, with Ali and Farrally (1991) reporting heart rate to decline from 169bpm$^{-1}$ to 164bpm$^{-1}$ in the second half among university soccer players. Ekblom (1986) detailed blood lactate concentration to decline from 9.5 mmol.L$^{-1}$ to 7.2 mmol.L$^{-1}$ between halves in elite Swedish soccer players. Bangsbo (1992) observed a similar finding and related this change in concentration to a lower mean heart rate of approximately 10bpm$^{-1}$ which together were related to a reduced work rate.

The work rate in the second half in particular has been observed to decline in relation to total distance (5%, Bangsbo, Norregaard and Thorsoe, 1991), high-intensity running (3%), sprints (23%, Mohr , Krustrup and Bangsbo, 2003) and ball involvements (8%, Rampinini *et al.* 2009) contrasted by an increase in low-intensity running (Bangsbo, Norregaard and Thorsoe, 1991; Bangsbo, 1994a; Mohr, Krustrup and Bangsbo, 2003). In their review, Mohr, Krustrup and Bangsbo (2005) confirmed this to occur for all players, regardless of position, level and gender. However, Reilly (1997) contradicts this by suggesting central defenders and strikers experience greater decrements as a result of their lower aerobic capacity. Also, Bradley *et al.* (2009) reported recovery between high-intensity bursts to be 15% longer in the second half and 28% longer in the final 15 minutes compared to the first 15 minutes of the match. Similar findings were reported by Bangsbo and Mohr (2005) who also found peak sprint speed to be at least 9% lower in the second half with recovery from sprints of 30m or more 47% longer than the average.

The fatigue observed in the latter stages of a match has been suggested by Bangsbo, Mohr and Krustrup (2006) to be caused by numerous factors, some of which have been described above. The impact of fatigue may be to cause heightened injury risk (Bradley *et al.* 2009) particularly in the last 15 minutes (Rahnama, Reilly, Lees, and Graham-Smith, 2002) due to an altered style of play and direct involvement in match activity. However, one might argue that decrements in performance are not related to any effect of fatigue. It could be that players are responding to a change in stimulus within the match, for example are several goals behind their opponent and are resigned to losing the match, thus lowering work-rate.

Knowledge of fatiguing patterns in soccer motion-analysis may prove beneficial in successful simulation of competitive soccer in a closed environment, helping to elucidate physical load experienced by players. This may then help to form strategies for training and injury prevention.

## 2.7 Match Analysis

The application of motion analysis in professional soccer has been increasingly accepted over the last thirty years, deriving largely from the classical study of Reilly and Thomas (1976). The concept of match analysis has been described by Carling, Williams and Reilly (2005) to *"refer to objective recording and examination of behavioural events occurring during competition"*. Thus, there is a dual focus both on the movements and actions of players of different positions within a team, and that of referees too.

Since the notion of soccer match analysis was conceived, a myriad of methods have been employed for data collection, from manual notation and video recording to semi-automated computerized tracking systems today. However, as technology has enabled more advanced methods, motion analysis of ergonomic movements has enabled greater accuracy in the measurement of work rate and its quantification in relation to subsequent physiological changes. As Bangsbo (1994a) stated, 'soccer is not a science, but science may improve soccer', and this is typified by analysis techniques, coupled with exercise physiology in a performance-enhancing role to understand the demands of soccer. The modern methods enhance this by breaking a match down into its component parts of running activities and sport-specific actions.

The work-rate profile of a soccer player can be said to describe the individual's gross physical contribution to the total team effort (Carling, Williams and Reilly, 2005), yet motion profiles have been found to depend on numerous factors such as positional role (Bradley *et al.* 2009; Bradley *et al.* 2010; Rampinini *et al.* 2007; Di Salvo *et al.* 2006), competition (Mohr , Krustrup and Bangsbo, 2003), success and rank of team (Wisloff, Helgerud and Hoff, 1998; Apor, 1988) and indeed the activity and quality of the opposing team (Rampinini *et al.* 2007). Moreover, individual variations must be taken into account, particularly in soccer, where activity and work-rate may be regulated by self-pacing strategies as well as responses to opponent's movements. As a result, it is important to take into account individual variations in total distances and intensities that will refute the generalization of data collected by differing methods.

### *2.7.1 Methods of Motion Analysis*

Since the first study of soccer motion profiles, many methods of data collection have been employed, each trying to elucidate physical demands of the sport, and are presented in Table 2.3. The earliest methods entailed collection by manual notation through visual cues and pitch markings from which movements were then applied to a map of the pitch, learned by a trained observer. Used by Reilly and Thomas (1976), this method was found to be valid and reliable in its application for speeds and distances of all types of activity. The evolution of computerized technology then began to be implemented in a similar way with 'concept keyboards' used to manually code match activity with the help of a pitch map superimposed on to the keyboard.

*Table 2.3 – Methods of Match analysis in recording distances covered*

| **Author** | **Method of Analysis** | **Mean Distance Covered** |
|---|---|---|
| Reilly and Thomas (1976) | Manual notation | 8680m |
| Bangsbo, Norregaard and Thorsoe (1991) | Video recording | 10800m |
| Rampinini *et al.* (2007) | Automatic video tracking (Prozone®) | 11019m |
| Randers *et al.* (2010) | GPS (Catapult MinimaxX, 5Hz) | 10720m |

The use of video recordings by one or several cameras strategically placed around the pitch soon became popular (Bangsbo, Norregaard and Thorsoe, 1991). This method recorded a single player per camera, with the specific player then recorded separately to determine stride length and frequencies over varying distances on the pitch in order to provide data with which to calibrate and code activities performed during the recorded match. Despite acceptable levels of accuracy and validity, the early methods of motion analysis do draw various limitations. Manual notation and coding for example may be subject to human-error in data entry, with subjectivity relating to locomotor interpretation causing potential discrepancies. As a result, some activities may be misrepresented through interpretations of velocity thresholds that produce incorrect work rate profiles. Bloomfield, Polman and O'Donoghue (2007a) were the first to then use recordings taken from Sky TV's 'Player Cam' facility that dedicated one camera to the movements of a single player to then be coded manually in a specially designed system. This method, termed the Bloomfield Movement Classification (Bloomfield, Polman, and O'Donoghue, 2007b) was deemed reliable in its strength of measurement of direction and intensity of game-related movements (distance was not reported), though it was later acknowledged by the authors to be very time-consuming due to the manual nature of recording match-play observations and training observers before coding information into the classification system.

The lack of detail in the level of analysis can also be questioned. Some studies have collected data only of certain players from certain periods of matches and then attempted to extrapolate this to the game as a whole (Mayhew and Wenger, 1985; Stroyer, Klausen and Hansen, 2004). This is clearly not ideal with variations apparent in match exposure as well as the inaccuracy of attempting to quantify an inherently unpredictable and spontaneous activity pattern through extrapolation. Similarly, others have used only a limited number of movement categories, neglecting utility actions and including static periods. As a result, a great loss of detail occurs which are vital contributions to overall work-rate profiles. The fact that these methods are so time-consuming and with a relatively poor level of detail in their analyses (i.e. observing one player at a time) suggests that new means of quantifying work rate characteristics in soccer are advocated (Carling *et al.* 2008). Contemporary research has therefore recruited new technological developments to enhance the level of detail in their analysis. The development of semi-automated tracking systems such as Prozone® has seen them used by many of the world's top soccer clubs for their ability to generate comprehensive reviews of match data, with this system in particular the subject of validation research by Di Salvo *et al.* (2006) finding it to be an acceptable and accurate method of tracking multi-directional movements in competitive match-play. Such systems allow live analytical tracking of multiple players' movements, on and off the ball at a sampling rate of 25 times per second, creating detailed individual databases. The data is collected by 8 fixed cameras within a stadium that cover all areas of the pitch, with a player captured by at least 2 cameras at any one time. The dimensions of the pitch are entered into the analysis system to be calibrated in conjunction with the defined velocity thresholds for each activity. Despite more in-depth analysis at the disposal of coaches and scientists, there are one or two inherent drawbacks with systems such as these. Firstly, is the huge expense in purchasing the system, in excess of twenty-thousand pounds, making them a viable option for only the wealthiest clubs. Additionally, the complications of installation for cameras and electronic equipment also means systems are not portable and therefore data may not be retrieved for away matches, potentially ignoring data from a large proportion of the season.

The emergence of even more practical tracking solutions have since been introduced into the sporting environment and are seen to be the future of movement tracking and scientific evaluation of soccer. The emergence of Global Positioning Systems (GPS) provides similar data, but with the use of orbiting satellites to determine speed and distances of movement. The tri-axial accelerometer facility also enables measurement of movement-associated ‘Player Loads’ in three planes that can help explain session intensity, and biomechanical tendencies that may contribute towards propensity for injury, although this is not currently been supported by any scientific evidence. For example, examining an accelerometry trace of player loads could pinpoint occurrences of injury that may be a result of excessive or unaccustomed vertical or lateral movement. A greater understanding of player loads over a greater number of matches would then prove beneficial in helping to understand physical demands in amateur soccer. The development of subsequently validated GPS technology and its application in football and this thesis will be addressed in more detail in the following sections.

Despite there being a large amount of research produced dedicated to motion analysis, this author believes there to be several limitations that can question some of the data offered. For example, analysis is at times only based on a solitary match observation and involves laborious methods that are susceptible to human error and contradiction. More recent methods furthermore entail expensive specialised systems that are impractical for mainstream scientific research. In this light, the author believes GPS technology to be more effective in data collection and depth of analysis available.

### *2.7.2 Global Positioning Systems (GPS)*

GPS systems have become appealing in the sporting context, specifically in terms of distances covered and speeds achieved. Although recent reviews (Drust, Atkinson and Reilly, 2007; Carling *et al.* 2008; Randers *et al.* 2010) have concluded there to be no ‘gold standard’ of measuring sporadic work rates in team sports, GPS could be seen as a further improvement in methodologies implemented through their compact nature, easier portability and value compared to ‘fixed’ semi-automated tracking systems.

GPS navigation systems were originally for exclusive use by the military, but are now widely used for domestic purposes. Global Positioning System receivers received signals from the 27 satellites orbiting the earth, with the time taken by the signals to travel between the two then used to calculate information on positions, time and velocity (Larsson, 2003). GPS has consequently been introduced into sports science research (Macleod *et al.* 2009; Hill-Haas *et al.* 2010 and Randers *et al.* 2010; Harley *et al.* 2010). Larsson (2003) explored the relevance of GPS in sport, finding it to have acceptable precision in its application. In the Larsson (2003) review, dGPS (Differential Global Positioning System) had an error in position of 3m with speed measures up to 40km/h$^{-1}$ having a correlation coefficient of 0.99 with chronometry (Schutz and Herren, 2000; Larsson and Henriksson-Larsen, 2001). However, he suggests several conditions that must be satisfied to obtain optimal benefits. The units must possess a big enough memory capacity in order to collect data from the desired time (i.e. a 90 minute match or training session). This will also depend on the sampling rate of the system per second (1Hz or 5Hz), with lower rates storing less data, thus producing less detailed analysis. Finally the ability to download data collected to computer analysis software is further advised to store and dissect the data thoroughly.

The discrepancy between methods of measurement has been explored by Randers *et al.* (2010), using four different methods of analysis; video recording analysis, 1 Hz and 5Hz GPS, and the Amisco® semi-automatic multiple-camera system. Through the use of one friendly match involving Spanish professional players, the aim was to deduce the ability of each method in tracking player movement and also detecting changes in distances covered at different speeds during the course of the game. The total distances recorded ranged from 9.51-10.83km, from video-based and multiple camera methods respectively. The 5Hz GPS distance was 10.72km with the 1Hz 9.52km. The 5Hz system and Amisco® package both measured total distance ~1km further than the other methods in this case. The 5Hz GPS was found to record the greatest walking distance (5.13km) with the lower frequency GPS found to be the lowest (4.4km). For high-intensity running, the 1Hz GPS reported a lower distance (1.66km) whereas the 5Hz system was within the expected range (2.03km). This difference in high-intensity running between the two GPS system can be partly explained by a lower total sprint distance at the highest velocities of the 1Hz system (0.23km and 0.37km), which it cannot detect effectively at speeds above 7.19m/s$^{-1}$ or 25.88km/h (Randers *et al.* 2010). Furthermore, the 5Hz GPS system produced the highest peak distance, sprint distance and second highest distance of high-intensity running in a 5 minute period of all four analysis methods employed in the study. All four systems were concluded to be effective in relation to the measurement of activity patterns and fatigue development, yet there should be caution when comparing such different methods due to large variations between each. In terms of the two GPS packages in this study, the 5Hz system would be more advisable in motion analysis due to the higher sampling rate being able to detect changes of a smaller magnitude on a more detailed scale across a range of intensities, from standing to HIR. A similar study by Harley *et al.* (2011) compared inter-changeability of 5Hz GPS and Prozone® tracking system. GPS was found to report greater total distance but less high-intensity and sprinting distances. The authors suggest this to be a result of differing algorithms and sampling rates between the two methods for high-intensity and sprint distances with potentially large differences comparing the two methods.

