

THE USE OF GPS TECHNOLOGY TO QUANTIFY THE GAME DEMANDS OF ELITE YOUTH SOCCER: IMPLICATIONS FOR TRAINING DESIGN.

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Dedicated to

Mrs Clarkson my year 4 primary teacher who said I wouldn't amount to anything

And

My Mother who didn't believe her.

ABSTRACT

The transition from academy to the professional level is one of the pivotal key stages in the development of elite professional soccer players and our understanding of this process is incomplete (Mills *et al.* 2012). A comprehensive detailed assessment of elite youth players match performance is limited and a clear gap in the literature exists which has consequences for the development programs of academy players (Harley *et al.* 2010). Global positioning systems (GPS) have been developed for use within a sports context to measure distance and velocity, however the methods employed for determining accurate capture conditions has not been examined and rely solely on historical criteria established before its use in dynamic sports such as soccer. The studies contained in this thesis are designed to further examine how an increase understanding of the match demands of youth soccer through the use of GPS technology to allow the development of highly tailored training programs to maximise the development of youth players.

The aim of the first study (Chapter 4) was to compare data collected using 5Hz GPS (MinimaxX, Catapult) and the ProZone™ (PZ) match analysis system and to establish satellite and Horizontal Dilution of Precision (HDOP) threshold limits to allow direct comparison between the two data sets. Ten elite outfield youth team players were monitored with PZ and GPS during a match and the data grouped into 10 minute capture periods and categorised into players who averaged a mean satellite lock of more than 5.5, 5, 4.5, and 4 over the ten minute period and a mean an HDOP of less than 1.8, 2, 3 and 4. The distance covered in each of the predetermined PZ speed categories were compared. The data showed significant differences ($p < 0.05$) in all of the capture categories with the exception of the less than 1.8 HDOP group ($p > 0.05$) with small to large effect sizes. These data therefore suggested that for the accurate assessment of high velocity running (>4m/s) using GPS a HDOP threshold of 1.8 be used.

Using the valid GPS capture conditions obtained in study 1, the aim of the second study (Chapter 5) was to quantify match play according to outfield playing position in elite youth soccer at a scholarship (U18) level and compare to First team players. Eleven Under 18 games were analysed using GPS. Total distance covered and the maximal sprinting speeds were comparable with first team players in addition to the type of sprint performed (leading or explosive). The very high intensity running distance was less than that of first team players (range 532 to 804m vs 632 to 1196m) with the youth performing less sprints (range 9 to 12 vs 23 to 44) and with each sprint over a longer distance (50% over 10m vs under 10m) . The data highlights that the acceleration profiles of youth players need to receive the greatest attention at Under 18 level for there to be successful progression to the elite level.

By highlighting the discrepancy in the number of sprints and the distance covered by elite youth players the purpose of study three (Chapter 6) was to adapt the Draper and Lancaster test (ADL) to soccer specific distances and determine its reliability and ability to discriminate between different levels of players. The reliability of the total time of the ADL proved to be highly reproducible (TE = 0.17, ICC = 0.99, CV = 0.7) along with the three sub-component tests (LE7m TE = 0.38, ICC = 0.93, CV = 1.6, 505 TE = 0.28, ICC = 0.96, CV = 1.3, and EX7m TE = 0.