The reliability and validity of the use of Catapult MinimaxX GPS in measuring distances covered in soccer with 1Hz and 5Hz sampling rates have been examined by Portas *et al.* (2010). It was found that both frequencies were valid in measuring distances and multi-directional soccer-specific activity, but was less reliable on a smaller course with sharper 180° compared to 90° turns with 1Hz GPS. Errors through underestimations of up to 11% were observed, whereas the 5Hz had an error of up to 2%. Moreover, Petersen *et al.* (2009) suggested that a threshold existed in GPS monitoring distance covered by multi-directional movements in restricted spaces, particularly with lower frequency sampling rates. This was similar to findings of Duffield *et al.* (2009) who reported GPS underestimations of distance in tight areas due to lower sampling rates. The 5Hz GPS in the same study was also found to be more reliable for distance covered at higher intensities.

GPS distances measured have also found to correlate well with actual distances measured by calibrated trundle wheel (Edgecomb and Norton, 2006) with a small source of error found using a 5Hz system when compared to a computer-based tracking (CBT) method. Both methods however were said to be practical in monitoring distance covered in team sports, particularly with an experienced CBT user. Coutts and Duffield (2010) however, found three different GPS devices (all 1Hz) to all produce measures of distances covered within <5% of the actual distance. The peak speed recorded during 20m sprints were also correlated between the three GPS systems.  However, the low sampling rate ensured low reliability in detecting changes in distances covered at speeds >20km/h$^{-1}$ and high-intensity activity in general, key to soccer performance assessment. As a result, newer GPS models are advised with higher sampling rates to identify changes in HI activity. However caution must be taken with sampling rate and algorithms applied by manufacturers that could affect accuracy of data comparisons (Witte and Wilson, 2004).

A cheaper and more practical method of motion-analysis, GPS will be implemented in the current thesis in order to analyse the locomotor and work-rate patterns of competitive amateur soccer. This will be achieved through monitoring distances covered, frequency of efforts and time spent exercising at different intensities. Collecting match data for a whole season will give greater reliability to the data that will be subsequently used to develop a validated squad-specific simulation of amateur match-play.

### *2.7.3 Accelerometry*

Carling *et al.* (2008) highlighted the importance of monitoring training load experienced by players and the built in tri-axial accelerometers in GPS units can aid the study of sport-specific utilities and associated accelerations and decelerations. The accelerometer is able to measure the accumulated magnitude of various utility movements indicative of team sports (Boyd, Ball and Aughey, 2011), differentiating between movements other than those in a forward motion through the inertial sensors and gyroscope. These tools measure movement in three planes; anterior-posterior, medio-lateral and longitudinal (Krasnoff *et al.* 2008). Furthermore, the variation in forces impacting upon the player can be examined through the collection of accelerometry data for changes in acceleration, deceleration and direction of movement and the effect they may have. Boyd, Ball and Aughey (2011) said that accelerometry use has "*the potential to represent gross fatiguing movements*" as well as conventional locomotion. Testing the reliability of accelerometers in sport, the same study found coefficients of variation of 0.9-1.04% for dynamic reliability, 1% for static reliability and 1.94% variation for reliability in a team sport setting. The use of accelerometry in team sports was concluded to have an acceptable level of reliability and capability in measuring non-running movements.

As Larsson (2003) suggested, the use of GPS (and accelerometry) in combination with heart rate monitoring provides an excellent tool in the monitoring of internal and external load and intensity with respect to the desired outcome in training or match-play. By quantifying changes in direction and associated mechanical stress, the loading of soccer can be further elucidated in addition to heart rate values. The existing literature on these facets is sparse, however, with further accelerometry data of soccer matches warranted. Such data can then be used to help validate simulations by comparing values of mechanical loading produced. Simulations may then be more indicative of match performance to test intervention strategies or for rehabilitation programmes.

### *2.7.4 Total Distance*

The energy expenditure in competitive performance is directly related to mechanical work output (Reilly and Thomas, 1976) with total distance considered a measure of this. The distance covered during a 90 minute match has been agreed to range between 8-12 kilometres (Reilly, 2003) with individual distances approaching 14 kilometres recorded (Di Salvo *et al.* 2007). A player's total distance is made up of the numerous locomotor running activities engaged in, the proportion of the total distance that they account for are illustrated in Figure 2.4.

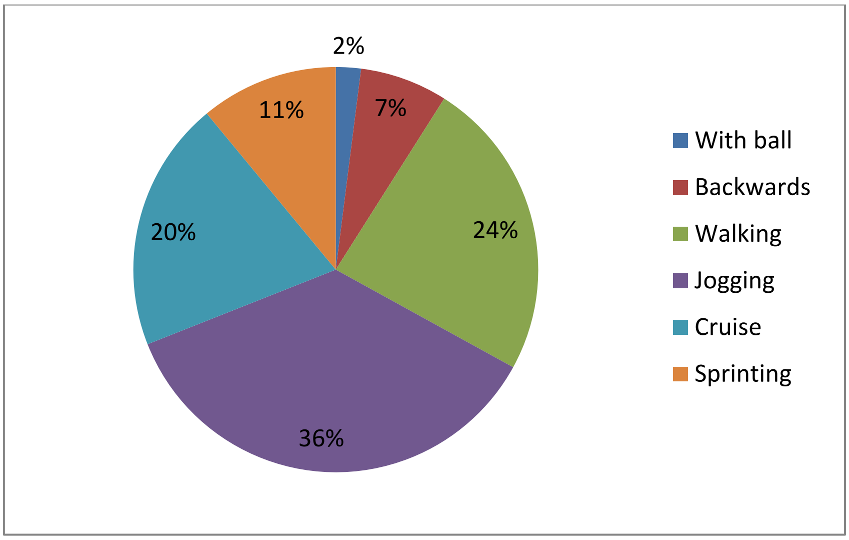

*Figure 2.4 - Distances covered per game by different locomotor activities, adapted from Reilly and Thomas (1976)*

Total distance covered during a game has been found to vary according to a variety of factors, simultaneously dictating the work rate profile and energy cost. Firstly, an individual's $VO_{2max}$ may influence the distance covered per match. A higher physical capacity has been positively correlated to enable further distance to be covered due to positional and tactical requirements. Each positional role is characterized by a specific activity profile due to tactical restrictions in attacking and defensive situations. Furthermore, the variation in $VO_{2max}$ between positions will also influence their ability to cover greater distances at higher running intensities. This is reflected by higher values of $VO_{2max}$ consistently obtained by midfielders and greater total distances, particularly in central roles where they act as 'linkages' in play between defensive and attacking thirds (Reilly and Doran, 2003). This relationship is displayed in Figure 2.5.  Improved training status was previously studied in relation to an increase in total match distance. Following the implementation of different aerobic training interventions over periods of 8-18 weeks during the season, improved aerobic capacity was consistently found to then increase total distances in both halves (particularly important in second half performance) and the match distance by 6% (Impellizzeri *et al.* 2006) and 20% (Helgerud *et al.* 2001).

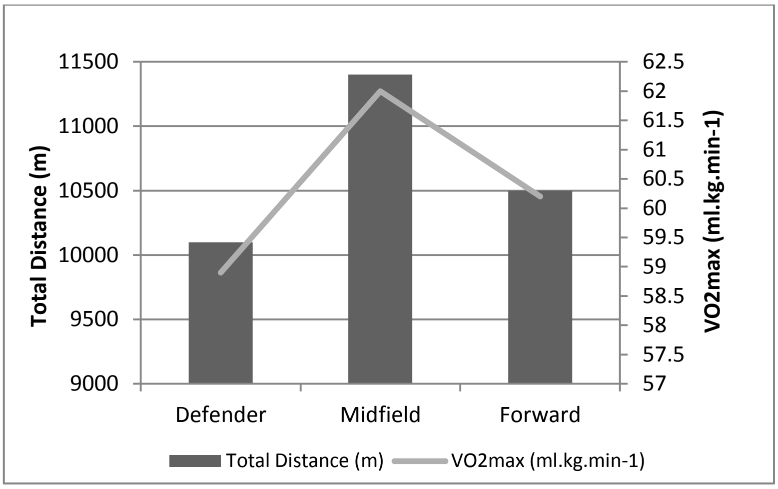

*Figure 2.5 – Relationship of distance covered and maximal oxygen uptake by position (Bangsbo, Norregaard and Thorsoe, 1991)*

The style of play has also been suggested to influence distance covered, with comparisons drawn over significant periods of time and between teams of different nationalities. For example, evolution of the style of play characterizing professional soccer in England has been suggested by Strudwick and Reilly (2001) who illustrated a significant increase in total distance covered by contemporary English Premier League players compared to those of the Old First Division originally observed by Reilly and Thomas (1976) (11.0 vs. 8.6 kilometres, Figure 2.6). Although there may be a difference in methodologies, conclusions could be drawn that changes to the proportion of the mode and intensity of locomotion have contributed to such an increase in total distance over the last thirty years. An apparent style of play more focused on ‘off the ball’ movement (~98% of total distance, Reilly, 1997) to exploit space and support teammates with different tactical requirements of a higher intensity with faster recovery may explain this.

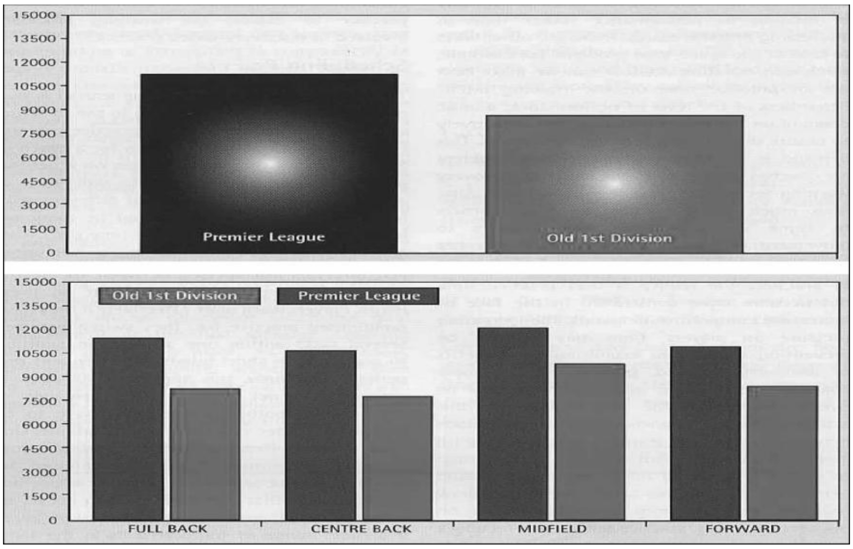

*Figure 2.6 – Comparison of distances covered in old First Division and modern Premier League (Strudwick and Reilly, 2001)*

Similarly, the study of Rienzi *et al.* (2000) compared activities of South American International and English Premier League players, finding that the different competitions, level and style of play produced a difference in total distance of 1.5 kilometres in favour of top level players in England (10.1 vs. 8.6 kilometres). Mohr, Krustrup and Bangsbo (2003) also highlighted the effect of playing standard on total distance, with top-class professionals covering 5% further on average then players of a more moderate standard from the top Danish league. Additionally, Rampinini *et al.* (2007) also showed that playing against opponents of higher quality seemed to increase the total distance of the reference team, with distances consequently lower when they played teams of a lower quality (Table 2.4), illustrating the effect of opponent activity and tactical set up on that of the team or player.

*Table 2.4 – Effect of opposition quality on Total Distance and High-Intensity Distance (Rampinini et al. 2007)*

| | **Total Distance (m)** | **High-intensity Running (m)** | **Very High-Intensity Running (m)** |
|---|---|---|---|
| **Against Best** | 11097 | 2770 | 902 |
| **Against Worst** | 10827 | 2630 | 883 |
| **% Difference** | 2.5% | 5% | 2.1% |

Although total distance may be a function of global work rate, it is regarded as a poor indicator of match performance (Van Gool, Van Gervan and Boutmans, 1988). This is due to the fact that it comprises running of all intensities. This is largely low-intensity with total distance not specifically taking into account the contribution of change of direction and utility movements (Figure 2.7) and running performed at high intensities key to the match outcome. As a result, it is acceptable to say that total distance underestimates energy cost in matches by its inability to account for these decisive actions that accentuate energetic and metabolic demands (Reilly and Ball, 1984; Reilly and Bowen, 1984). Furthermore, variability in total distance covered has been attributed to differences in the amount of low-intensity activity (Bangsbo, Norregaard and Thorsoe, 1991), which is a more stable parameter compared to that of high-intensity running, which is seen to be more variable (16-30% match-to-match, Gregson *et al.* 2010) and so a more sensitive measure of performance.

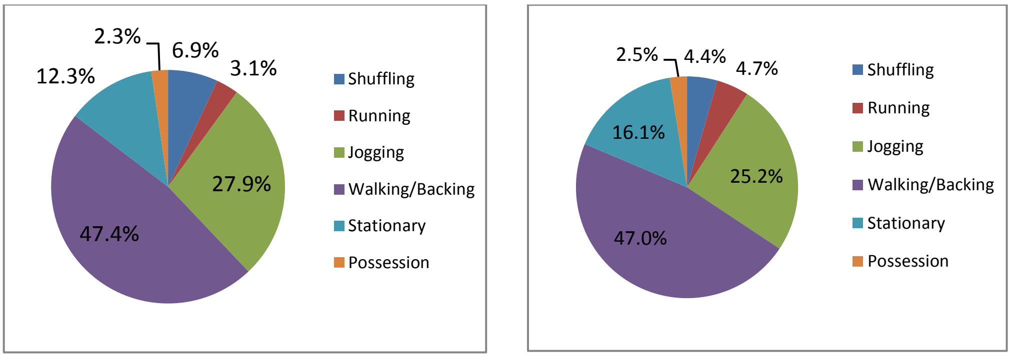

*Figure 2.7 - Percentage Time spent in locomotor categories for Elite (left) Amateur (right) players (O'Donoghue et al. 2001)*

### 2.7.5 High-intensity activity

High-intensity running (HIR) is the umbrella term that describes running activities above certain velocities, often termed; running, high-speed running, sprinting, with very high-intensity running (VHIR) incorporating high-speed running and sprinting only. As part of the intermittent exercise pattern, bursts of intense exercise form the basis for the decisive events and skills from which successful execution often determines the outcome of the match. High-intensity running has been found to account for 8-12% of the total distance covered during a soccer match (Rampinini *et al.* 2007) or up to 13% of total time (O'Donoghue *et al.* 2001, Figure 2.8). Bradley *et al.* (2009) recorded HIR distance in the English Premier League to average approximately 2500m with VHIR 900m (23% and 8% of total distance respectively).

As Bangsbo (1994a) stated, soccer performance is underpinned by the ability to produce repeated high-intensity actions and recover quickly. As a result, the link shared between a high aerobic capacity ($VO_{2max}$) and total distance covered is also apparent between one's physical capacity and the proportion of time and distance performed at high-intensity. This was found to be the case for midfield players in the study by Bangsbo, Norregaard and Thorsoe, (1991), covering significantly more distance and producing more HI efforts. In this way individuals are able to sustain high-intensities for longer and produced repeated efforts with shorter separating recovery times. However, as mentioned previously, total distance is a weak indicator of match performance with high-intensity running (normally >13-19.8 km.h$^{-1}$) seen as a more valid parameter (Bangsbo, Norregaard and Thorsoe, 1991; Mohr, Krustrup and Bangsbo, 2003; Krustrup *et al.* 2003) to describe performance due to high coefficients of variation associated with this type of activity (Gregson *et al.* 2010). The value of high-intensity activity can be justified by findings of Mohr, Krustrup and Bangsbo (2003) that players of a high standard covered only 5% more total distance than players of a moderate standard, yet this distance was made up of 28% more high-intensity running then those of a lower standard, reflecting higher levels of fitness contributing to higher and sustained physical performance.

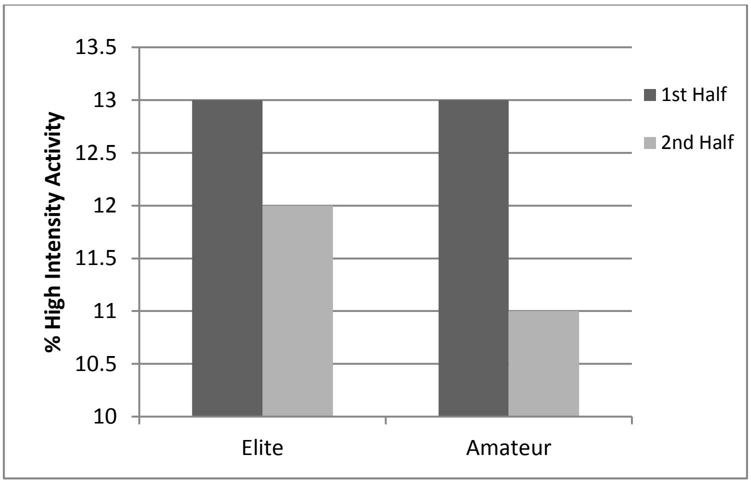

*Figure 2.8 – Percentage time high-intensity activity between halves in elite and amateur soccer (O'Donoghue et al. 2001)*

Different populations such as less ‘successful’ teams have also been found to produce greater distance at high-intensity (Rampinini *et al.* 2007; Rampinini *et al.* 2009; Di Salvo *et al.* 2009), contrasting perhaps with previous results suggesting higher standards to be superior (Mohr , Krustrup and Bangsbo, 2003). Similarly, league differences may demonstrate variations in the proportion of HI distance (i.e. English, 23%, Bradley *et al.* 2009; Italian, 22%, Mohr , Krustrup and Bangsbo, 2003; Spanish, 21%, Di Salvo *et al.* 2007; Australian, 18.8%, Withers *et al.* 1982 and Danish, 18%, Mohr, Krustrup and Bangsbo, 2003) reflecting differences in physical capacities, tactics and style of play employed. Therefore caution should be taken when comparing such populations.

Perhaps one of the most frequently observed variations in HIR reflects changes with positional role. Distance run at high-intensity during matches has been studied by several authors (Rampinini *et al.* 2007; Di Salvo *et al.* 2007; Di Salvo *et al.* 2009; Mohr, Krustrup and Bangsbo, 2003; Bradley *et al.* 2009; Bradley *et al.* 2010), finding midfielders to cover the greatest distances of up to 3000m, equating to 26% of the total distance covered. Using the same thresholds Bradley *et al.* (2009) and Rampinini *et al.* (2007) also found midfield players, particularly in lateral positions, perform most work at very high intensities (600-1200m, 11% of total distance).

Although a valid measure of performance, variability in high-intensity activity may result from impact of the players levels of fitness (Mohr, Krustrup and Bangsbo, 2003) and environmental elements (Ekblom, 1986), tactical/positional roles (Rampinini *et al.* 2007; Di Salvo *et al.* 2007) and the degree of self-regulation of the overall activity profile may also see match-to match variation in high-intensity activity. The activity profile of opposition has also been said to dictate that of the reference team (Rampinini *et al.* 2007) as well as the activity completed in the first half of the match playing a role in how much distance is covered and at what intensities in the second half (Di Salvo *et al.* 2009; Rampinini *et al.* 2007). For example, there may be less HI efforts, with greater intervening recovery and more low-intensity running performed in the second half as a sparing strategy (Bradley *et al.* 2009).

As a result of dynamic factors and the influence of fatigue during different matches, Gregson *et al.* (2010) looked to determine the extent of variability in the more intense running in soccer, finding discrete modes of ‘high-speed activities’ with and without the ball to produce coefficients of variation of ~16-30.6% between matches. Rampinini *et al.* (2007) and Mohr, Krustrup and Bangsbo (2003) also found similar coefficients for this measure (~20% and ~24%). It was suggested that an increase in variability was influenced by the stage of the season, possession of the ball, and playing position, with central roles being most susceptible to HIR variability. This makes practitioners more acutely aware of inherent variations within high-intensity sub-components and which may be most sensitive in matches. However, different data collection methods between studies may vary in interpretation of what constitutes ‘high-intensity activity’ and so applying varying velocity thresholds at which high-speed intensity status is attained. With more awareness of the nature and variation in HIR, validity of simulations may be improved by using data from more match observations giving greater statistical power. The simulation will then be developed from a larger amount of data that will more reliably take into account HIR variation between matches.

### *2.7.6 Within match variations*

Despite success of training interventions in physical performance, studies have often reported decrements in various areas of physical performance, notably in the second half of a soccer match (Randers *et al.* 2010; Bangsbo, 1994b; Bangsbo, Norregaard and Thorsoe, 1991; Bangsbo and Mohr 2005, Di Salvo *et al.* 2007, Ekblom, 1986, Mohr, Krustrup and Bangsbo, 2003; Rampinini *et al.* 2007; Rampinini *et al.* 2009, Reilly and Thomas, 1976). Mohr , Krustrup and Bangsbo (2003) and Bangsbo (1994a) have suggested that players in all positions experience a loss in performance as the game progresses, particularly between halves, in relation to distances covered (~5-10%), direct interactions in play and high-intensity efforts (10%). The resultant indication is that players do indeed utilise their physical capacities during a match (Bangsbo, Mohr and Krustrup, 2006), further reflected by significantly longer times spent recovering from HI efforts (Mohr, Krustrup and Bangsbo, 2005). However Rampinini *et al.* (2007) was one of the first studies to suggest that activity profiles in the first half and the activities of opponents regulate that of the second half. This depended on the amount and type of exercise engaged in, clarified by Rampinini *et al.* (2009) regarding self-imposed decisions to engage in high or low-intensity activity that have a subsequent effect on distances covered and the degree of intensity employed in the second half.  Edwards and Noakes (2007) suggested that self-pacing limits dehydration and excessive peripheral physiological failure during a match. Furthermore, performance between halves was also shown to correlate with the work rate and indeed the quality of the opposing team as to how the reference team adapted its own patterns of exercise in the second period. As a result, motion-analysis should be carried out over a prolonged period of time, rather than a single observation, where participants are exposed to different opponents and formations that will affect match work-rates. The result is a large variation in match distances covered, especially at high-intensity (Gregson *et al.* 2010), which is a significant limitation of some SSEP's based on single match observations (Lovell, Knapper and Small, 2008). Collecting match data over a longer period of time will benefit from taking into account to match-to-match variation of locomotor activity. The collection of motion analysis over the course of an entire university soccer season is a notable strength of the present study (USAFT$^{90}$ validation). Analysing multiple matches of the same squad enhances the reliability of the physical demands observed to then form a squad-specific soccer simulation.

### *2.7.7 Utility Movements*

The measurement of total distance covered during a match is seen as a global estimate of work rate that comprises of many different discrete running and utility activities of differing frequency, duration and intensity that more accurately represent measures of energy expenditure over 90 minutes. Mayhew and Wenger (1985) applied measures of walking and jogging backwards and sideways activities as well as distance with the ball. Durations for each of these were recorded to deduce exercise to rest ratios, A similar approach was also applied by Bloomfield, Polman and O'Donoghue (2007a) with the inclusion of duration of activities warranting direct match involvement such as shuffling (7% total time), forward movement (48.7%), lateral movement (4.2%) and the frequency of angular movements (300 occurrences between 0-90º). Again, this allows scientists as well as coaches to understand physiological responses and mechanical load to match play as a result of movement patterns that then help to tailor training practices in terms of mode and structure.

As alluded to previously, motion profiles and energy expenditure are also greatly influenced by soccer-specific actions. Such activities have greater energetic demands and thus induce elevated physiological stress, dictating subsequent patterns in motion profiles. For example, it has been found that there are approximately 14,000 changes in activity, around 1400 per player, changing every 6 seconds (Mohr, Bangsbo and Krustrup, 2003). Soccer-specific actions are skills such as jumping, heading, passing and involvements with the ball as well as high-speed runs requiring acceleration and changes in direction. Only 2% of total distance covered is performed in possession of the ball, which increases the energy cost by 8% or 5.2kJ/min$^{-1}$ (Reilly, 1997) as well as increased heart rate, blood lactate and perceived exertion levels (Reilly and Ball, 1984). Furthermore, the intermittent nature of soccer produces energy costs in excess of that associated with continuous running of the same equivalent total distance (Greig, McNaughton and Lovell, 2006). Over 90 minutes a male of 75kg body mass will typically expend around 75kJ/min$^{-1}$, largely contributed to by high-intensity utility actions accounting for 16% of the total distance (Reilly, 1997). Bloomfield, Polman and O’Donoghue (2007a) previously found these movements to vary greatly in type according to position.  Factors such as the angle, direction (i.e. arced) and type of movement (i.e. shuffling) were suggested to highlight different positional physical prerequisites. Despite their significant influence on energy cost and types of locomotion engaged in during soccer motion-profiles (Carling, Williams, Reilly, 2005), utility movements are often neglected in match analyses and laboratory soccer simulations (Thatcher and Batterham, 2004; Drust, Reilly and Cable, 2000), reducing validity of data produced. This is particularly prevalent when relating distances covered, work intensities and physiological responses that are likely to be underestimated as a result of omitting such important factors. According to Buttifant, Graham and Cross (2002) this reflects a ‘failure to provide a complete representation’, simplifying the complex demands of soccer match-play (Bloomfield, Polman and O’Donoghue, 2007a). These were highlighted by Osgnach *et al.* (2010) who used algorithms devised by Di Prampero *et al.* (2005), with the aim of deducing the metabolic power and energy cost of accelerated and decelerated running associated with sports such as soccer. It was found that using match-analysis from a semi-automated system, energy expenditure from the same total distance may vary in individuals by 15% due to the nature of accelerations and decelerations in match-play. Anaerobic energy yield was also calculated to be 11-27% of total expenditure and the cost of running on natural grass to be 25% higher than that of treadmill running (as used in laboratory simulations, e.g. Drust, Reilly and Cable, 2000). Osgnach *et al.* (2010) proposed their method of video analysis and algorithms to be a more specific measure of metabolic cost during match-play, producing a more accurate measure of individual ‘high-intensity activity’ that is not purely based on velocity, but mechanical movements too.

Utility movements are therefore key to soccer performance analysis and should be taken into account in motion-analysis of match-play. The benefit of accelerometry use in evaluating the contribution of these movements to mechanical load will be explored later in this chapter.

In summary, there are numerous facets that make up soccer performance, with the majority of literature detailing motion analysis of elite populations. However, there are few examples of research that utilise GPS and accelerometry data in their methodologies that could help to describe more discreet movements patterns more readily. These technologies could be employed to distinguish characteristics between positional roles and how these may change over the course of a whole soccer season in populations as well as those at the elite level.

## 2.8 Soccer-Specific Exercise Protocols

Soccer-specific exercise protocols (SSEP's) have become more popular in recent years, attempting to mimic the exercise patterns of soccer match play collected by motion analysis. Such protocols can be in either laboratory or field environments, meaning there can be restrictions to the two environments. Laboratory protocols are carried out in controlled conditions where the use of accurate measuring equipment allows testing of physical responses to simulated match-play. The benefit of SSEP's is that they are able to manipulate exercise intensity whilst observing physiological responses at fixed time points or intensities which may then be related to changes in physiological and mechanical parameters in matches. Validated SSEP's also provide reliable simulations of match-play with which to test intervention strategies and stage of rehabilitation. Previous attempts to validate SSEP's have been hindered by certain methodological limitations however. Some protocols are not true representations of intermittent exercise in soccer. Furthermore, the changes in direction are often not possible in treadmill-based methodologies and the motion-analysis data on which the simulation is based is often different to that of the population validating the protocol.

The open and unpredictable environment of soccer match-play is difficult to simulate in such protocols. The aim of SSEP's is to simulate match-play in a controlled environment. However, this means that major factors contributing to the energy cost of soccer are discarded, such as environmental conditions, ball skills, multi-directional movements and movement and contacts from opposing players (Drust, Reilly and Cable, 2000; Thatcher and Batterham, 2004). As a result, the reliability of such validation methods to effectively simulate energetic demands of the game is questionable. The inclusion of specific movement patterns in soccer would therefore be more representative of mechanical match demands and still in a controlled environment. The magnitude of this external loading could be quantified by 'player load' accelerometry data that can produce information on the physical demands on players in non-locomotor motion, therefore taking into account typical changes of direction, accelerations and decelerations that contribute significantly to elevating energy cost. This tool will assess mechanical load of match-play in Chapter 3 and subsequently help validate the SSEP in Chapter 4. Also, previous studies measuring lactate responses during SSEP's have found lactate levels to range from 1.1mmol.L$^{-1}$(Greig, McNaughton and Lovell, 2006) to 5mmol.L$^{-1}$ (Nicholas, Nuttall and Williams, 2000; Thatcher and Batterham, 2004). However, these studies were not ecologically valid due to the absence of multi-directional movements and ball involvements previously mentioned, associated with a high anaerobic energy cost and accumulation of lactate that were not possible on a treadmill (Greig, McNaughton and Lovell, 2006). The results obtained also may not reflect the average for a soccer match given that sampling is related to the activity performed immediately prior to sampling (Bangsbo, Norregaard and Thorsoe, 1991). This is problematic with SSEP's of a fixed intensity as the locomotor patterns are dictated (i.e. 15 minute bouts; Nicholas, Nuttall and Williams, 2000) and will not vary lactate levels to the extent in matches where activity is more sporadic and unpredictable. The true intermittent nature of soccer is therefore not effectively simulated, therefore affecting the validity of a match simulation.

The recent development of a soccer-specific aerobic field test ($SAFT^{90}$, Lovell, Knapper and Small, 2008) that simulated the intermittent, multidirectional nature of soccer sought to address some failings of previous SSEP's by including skills and multi-directional movements typical of soccer. Physiological responses obtained showed that $SAFT^{90}$ elicited physiological responses to match play previously reported, with similar elevations in heart rate (162 $bpm^{-1}$ *vs.* 170 $bpm^{-1}$, Bangsbo, 1994a), blood lactate ($4.7mmol.L^{-1}$, Krustrup *et al.* 2006) and oxygen consumption (70% $VO_{2max}$, Bangsbo, 1994a) as well as reductions in sprint performance (~3% between halves, Mohr, Krustrup and Bangsbo, 2003) and body fluids (~1.5L, Reilly, 1996) also apparent. Reductions, particularly in the second half, suggest the onset of fatigue previously observed by Mohr *et al.* (2004) and Krustrup *et al.* (2006). Despite acceptable conclusions regarding the simulation of soccer match-play and associated fatigue, it should be noted that the original data supplied for the speed zones and activity profile of the simulation was from a single match from professional players of the English Championship and then performed by a different population of semi-professional players.

The use of different populations is common to numerous studies attempting to validate SSEP's and entails the use of match-play data of a population different to that completing the validation of the simulation. Similar to Lovell, Knapper and Small (2008), Nicholas, Nuttall and Williams (2000) used university level soccer and rugby players to validate The Loughborough Intermittent Shuttle Test (LIST) that was based around the activity pattern of professional soccer players (Reilly and Thomas, 1976; Withers *et al.* 1982). This was also the case in the work of Greig, McNaughton and Lovell (2006) that used match data from the notational analysis of professional Danish players by Bangsbo (1994a) and employed semi-professional players to perform their simulation. The main limitation in using motion-analysis of different populations and standards to validate SSEP's is that it does not take into account differences between the physical capacities of the two. This is important as Mohr, Krustrup and Bangsbo (2003) have shown that match performance differs between standards of play. As a result the match data utilised is not representative of the validation population and therefore physiological and mechanical responses to the SSEP are unrealistic and not representative of a soccer match for these participants.

According to Drust, Atkinson and Reilly (2007), the ecological validity of simulations should only be confirmed directly with the use of the same population throughout the process, as was performed by Thatcher and Batterham (2004). This study provided a more appropriate method of attempting to directly validate a soccer-specific protocol. Using match-play data from video recording of 24 professional English players, running activities were calculated on a micro-computer and then coded into categories. The average speed and duration of locomotion in each activity per 5 minute period was calculated to create a non-motorised treadmill SSEP. Two halves of 9 x 5 minutes were run by the subjects, with a visual unit displaying the target speeds to be achieved during each bout within the cycle. The SSEP induced an average heart rate response of 166 bpm$^{-1}$ (83%HR$_{max}$), lower than that reported in a previous study of match-play heart rate (~170 bpm$^{-1}$, 85%HR$_{max}$, Bangsbo, 1994a), although it is not known if this difference is statistically significant. This may be due to the omission of utility and ball actions as well as locomotor restraints associated with non-motorised treadmills overestimating physical demands of running. Values of VO$_2$ (70%) and blood lactate (5mmol.L$^{-1}$) were also in close agreement with Ekblom (1986), Reilly (1996) and Krustrup *et al.* (2006), indicating the protocol developed elicited a similar physical load to that experienced in matches. This method could be considered more appropriate in using the same population for match analysis, used to construct an SSEP based on their own competitive match data. This approach is then more ecologically valid by observing and testing the same subjects and would be useful to researchers in universities who primarily use students as research participants.

To review, although there is numerous existing literature on SSEP's, there are some inherent limitations in this authors opinion. For example, simulations developed have often been based on limited match observations, and omit key skill-related actions and changes in direction which reduce the reliability of data produced as there is likely to be a lowered energy cost and subsequent physiological response in comparison to actual match-play, with no measure that mechanical load is also being simulated effectively. As a result, previous methods have entailed unrealistic activity profiles in terms of the bout duration of locomotor intensities that are not typical of soccer.

Furthermore, validity is compromised by the use of different populations to validate a simulation based on match data of an entirely different population.

It is therefore the aim of this thesis to determine the activity profile and mechanical load of amateur soccer players in order to provide comparative data to the substantial literature that already exists on the elite level.  A greater level of analysis of amateur soccer would then provide subsequent simulations with more data around which to design their intervention as the majority of such studies employ semi-professional or university soccer players (Van Gool, Van Gervan and Boutmans, 1988; O'Donoghue *et al.* 2001). The secondary aim is to utilise the match data to create and validate a new squad-specific soccer simulation (USAFT$^{90}$). It is hoped that directly validating a new SSEP by producing the same internal and external responses of match-play in the field test could provide an effective tool for use with injury rehabilitation and scientific performance intervention strategies.

# Chapter 3

# Motion Analysis of Competitive Amateur Soccer

## 3.1 Introduction

An intermittent sport, soccer involves activity patterns that are highly complex and influenced by numerous factors, both internal and external. The locomotor activities employed entail often repetitive bouts of high-intensity exercise that are interspersed with periods of low-intensity recovery (Drust, Atkinson and Reilly, 2007). The types of running employed form the basis of soccer fitness demands. The presence of high-intensity utility movements and key soccer-specific skills also serve to elevate physiological and mechanical demand on the individual player. For example, average heart rate in match-play has been found to be around 170bpm$^{-1}$ (Bangsbo, 1994a), rising disproportionately to oxygen consumption during intense intermittent periods of play, increasing energy expenditure with accelerations and decelerations in different directions (Reilly and Bowen 1984).

Soccer players may cover a total distance of approximately 8-14 kilometres (Reilly, 2003), with midfield players assumed to cover the greatest distance, due to their requirement to cover considerable ground (Di Salvo *et al.* 2007). The variation in distances covered and the intensities employed are therefore greatly inherent according to positional role (Rienzi *et al.* 2000; Di Salvo *et al.* 2006; Bradley *et al.* 2009). In high-intensity and sprinting activities, wide defence and midfield positions consistently demonstrate higher distances due to their supporting role in lateral areas of the pitch where there is more space to exploit, accelerating towards maximal running speeds (Di Salvo *et al.* 2007). The large variability and changes in exercise intensity and movements executed are typical of soccer match-play due to the dynamic and spontaneous environment. As a result, these frequent changes that increase energy cost make it difficult to quantify physical demands, loading and work rate profiles in soccer. Furthermore, variation in high-intensity running distance, for example, warrants extended observations, perhaps across a season to account for match-to-match variation. Consequently, information regarding fatigue-related decrements in work-rate and the contribution of utility movements can be identified that may too be used to improve reliability of specific match simulations.

There have been numerous methods into movement patterns, from basic manual notation (Reilly and Thomas, 1976), recording and coding by video camera (Bangsbo, Norregaard and Thorsoe, 1991) to contemporary multiple camera analysis systems (Di Salvo *et al.* 2006). Although such systems are simultaneously able to track multiple players, building profiles for individuals regarding their match activity, there are limitations. Fundamentally, such methods are often expensive and difficult to install, requiring specialist companies and technicians. Furthermore, they are also not easily portable and so are generally only used in one fixed environment, and as such are not practical. However, such issues may be overcome with the use of new global positioning system technology, emerging to be accurate measures of distances covered and velocities attained in teams sports such as soccer (Coutts and Duffield, 2008). Also, built-in accelerometers are able to discriminate between locomotion such as walking and running and ‘non-locomotor’ activity (such as accelerations and decelerations) in each plane of motion. Boyd, Ball and Aughey (2011) found one model of accelerometers to have acceptable reliability in measuring skill and impact of mechanical load in team sports. This can then help quantify match movement demands in soccer in greater detail. The validity and specificity of the data collected in competition is then optimised for scrutiny, then forming the basis of soccer-specific exercise protocols (in the laboratory or field environment) to test intervention strategies and regulate end-stage rehabilitation prescription.

It is therefore the aim of this study to research and analyse the work rate profiles and player loads of a squad of amateur soccer players. This will be approached through the use of heart rate telemetry, GPS and accelerometry to compare motion characteristics and internal and external loads to those at the elite level. The study will produce data on the amateur game, which is currently scarce. Only O'Donoghue *et al.* (2000) have reported motion-analysis data on amateur soccer, yet this was based around only time spent exercising at different intensities, using video recording methods. The quality of the method in the current study is supported by the previous validation of the reliable use of 5Hz GPS for measuring time spent at different velocities as well as the distance covered at varying intensities (Portas *et al.* 2010). As a result, it is possible to measure exercise at high-intensities, which have been reported to vary ~30% from match-to match (Gregson *et al.* 2010) and has not been analysed in the amateur game.

## 3.2 Methods

All participants used in the study were outfield players of the University of Hull 1st XI amateur soccer squad (*n* = 22). Participant characteristics are shown in Table 3.1. The 22 players used in the study were all of a proficient standard, with several having previously been signed to professional clubs both in England and abroad. Subjects consisted of players from all positions; wide defenders (*n* = 5), central defenders (*n* = 4), wide midfielders (*n* = 3), central midfielders (*n* = 6) and strikers (*n* = 4).

*Table 3.1 - Subject characteristics*

| **Age** | **Height** | **Weight** | **$VO_{2\ max}$** | **$HR_{max}$** |
|---|---|---|---|---|
| 21 ± 2 yrs | 185.3 ± 8.0 cm | 79.4 ± 7.9 kg | 54.9 ± 6.6 $ml.kg.min^{-1}$ | 188 ± 8 bpm |

The study took place over the course of the 2009-2010 season in the British Universities and Colleges Sports (BUCS) Northern Conference 2B consisting of 10 matches, with 4 additional matches from domestic cup competitions. The players typically trained as a squad for one-and-a-half to two hours, twice weekly, with Wednesday being match days. Only data from full matches (90 minutes) was included in the analysis while each player had to play a minimum of 3 games to qualify as a member of the subject squad and to then perform the field test validation. This was to account for match-to-match variability in work rates as previous studies of motion analysis have often used single match observations, reducing reliability of data of match demands. Two players were excluded from data analysis and the soccer simulation because they had not played the required amount of games, or were injured at the time of the test validation. Six participants were then selected to complete the simulation in Chapter 4.

Before the study commenced, all subjects were fully briefed about the experimental design and protocols involved in the study. Having given their informed consent to participate in the study, they were then subject to appropriate medical screening procedures prior to testing. Ethical approval was also obtained from the University of Hull Ethics Committee to carry out the research proposal.

### *Preliminary Tests*

#### *Maximal Oxygen Uptake*

In order to obtain physiological values for maximal oxygen uptake ($VO_{2max}$) and heart rate ($HR_{max}$) with which to compare to subsequent competitive match analysis and match-play simulation responses in the study, it was necessary to conduct an incremental treadmill test to exhaustion. On arrival at the lab, the subject's height and weight were recorded before undertaking the test and entered into the gas analysis software. The test was performed on a standard motorised treadmill (HP Cosmos Mercury, Nussdorf-Traunstein, Germany). The protocol design was for the subjects to exercise on the treadmill at a gradient of 1%, beginning at a speed of $9km/h^{-1}$ and then increasing by $1km/h^{-1}$ every minute. Exercise was continued under this pattern until the subject reached volitional exhaustion.

During the test, expired air was measured breath-by-breath by a gas analyser (Cortex Metamax, Leipzig, Germany) that subsequently produced a value for the subject's maximal oxygen consumption (measured in $ml.kg.min^{-1}$) following the termination of exercise. This value was obtained as a 15-second stationary average from the breath-by-breath data. The gas analyser was calibrated for barometric air pressure, as well as air composition for ambient air in conjunction with known gas concentrations. The volume sensor was calibrated with the use of a Hans-Rudolph calibration.

Heart rate was recorded throughout the test by a short-range telemetry system (Polar, Kempele, Finland) that required the subject to wear both a chest monitor and wrist watch displaying the heart rate constantly as well as on the visual display unit of the treadmill. The heart rate recorded at exhaustion was taken as the individual's maximum heart rate ($HR_{max}$) in beats per minute.

### *Experimental Design*

The experimental design of the thesis was to observe and record time-motion analysis of competitive amateur soccer match-play using 5Hz Global Positioning System and 100Hz Accelerometer for external load with internal load from a heart rate telemetry system. The data would then be used to create a squad-specific soccer-aerobic fitness test according to velocities employed by the subject squad in matches. The methodology then serves to create a population-specific version of SAFT[90], attempting to elicit the internal (heart rate) and external loading (accelerometery) of match play. The test may then be used in rehabilitation, conditioning and intervention settings in a controlled environment

### *Motion Analysis*

The match analysis of the subjects during every match of the 2009-2010 season (*n* = 14 matches) primarily entailed the study of motion profiles and work rates of the players during competitive match-play. In the present study, 5Hz GPS units (MinimaxX, Catapult, Australia) were positioned in the small of the player's back, between the shoulder blades, with the help of a purpose-made support vest worn underneath the playing shirt. As described in Table 3.2, the units were activated at least 10 minutes prior to kick off to allow a signal to be received from the corresponding satellites. The units were then switched off immediately after the final whistle.

*Table 3.2 – Match-day testing protocol*

13.30 – Warm up

13.50 – Turn on GPS units

13.55 – Fit GPS and Heart rate monitor

14.00-14.45 – First Half

14.45-15.00 – Half-Time

15.00-15.45 – Second Half

Remove GPS and HR monitors

### *Heart rate*

Similarly, prior to kick off, the subjects were also fitted with the same heart rate monitor (Polar Team System, Kempele, Finland) around the chest. Heart rate was recorded at a sampling rate of every 5 seconds with recording enhanced by the application of electrocardiogram gel to the electrodes on the heart rate monitor.

For both GPS and heart rate data, only the starting 10 outfield players were monitored. Furthermore, subsequent analysis of each match only employed data of players that had completed the full 90 minute match, excluding any extra- or injury time. The GPS data from every match was downloaded from the base unit immediately after the match using Logan Plus software (Catapult Innovations, Australia). For the purposes of this study, the activity trace from the match produced with the GPS was first divided in to first and second halves (45 minutes each, not including extra time), and then further divided in to two 9 x 5 minute periods.

To then analyse the motion profiles of each player, it was then necessary to define the various speed zones that were entered during match-play. In this study 7 bands were set, based on speed thresholds (Table 3.3).

*Table 3.3 – Speed thresholds employed for post-match analysis of GPS data*

| **Band** | **Velocity (km/h$^{-1}$)** |
|---|---|
| **Standing** | 0 – 0.7 |
| **1** | 0.71 – 6 |
| **2** | 6.1 – 12 |
| **3** | 12.1 – 15 |
| **4** | 15.1 – 18 |
| **5** | 18.1 – 25 |
| **6** | >25 |

The total distance covered, and the distances and proportion of time spent at high intensity (HIR), very high intensity (VHIR) and sprinting (Table 3.4), were determined, together with the average and peak velocities and player loads experienced over the course of a 90 minute soccer match.

*Table 3.4 – Classification of high-intensity running activities*

| **Classification** | **Velocities (km/h$^{-1}$)** |
|---|---|
| **HIR** | 4 (>15.1 km/h$^{-1}$) |
| **VHIR** | 5 (>18.1 km/h$^{-1}$) |
| **Sprinting** | 6 (>25 km/h$^{-1}$) |

Player Load values were calculated through the in-built tri-axial accelerometer sampling at a rate of 100Hz. Player Load measures instantaneous rate of change in acceleration, helping to separate work loads of different types of movement in sports. Player Load values are divided by a scaling factor to produce a figure of approximately 1000AU for a full football match. Figure 3.1 below details the formula equation for the running-based accumulated player load variable.

$$\text{Player load} = \sqrt{\frac{\left(a_{y1} - a_{y-1}\right)^2 + \left(a_{x1} - a_{x-1}\right)^2 + \left(a_{z1} - a_{z-1}\right)^2}{100}}$$

where

$a_y$ = Forward accelerometer
$a_x$ = Sideways accelerometer
$a_z$ = Vertical accelerometer

*Figure 3.1 – Calculation equation of accelerometer Accumulated Player Load*

### *Statistical Analysis*

Statistical analyses of results were conducted on SPSS for Windows version 17 (SPSS Inc. Chicago, IL, USA). Normality of the data was assessed by the skewness and kurtosis of the variables listed below. The skewness score was divided by the standard error of skewness and the kurtosis divided by the standard error of kurtosis. The *z* scores produces were used to confirm normal distribution, between +2 and -2. Differences between first and second halves were determined using paired sample *t*-tests, whereas positional differences were determined using one-way analysis of variance (ANOVA) with repeated measures. The variables compared by position and for the whole team were that of mean total distance covered, high-intensity, very-high intensity and sprint distances, accumulated player load and heart rate. Each of these variables was also analysed between first and second halves of a match. High-intensity running was also analysed in 5 minute periods using repeated measures ANOVA. Significant paired mean differences were identified using Bonferroni's *post-hoc* tests, with significance levels set at $P < 0.05$. Coefficients of variation were obtained by dividing the standard deviation by the mean and multiplied by one hundred to produce a percentage figure.  Results data are presented as means and standard deviations.

## 3.3 Results

### *Activity Profile*

The average percentage of time spent in different locomotor categories is presented in Table 3.5 and Figure 3.2. During match-play players spent 26.1 ± 11.7% of total time standing. Low-intensity activity accounted for 67.2 ± 11.7% of total match time, comprising of 34.8 ± 8.9% jogging and 32.2 ± 6.7% of time spent walking. High-Intensity running activity therefore consisted of 6.4 ± 2.3% of total time, 3.2 ± 1.1% of which was at very-high intensities and 0.8 ± 0.4% of time was spent sprinting.

*Table 3.5 – Percentage of time spent exercising at low and high intensities*

| Activity | | First Half | Second Half | Match Total |
|---|---|---|---|---|
| | | % Time | % Time | % Time |
| | Standing | 25.5 ± 14.8 | 27 ± 7.9 | 26.1 ± 11.7 |
| Low-Intensity Activity | Walking | 31.7 ± 6.5 | 33 ± 6.8 | 32.2 ± 6.7 |
| | Light Jogging | 28.8 ± 8.5 | 27.5 ± 4.9 | 34.8 ± 8.9 |
| | Jogging | 7.1 ± 2.3 | 6.3 ± 1.7 | |
| | **LIR Total** | **67.6%** | **66.8%** | **67%** |
| High-Intensity Activity | HIR | 6.8 ± 1.4 | 6 ± 2.5 | 6.4 ± 2.3 |
| | VHIR | 3.3 ± 0.6 | 3 ± 1.3 | 3.2 ± 1.1 |
| | Sprinting | 0.8 ± 0.4 | 0.6 ± 0.4 | 0.8 ± 0.4 |
| | **HIR Total** | **6.8 %** | **6 %** | **6.4%** |
| | **Total** | **99.9** | **99.8** | **99.5** |

*Table 3.6 – Match performance parameters*

|  | **Walking**<br>(0.6-4km/h) | **Light Jogging**<br>(4-12km/h) | **Jogging**<br>(12-15km/h) | **HIR**<br>(>15km/h) | **VHIR**<br>(>18km/h) | **Sprinting**<br>(>25km/h) |
|---|---|---|---|---|---|---|
| **Frequency*** | 319 ± 17.4 | 202 ± 12.2 | 331.7 ± 17 | 135.3 ± 34.3 | 60.3 ± 15.9 | 9.8 ± 4.3 |
| **Total Duration** | 1739.1 ± 83 | 1511.4 ± 188 | 1874.1 ± 110.6 | 344 ± 66.4 | 169.83 ± 32.1 | 42.8 ± 0.4 |
| **% Total Time** | 32.2 ± 6.7 | 28 ± 7.1 | 34.8 ± 6.2 | 5.8 ± 1.5 | 3 ± 0.9 | 0.8 ± 0.4 |
| **Total Distance (m)** | 2318.2 ± 61.2 | 3704.6 ± 496 | 1342.9 ± 213.8 | 1593.1 ± 397.8 | 817.1 ± 207.8 | 137 ± 60.6 |

**Describes number of efforts perfomed within specific velocity band in match-play*

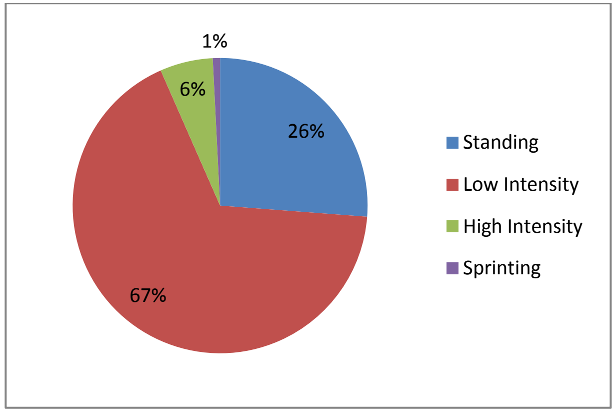

*Figure 3.2 – Percentage of time spent in different locomotor categories*

### *Distance Covered*

The mean total distance covered during a match over the course of the season was 9423 ± 1127m (range: 7223-12158m). The coefficient of variation for total distance covered was found to be 12%. The distance covered between halves was found to be significantly greater in the first half compared to the second (4855 ± 714m vs. 4562 ± 647m, $P < 0.01$). This was a reduction in distance covered of 293m or 6%.

### *High-Intensity Activity Profile*

At high-intensity, the mean distance covered over the course of a whole match was 1593 ± 397m (Table 3.6), 17% of total distance. Coefficient of variation for HIR for a match was 24.9%. Mean very high-intensity distance was 817 ± 208m with, 8.6% of the total distance covered. Coefficient of variation was 25.4%. Sprint distance for a match was 137 ± 60m, coefficient of variation 44%.  Sprinting accounted for 1.5% of total distance covered. The mean peak distance covered at high-intensity in a 5-minute period was 142 ± 66m. The subsequent 5-minute period saw a significant 46% decrease in high-intensity running (76 ± 52m, $P < 0.01$), which was calculated to be 18% below the average high-intensity distance in a 5-minute period for the entire match (90 ± 22m, $P = 0.96$). The final 5 minutes in a match involved 66 ± 36m HIR on average, 36% below the match mean ($P = 0.14$).

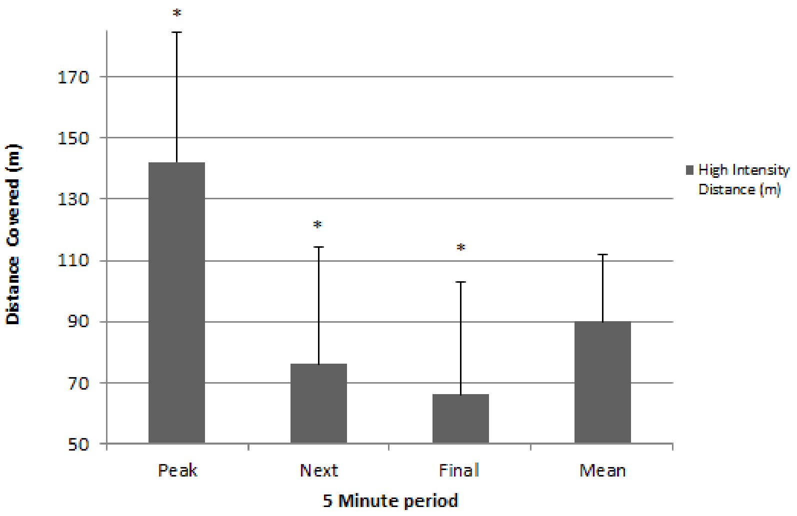

*Figure 3.3– Peak high-intensity running in a 5 minute period (* Significantly different to mean value, P < 0.05).*

The average number of high-intensity efforts during a game was found to be 135 ± 34. Frequency of very high-intensity efforts during a match was 60 ± 16 while the number of sprinting efforts on average during a game was 10 ± 4.

### *Accumulated Player Load*

The median accumulated player load for a match was 909 (interquartile range 342), with the mean load 567 ± 131 in the first half, decreasing 16% to 427 ± 147 in the second period ($P < 0.01$). The coefficient of variation was 24.9% between matches.

### *Heart Rate*

The average heart rate for match play was 164 ± 8 bpm$^{-1}$ (86.3%HR$_{max}$). The mean was statistically greater in the first half compared to heart rate in the second half of a match (165 ± 10 bpm$^{-1}$ vs. 164 ± 7 bpm$^{-1}$, 87.8 vs. 86.7%HR$_{max}$, $P < 0.01$). This represented a 1.2% decrease in mean heart rate between the two halves in match play.  Coefficient of variation for heart rate between matches was 5.9%.

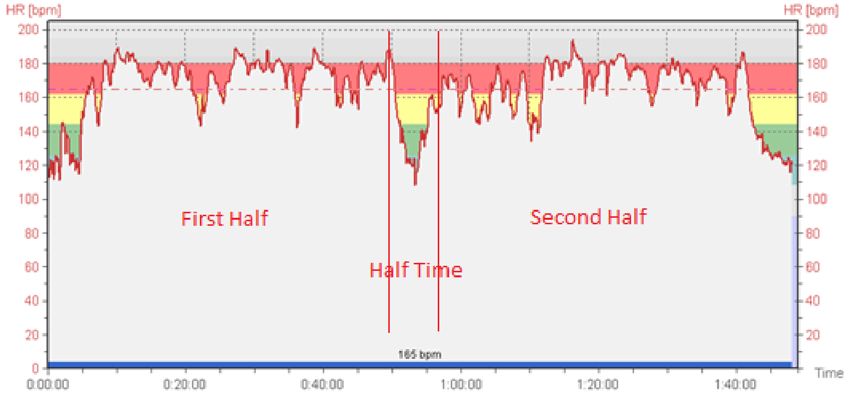

*Figure 3.4 – Example heart rate trace of a central defender during match-play*

### *Positional Differences*

Positional differences examined in previous studies of elite soccer were also evident in the motion analysis of amateur soccer players (Table 3.7). Positional variations were found in parameters such as total distance covered, high-, very-high intensity and sprint distance covered, heart rate and player load scores. Some statistical differences were also found between positions. Any differences between positions help to accounting for match-to-match variability across the season that would then contribute to the SSEP validation, simulating match-play of this squad.

*Table 3.7 – Total distance and distances covered at high and very high-intensity and sprinting and peak velocity achieved by each positional group*

| | **Wide Defence** | **Central Defence** | **Wide Midfield** | **Centre Midfield** | **Striker** |
|---|---|---|---|---|---|
| **Total Distance (m)** | 9166 ± 858 | 9103 ± 930 | 10024 ± 1084[a] | 10466 ± 1002[b,c] | 8477 ± 630 |
| **High Intensity Running (m)** | 1450 ± 340 | 1397 ± 357 | 1668 ± 378 | 1970 ±480[c,d] | 1532 ±137 |
| **Very High Intensity Running (m)** | 742 ± 192 | 771 ± 250 | 808 ± 217 | 920 ± 226 | 852 ± 103 |
| **Sprinting (m)** | 140 ± 51 | 146 ± 84 | 131 ± 55 | 125 ± 49 | 142 ± 59 |
| **Average Peak Velocity (km/h)** | 27.7 ± 1.3 | 27.3 ± 0.9 | 27.6 ± 1.0 | 27.5 ± 0.9 | 27.5 ± 0.6 |

[a] – significantly different to Striker ($P < 0.01$); [b] – significantly different to Central Defender and Striker ($P < 0.01$); [c] – Significantly different to Wide Defender ($P < 0.05$); [d]- significantly different to Central Defender ($P < 0.01$).

### *Accumulated Player Load*

The final Accumulated player load was also greatest in central midfield players (1276 ± 143), higher than central defenders, wide defenders and midfielders and strikers (1024 ± 289; 917 ±123; 882 ± 194 and 780 ± 110, $P > 0.05$).

### *Heart Rate*

No statistical differences were found between the average heart rate of different positional roles. Although there was a trend for central defenders to have a lower average heart rate in a match (161 ± 8bpm$^{-1}$, 85.4%), compared to wide defenders (165 ± 8bpm$^{-1}$, 88.8%HR$_{max}$), central midfielders (165 ± 8bpm$^{-1}$, 87.8%), wide midfielders (165 ± 8bpm$^{-1}$, 87.6%), and strikers (164 ± 7bpm$^{-1}$, 86.5%).

## 3.4 Discussion

The results of the present study show the extent of the physical demands of competitive amateur soccer match-play to be relatively high. As a result it is possible to use the data presented to compare how motion characteristics of the amateur game differ with respect to the elite level populations employed in earlier studies (Reilly, 1976; Bangsbo, Norregaard and Thorsoe, 1991; Bangsbo, 1994a; Mohr, Krustrup and Bangsbo, 2003; Rampinini *et al.* 2007; Di Salvo *et al.* 2009 and Gregson *et al.* 2010). The results may also form the basis of directly validated Soccer-Specific Exercise Protocols that simulate both internal and external loading of competitive amateur match-play.

In the present study, motion analysis found mean total distance covered in a match to be 9423 (SD = 1127m), 14% lower than that found by Bradley *et al.* (2009) in the English Premier League and 21% lower than that in La Liga in Spain (Di Salvo *et al.* 2009). However, this was still in the range of 8-13km covered in a match suggested by the classical study of Reilly and Thomas (1976). Distance covered declined by 6% between halves which is within the 5-10% reduction reported by Bangsbo (1994a) suggesting reduced work rate in the second period as seen in elite studies. This may be an effect of transient fatigue that has manifested gradually over the course of the match (Bradley *et al.* 2009). However, previous research has suggested that the notion of high-intensity running, in terms of distance and ability to execute repeated bouts more frequently, is a more valid indicator of physical match performance (Bangsbo, 1994a; Rampinini *et al.* 2007). Distance at high-intensity for the present study was 1593 (SD = 397m) accounting for 17% of total distance, compared to 18% in high-level soccer players by Bradley *et al.* (2010). The coefficient of variation in the present study was found to be

25%, also within the 16-30% variation in high-speed activities found by Gregson *et al.* (2010). However, one previous study has highlighted the difference between sampling rates of semi-automated tracking systems (25Hz) and GPS (5Hz) and the bias they may bring by under or over-estimating distances covered in different studies. Harley *et al.* (2010) found total distance covered to be 7% higher in GPS with the semi-automated tracking system producing a sprint distance 68% higher than that of GPS. This highlights that caution should be taken when comparing systems of different sampling rates for locomotion at higher intensities, particularly above 25km/h where some studies have questioned GPS reliability (Randers *et al.* 2010; Harley *et al.* 2011). To this end, Gregson *et al.* (2010) employed discreet sprint categories in order to distinguish between different types of sprint activities more effectively. Similarly, Randers *et al.* (2010) found only a 1% difference using the same two systems to measure distance covered but high-intensity distance covered was 24% higher in the semi-automated system. It must be noted however that both studies observed only one match reducing the strength of the data and further observations may be required to justify the findings between tracking methods of differing sampling rates. Furthermore, the author acknowledge that although the match observations are greater than previous studies, the use of a minimum of three observations per player in the present study may still not be enough to account for coefficients of variation present that has been suggested by Gregson *et al.* (2010). It has also been advised that analysis of at least thirteen matches should be more sufficient to more accurately account for individual match-to-match variations (Gregson, unpublished data, 2012). Despite this limitation, the subsequent study is the first to validate a laboratory-based study using motion-analysis for a soccer squad data from a whole season.

The present results indicate that there is indeed a clear requirement for the ability to maintain aerobic performance in amateur soccer matches, although this is lower than elite matches where high-intensity efforts occur approximately 250 times per match (Mohr, Krustrup and Bangsbo, 2003) compared to the mean of 135 efforts in this study. Furthermore, its validity as a gauge of performance is vindicated with high-intensity activity distance seemingly quite variable between matches.

Average heart rate for match-play indicated a level of cardiovascular strain in amateur soccer. Heart rate was found to average 164bpm$^{-1}$, similar to the 166bpm$^{-1}$ reported in university-level players by Ali and Farrally (1991), although this was also based on one match. As a result and individual variability in heart rate responses may not be sufficiently taken into account. In addition to a smaller sample of match observations the difference between the two studies may also be due to the fact that the present study analysed more players ($n$ = 20 vs. $n$ = 9). The average heart rate was within the intensity (86%HR$_{max}$) previously suggested for soccer match-play of between 80-90%HR$_{max}$ (Stolen *et al.* 2005) and also relatively close to the 170bpm$^{-1}$ reported for elite level players by Bangsbo (1994a), indicating a similar internal load as a result of intense intermittent exercise. This was supported by the high external load of accelerometery data collected during matches. The average of 994AU for accumulated player load helps to give an idea of the level of mechanical load that accompanies the high physiological exertion of competitive amateur soccer matches.  These results may justify the inclusion of measuring non-uniform locomotor activities, such as sport-specific skills and impacts experienced during matches with accelerometers of a high sampling rate to detect changes in force and direction (Boyd, Ball and Aughey, 2011).

Although patterns in total distance covered in relation to positional differences were not all that dissimilar between elite and amateur it does not adequately discriminate between levels of performance. The next chapter will utilise the average time and distances spent at different intensities in Chapter 3 to form a squad-specific SSEP that simulates physiological and mechanical load. Although positional differences were found in distances for some locomotor activities, they will not be specifically utilised in the development of USAFT$^{90}$ as the simulation is aimed at being squad-specific rather than position specific and as such may be a limitation of this study. The differing fitness characteristics of certain positions may potentially skew responses to the simulation as some positions may be able to cope with the squad-specific test more easily than others (Krustrup *et al.* 2003), eliciting lower loading values on completion of the simulation. Moreover, any fatigue-related decrements observed between halves in physical and physiological parameters will not be taken into account when devising the 90 minute test, which is also a limitation.

The ability to develop even more reliable simulations of soccer matches by including external loading from utility actions as well as traditional heart rate measures of the same population is greatly beneficial. This way the energy expenditure and musculoskeletal loading can be simulated more realistically for intervention strategies and testing physical proficiencies in rehabilitation.

## 3.5 Conclusion

The present study is one of the first to report the physical demands and work-rate of competitive amateur soccer match-play through the use of heart rate, GPS and accelerometry data to examine exercise intensity and presence of fatigue, allowing for more reliable soccer-specific simulations to be developed. Many studies have focused on elite players with few on amateur, yet patterns in match-play have been found to be similar although to a lesser extent, perhaps due to lower experience and training status in comparison. With the help of heart rate technology, GPS and accelerometry, running activities and game-related movements can be monitored to help in developing a simulation of internal and external loading of competitive soccer match-play (i.e. USAFT$^{90}$).

In summary, the results showed that although demand is not as high as elite soccer, amateur soccer has similar demands and requirements throughout a 90 minute match, with fatigue affecting performance and locomotor activity in the second half and towards the end of a match. The data in this chapter provides the basis for the following experimental chapter and will be utilised to develop a soccer-specific simulation of physiological and mechanical match demands by direct validation of participants from the same soccer squad.

# Chapter 4

# Soccer-Specific Match Simulation ($USAFT^{90}$)

## 4.1 Introduction

The unpredictable nature of soccer's complex intermittent activity pattern has been the focus of numerous research studies. Its unique make up of fitness and skill elements combine to create a significant demand on players in terms of energy cost and load that dictate subsequent motion-profiles.

Motion analysis has been heavily used in order to quantify how work rate can vary between teams and individuals. The data collected from motion analyses has then been utilised to develop soccer-specific simulations in both laboratory and field environments. However, the replication of match activity profiles and physiological load together has so far been unsuccessful. Some studies have simulated match locomotor patterns on treadmill-based protocols with some degree of success but not matched by the physiological load (Grieg, McNaughton and Lovell, 2006) observed in match play (Bangsbo, 1994a). Based on only a single match observation, Thatcher and Batterham (2004) produced an SSEP that used match-velocities from video recording programmed to a non-motorised treadmill. This was a more appropriate method of 'direct-validation' using the same population for data collection and testing purposes. Despite the lack of utility and sport-specific actions, and perhaps the limited match data collected, physiological responses were found to be close to those previously reported in competitive match-play with heart rate, 166bpm$^{-1}$ vs. 171bpm$^{-1}$ (Bangsbo, 1994a). The close agreement may be because the study employed a non-motorised treadmill, increasing energy cost through the necessity of the participant to drive the belt themselves.

The Loughborough Intermittent Shuttle Test was also developed (Nicholas, *et al.* 2000) in order to simulate the work-rate of soccer. The test involved running to commands dictated by audio CD, employing running of varying intensities over the 20m track, that derive from original match analysis by Reilly and Thomas (1976) and Withers *et al.* (1982). The test, however, does not incorporate the utility movements typical of competitive match play, therefore lowering the energy demands on the player and thus, the specificity of the test. Several limitations are often noted with such protocols. Depending on their setting, laboratory or field, these include the omission of utility movements that have changes in acceleration or deceleration and direction with lateral movements, and over-estimated activity durations and intensities (Drust, Reilly and Cable, 2000). This is compounded by the application of dated match-play data with a study population of differing characteristics. This is inappropriate, largely due to the fact that the style of play in professional soccer has greatly evolved each year, with their being greater emphasis on off the ball movement and high-intensity efforts coupled with a reduction in average recovery time (Reilly, 2003; Bradley *et al.* 2009).

The development of the SAFT$^{90}$ protocol (Lovell, Knapper and Small, 2008) sought to introduce a more soccer-specific simulation of match-play by including multi-lateral movements typical of soccer. Physiological measures of core temperature, blood lactate, heart rate and oxygen consumption were all measured from the 90 minute simulation. However, heart rate (162bpm$^{-1}$) and oxygen consumption (69%) were perhaps slightly lower than previously reported for match-play in soccer. Furthermore, the subject population used were semi-professionals, performing the protocol based on data and speed thresholds deriving from Prozone® data of elite soccer players. As a result it is difficult to draw conclusions as to the effectiveness of the protocol as the participants were different to the testing sample and have inferior physical fitness characteristics. Given such limitations of these studies, a more logical approach to developing and validating soccer-specific exercise protocols is necessary. Therefore, the aim of this study is to utilise the motion analysis data of University level soccer players (collected in the previous chapter) to create a squad-specific version of SAFT$^{90}$. The player's responses to the simulation will be compared by analysis of internal (heart rate) and external (accelerometer) loads to those reported in match-play. If validated, the squad-specific USAFT$^{90}$ would provide an effective tool for rehabilitation purposes and to examine intervention strategies for nutrition, hydration and thermoregulation, in 90 minute soccer match-play.

## 4.2 Pilot Testing

Before the protocol was carried out on the study sample, pilot testing was carried out in order to clarify the distances, velocities and times that were used in the USAFT$^{90}$ during the validation trials. The course was run by 2 healthy males (age: 22 years; height: 181.7 ± 6.7cm; weight: 79.6 ± 11.6kg; $VO_{2max}$: 60 ± 6 ml.kg.min$^{-1}$). Wearing the same 5Hz GPS units (Catapult MinimaxX, Australia) as in Chapter 3, each ran the course with 3 repetitions of each match activity to clarify the velocities and times at which each bout of activity was run in relation to the data collected from matches over the season by GPS. This was carried out over the distances of the test course (20 and 25m).

The test CD was created by using the mean total distance for the whole match for each speed zone (i.e. standing and zones 1-6) from the data in Chapter 3 as well as the average time, frequency and average velocity employed in each of these zones. The standing and walking distances and high- and very-high intensity distances were then added together with the percentage of total distance in each locomotor category calculated to produce the movement commands for the test; standing and walking, jogging, striding and sprinting (Table 4.1). The total times spent in each of these categories in a match were divided by six to produce the time for each one in a 15 minute period (the test CD duration, Figure 4.1). The total distance covered in a 15 minute period in each speed category was then divided by the distance of the test track (25m ‘up, or 20m ‘back’). The time deduced for each movement category was found by dividing the total time by total frequencies for the 15 minute period which also enabled speed to be confirmed through the equation speed = distance / time.

*Table 4.1 - USAFT$^{90}$ activities and velocities*

| **Activity** | **USAFT$^{90}$ Velocity (km/h$^{-1}$)** |
|---|---|
| Standing | 0 |
| Walking | 5.76 |
| Jogging | 7.76 |
| Striding | 14.16 |
| Sprinting | 19.83 |

Each speed zone was then classified into five locomotor categories based on the match data from which the original protocol was devised; standing, walking (0-6km/h$^{-1}$), jogging (6-15km/h$^{-1}$), striding (15-25km/h$^{-1}$) and sprinting (>25km/h$^{-1}$) and the distance, time, frequency and average velocity were then calculated for these over the course of a full 90 minute game. The pattern of different intensity zones was produced in accordance with the match data collected in the first study. For the sprints in the simulation, 20m sprint tests were conducted, with every member of the squad performing 5 sprints.

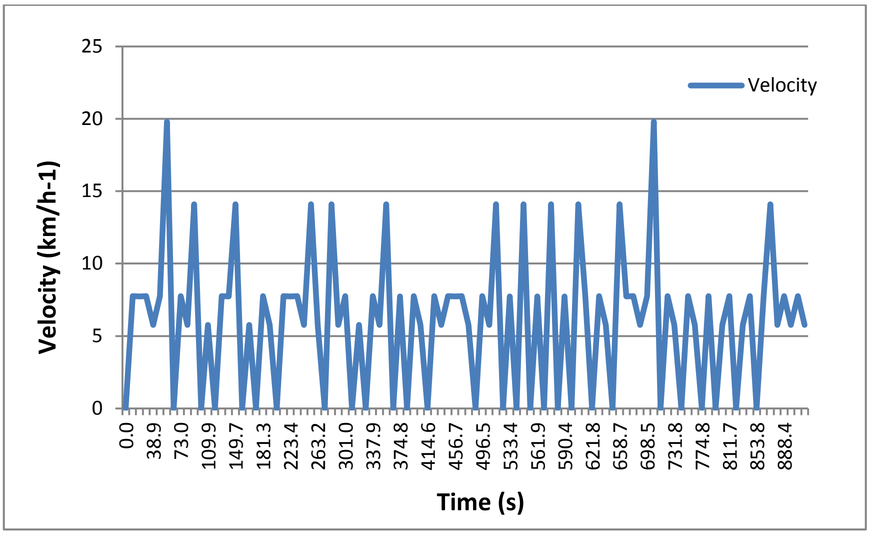

*Figure 4.1 – Representation of 15 minute cycle of USAFT$^{90}$ velocities and activities*

The average times taken to complete the sprints by the squad were then used as the time permitted for the sprints in the simulation. Times were measured using timing gates (Smart Speed, Australia).

*Table 4.2– Frequencies, durations and distances of USAFT$^{90}$ activities*

| | Standing | Walking | Jogging | Striding | Sprinting | TOTAL |
|---|---|---|---|---|---|---|
| **Frequency per 15 mins** | 28 | 23 | 35 | 10 | 2 | 98 |
| **Frequency per 90 mins** | 168 | 138 | 210 | 60 | 12 | 588 |
| **Time per bout (s)** | 6.3 | 12.5 | 32.5 | 12.7 | 3.63 | 67.63 |
| **Total Activity Time (s)** | 1058.4 | 1725.0 | 2284.2 | 381 | 43.6 | 5492.16 |
| **Total Activity Time (mins)** | 17.6 | 28.8 | 38.07 | 6.35 | 0.7 | 91.57 |
| **Total Distance per 15 mins (m)** | 0 | 460 | 820 | 250 | 40 | 1570 |
| **Total Distance per 90 mins (m)** | 0 | 2760 | 4920 | 1500 | 240 | 9420 |

The sprint tests were conducted on a ‘third generation’ rubber pitch surface, identical to that used in the running of the protocol itself, allowing for players to wear the same footwear as they would in a match.

The data produced from match play in Chapter 3 used was applied to the framework of the original SAFT test in terms of the activity pattern, with the frequency, time and velocity employed for each running activity specific to the squad tested from their match data (Table 4.3).

*Table 4.3 – Match activities of USAFT$^{90}$ and competitive match play*

| | **Frequency** | | **Duration (s)** | | **% Duration** | | **Total Distance (m)** | | **% Total Distance** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Activity** | USAFT$^{90}$ | *Match* | USAFT$^{90}$ | *Match* | USAFT$^{90}$ | *Match* | USAFT$^{90}$ | *Match* | USAFT$^{90}$ | *Match* |
| **Standing (0-0.7km/h$^{-1}$)** | 168 | - | 1058.4 | 248.14 | 19.2 | 4.36 | 0 | 329 | 0 | 3.5 |
| **Walking (0.7-6km/h$^{-1}$)** | 138 | - | 1725.0 | 3150.82 | 31 | 55.42 | 2760 | 2318 | 29.3 | 24.6 |
| **Jogging (6-15km/h$^{-1}$)** | 210 | - | 2284.2 | 1915.82 | 42 | 33.69 | 4920 | 5046 | 52.2 | 53.4 |
| **Striding (15-25km/h$^{-1}$)** | 60 | - | 381 | 344.36 | 7 | 6.06 | 1500 | 1593 | 15.9 | 16.9 |
| **Sprinting (25-40km/h$^{-1}$)** | 12 | - | 43.6 | 26.55 | 0.8 | 0.47 | 240 | 137 | 2.5 | 1.5 |
| **Total** | **558** | **-** | **5492.2** | **5680.69** | **100** | **100** | **9420** | **9423** | **99.9** | **99.9** |

## 4.3 Methods

### *Subjects*

Six participants from the university male soccer squad who had completed at least 3 full 90 minute matches over the course of the season in Chapter 3 were then required to perform USAFT$^{90}$ once each ; *n* = 2 defenders, *n* = 2 midfielders, *n* = 2 strikers (age: 20.6 ± 1.8yrs; height: 185.2 ± 10.6cm; weight 83.4 ± 7.0kgs). Using paired sample *t* tests the mean motion analysis characteristics of six participants from match-play were not statistically different from the remainder of the subject squad used to create the USAFT$^{90}$. Total Distance of the six players was 9387 ± 1077m compared to the squad 9423 ± 1127m ($P > 0.05$), whereas high-intensity distance was 1567 ± 681m and 1593 ± 397m ($P > 0.05$).

### *Exercise Protocol*

The intermittent activity pattern was dictated by commands from a 15 minute audio CD consisted of two 3 x 15 minute periods with a full 15 minute half time period. Figure 4.2 shows a schematic representation of the course design, with agility poles at 2, 9, 10 and 11 m of the tracks full length of 20m which the player must negotiate.

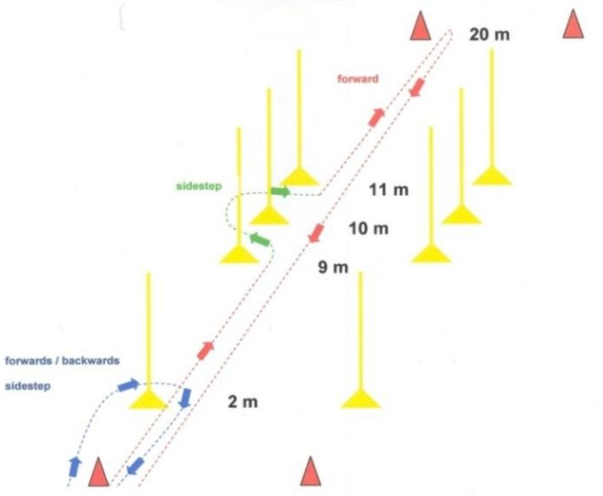

*Figure 4.2 – Schematic representation of USAFT$^{90}$ course*

*(reproduced from Lovell, Knapper and Small, 2008)*

Prior to the test all subjects performed a standardised 15 minute warm up involving linear and lateral mobilising movements of increasing tempo as well as static and dynamic stretching. The test involved an intermittent activity pattern that also incorporated multilateral movements associated with soccer that served to improve the replication of movements experienced during competitive match environment. The various intensities that are required in the test are similar to traditional locomotor descriptions used in previous studies (Lovell, Knapper and Small, 2008; Mohr, Krustrup and Bangsbo, 2003); standing, walking, jogging, striding and sprinting (Table 4.4). However, the time allowed to perform each activity was modified to replicate the average match data in order to reproduce their physiological and mechanical demands.

As in Chapter 3, the subjects were again fitted with the same GPS and heart rate monitors for the duration of the 90 minute field test. The test was conducted in an indoor facility that had an artificial grass surface to ensure a closer simulation of natural grass pitches used in match-play allowing the subjects to wear their normal football boots worn in matches (Figure 4.3). This surface is also justified by research by Andersson, Ekblom and Krustrup (2007) who found movement patterns in male and female elite Swedish soccer players to be similar to those employed on natural grass surfaces. During the 15 minute half-time, subjects rested passively and were allowed to consume fluid freely.

*Figure 4.3 – USAFT$^{90}$ field-testing set up*

## *Statistical Analysis*

Statistical analyses of results were conducted on SPSS for Windows version 17 (SPSS Inc. Chicago, IL, USA). Normality of the data was assessed by the skewness and kurtosis of the same variables listed below. The skewness score was divided by the standard error of skewness and the kurtosis divided by the standard error of kurtosis. The *z* scores produces were used to confirm normal distribution, between +2 and -2. Differences between first and second halves were determined using paired sample *t*-tests, with comparisons between physical responses to the field test and match-play compared using the same method. The same paired sample *t* tests were used to compare heart rate and player load data between match-play and the USAFT$^{90}$ protocol. A Bonferroni *post-hoc* test was applied to the *P* value derived from the *t* test, with significance set at $P < 0.05$. Results data are presented as means and standard deviations.

## 4.4 Results

### *Heart rate*

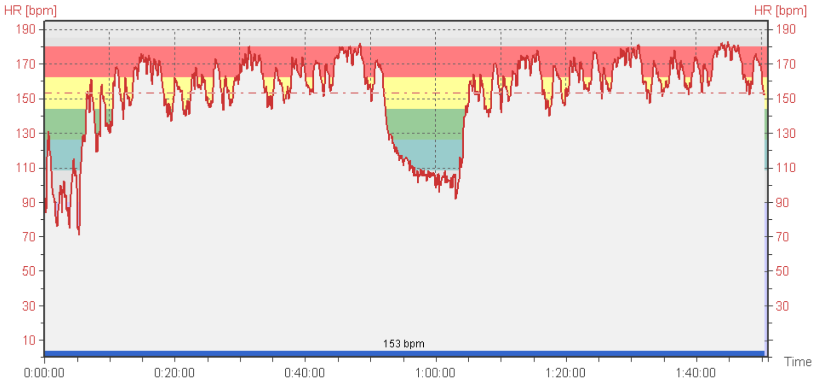

*Figure 4.4 – Example heart rate curve of central defender for the USAFT$^{90}$*

The average heart rate for the entire 90 minute duration of the USAFT$^{90}$ was 162 ± 6bpm$^{-1}$ (85.3%HR$_{max}$). In comparison, the average heart rate was 164 ± 8 bpm$^{-1}$ (86.3%HR$_{max}$) during match-play (Figure 4.5).

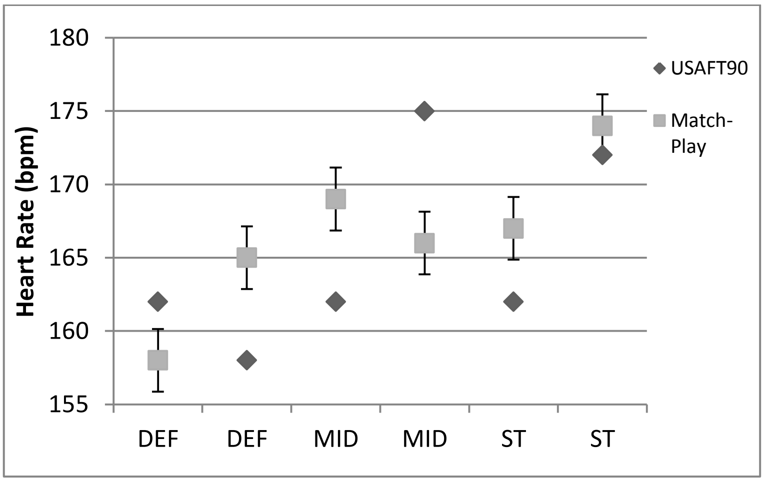

*Figure 4.5– Mean heart rate of USAFT$^{90}$ and match-play*

*Accumulated Player Load*

The average accumulated load in the USAFT$^{90}$ independent of position was 1067 ± 152. In match play the total accumulated load was 994 ± 248 on average (Figure 4.6).

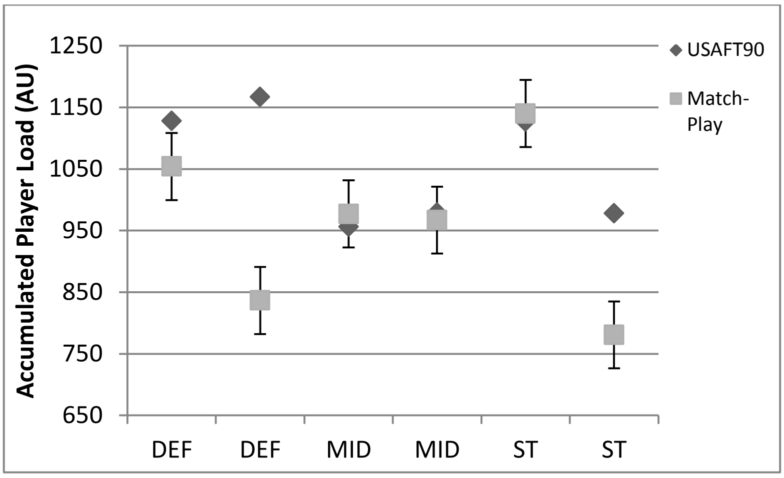

*Figure 4.6 – Mean player load of USAFT$^{90}$ and match-play*

## Match-Play and USAFT$^{90}$ comparison

The accumulated player load values were higher in USAFT$^{90}$ compared to match-play but the difference between the average of each activity was not found to be significantly different ($P = 0.42$). A correlation of -0.204 was found between player load values between match-play and SSEP with a significance of 0.138.

Average heart values for the ninety minute durations were not found to be significantly different between match-play and USAFT$^{90}$ ($P = 0.15$). A correlation of 0.247 was found between heart for match-play and SSEP.

## 4.5 Discussion

The results from the USAFT$^{90}$ showed the simulation was highly intermittent in nature similar to that of match-play. USAFT$^{90}$ incorporated locomotion of varying intensities employed in matches, from standing and walking to sprinting as were used in previous studies (Mohr, Krustrup and Bangsbo, 2003; Bradley *et al.* 2009). Furthermore total distance, as well as the time and distance spent exercising at each intensity was similar to the squads average data from match-play. The time spent exercising at high-intensity in matches has been reported to range between 1-10%, with the present study 6%, similar to the 6.6% found in moderate standard players by Mohr, Krustrup and Bangsbo (2003). The simulation had high internal and external physical demands on amateur soccer players and were relatively similar to those attained in match play by the same squad. Average heart rate for the test was similar to that reported in match-play in Chapter 3 (162 bpm$^{-1}$ *vs*. 164 bpm$^{-1}$), indicating a similar level of cardiovascular strain for a 90 minute match. However, this is slightly lower than the 170 bpm$^{-1}$ reported by Bangsbo (1994) in elite soccer players.

In terms of Accumulated Played Load measured through accelerometery, values were also relatively high and comparable to that attained by the subject squad in match-play (1067 *vs*. 994 AU, $P > 0.05$) suggesting a similar mechanical load, although lower than the 1215AU found by Casamichana, Castellano and Castagna (2012) using the same accelerometer. Obtaining such data may then also promote the use of accelerometers and the movements included in USAFT$^{90}$ specific to soccer match-play as they were able to simulate an external load that was representative of their matches analysed in Chapter 3.

Although a relatively week agreement was produced between heart rate and player load responses of match-play and USAFT$^{90}$, this could be due to influences positional differences. The motion analysis in Chapter 3 entailed a squad of 20 of various positions providing match-play data, whereas the simulation in this study only utilised 6 players, two from each position group, whereas Thatcher and Batterham (2004) used 4 players in each group. As was alluded to in Chapter 2, different physical capacities (such as $VO_{2max}$) between certain positions may influence physical performance and work rate reflected in their motion-profiles (Di Salvo e*t al.* (2007). A lower ability to deal with the simulated demands of the participants in USAFT$^{90}$ may then have contributed to the relatively weak agreement in heart rate and player load measures compared to the whole squad average from matches. As such this could be attributed to the small sample size that could have benefited from more participants to represent each position (Hopkins, 2000). Also, the simulation was completed several weeks after the end of the university soccer season and as such may have been affected by a lowered training status of the participants (Helgerud e*t al.* 2001). This may partly account for the decline in second half heart rate. Despite the simulation being of a fixed intensity, the cessation of training may have influenced a decreased ability to cope with the internal and external demands of one of their own simulated matches as well as there being no ball skills required which may compromise mechanical player load and metabolic cost (Reilly and Ball, 1984) in this study's simulation. Despite this, the method of the current study was different to those of previous SSEP's (Grieg, McNaughton and Lovell, 2006; Drust, Reilly and Cable,

2000) as it employed the same population for motion-analysis and simulation validation, trying to elicit the same physical demand of a university squad’s soccer matches. Furthermore, motion-analysis was carried out over a whole season to account for match-to-match variation and provide a more reliable representation of amateur soccer demands to simulate (Hopkins, 2000). The ecological validity of the process was consequently greater than that of previous attempts to simulate soccer matches in a controlled environment.

## 4.6. Conclusion

The USAFT$^{90}$ produced relatively high values for both heart rate and accumulated player load compared to those elicited in match-play in Chapter 3, although the agreement was still weak. These findings indicate that the USAFT$^{90}$ produces similar internal and external physical load in a closed environment compared to competitive match-play. This may have implications for researchers, fitness coaches and medics with the test lending itself to intervention studies and final stage rehabilitation settings. The use in rehabilitation should be done so with caution as the player load and heart responses were shown to be high in USAFT$^{90}$ and may exceed what an individual may achieve in a match, which could be seen as a limitation. However, the principles of training, more specifically ‘overload’ may also be adhered to in order to progress the player’s performance capabilities. In these instances the test represents a reliable simulation of the loading of competitive amateur soccer match-play with which to gauge the effect of implemented strategies to improve performance or one’s readiness to train safely.

# Chapter 5

# General Discussion

## 5.1 General Discussion

The aim of the present study was to monitor the physical demands of competitive amateur soccer and use average velocities of the squad achieved in match-play to then create a ‘squad-specific’ simulation of a competitive match in a controlled laboratory environment.

When comparing the results from motion analysis of match-play and the USAFT$^{90}$, heart rate and accumulated player load values were not significantly different (164bpm$^{-1}$ vs. 162bpm$^{-1}$; 993 AU vs. 1097 AU) but demonstrated a relatively weak statistical agreement ($P = 0.15$ and $P = 0.42$).

*Table 5.1 – Comparison of heart rate and player load in Match-Play and USAFT$^{90}$ (Mean ± Standard Deviation)*

| | **Heart Rate (bpm$^{-1}$)** | | | **Accumulated Player Load (AU)** | | |
|---|---|---|---|---|---|---|
| | **First Half** | **Second Half** | **Total** | **First Half** | **Second Half** | **Total** |
| **Match Play** | 165 ± 10 | 164 ± 7 | 164 ± 8 | 520 ± 131 | 474 ± 147 | 994 ± 248 |
| **USAFT$^{90}$** | 164 ± 5 | 162 ± 4 | 162 ± 6 | 596 ± 100 | 532 ± 108 | 1067 ± 152 |

Such a weak agreement may be due to the small number of participants completing the simulation and also the fact that positional differences are not taken into account in USAFT$^{90}$. Some positional roles may therefore have found the loading produced in the simulation less taxing than other positions of lower physical capacities. Despite this, in line with the aims of the study, using motion profiles of competitive match-play it is possible to simulate the internal and external loading of match-play in a controlled setting. Furthermore, the 90 minute test mirrors the average total distance covered in match-play (9420m vs. 9423m). There are also comparisons between the proportion of time spent at high-intensity between matches and simulation (6 and 7%), proportion of total distance at high-intensity (15.3 and 16.9%) and also the number sprinting efforts executed in matches (10 and 12 respectively). Employing locomotor activities of similar proportions then aids the validity and specificity of the methodology in utilising match data collected via GPS and accelerometry to replicate the physical demands of a 15 minute period to a full 90 minute university soccer match.

For this study 5Hz GPS technology in amateur soccer has been used to describe physical demands in match-play as was previously used in elite settings (Randers *et al.* 2010; Harley *et al.* 2011). The methodology of validating a soccer simulation using match-data of the same squad performing the protocol has made it possible for fitness coaches and sports scientists to reliably implement such a test with the intention of replicating mechanical and physiological demands on a player in the latter stages of rehabilitation to gauge readiness to train or compete by their ability to cope with a required loading, before re-commencing full training and competitive match-play. It may also be possible to test new intervention strategies, such as nutritional aids and the effect of strength and conditioning programmes. Changes may then be monitored by work-rate or internal and external load responses to the simulation. If changes are minimised, demonstrating a greater ability to cope with the simulation, it may be suggested that physical demands in competitive match-play are managed more easily.

## 5.2 Future Research

Future research may be directed to look more specifically at factors already described in the elite game relating particularly to the area of positional differences. Contrasts between positions regarding motion-analysis data were described in Chapter 3, however this was not specifically taken into account in Chapter 4 as USAFT$^{90}$ was aimed to be developed as a squad-specific simulation and took averages from the motion analysis data to then develop the test. The simulation could be developed further in future research in order to cater for *individual* physical capabilities specific to certain positions. This would be more beneficial on an individual level as depending on the player's position and style of play, USAFT$^{90}$ may be produce either excessive or reduced heart rate and player load values depending on how difficult the individual finds the simulation having been based on a squad average.

The use of more participants and match observations per player would also be favourable in validating the subsequent SSEP in developing individual motion-profiles. This would help to create specific simulations with regards to locomotor patterns and work rate as well as high-intensity activity for certain positions and also account for match-to-match variability of match performance parameters that further improves ecological validity and specificity. Furthermore this should allow agreement of heart rate and player load from match-play and SSEP to be improved.

# Chapter 6

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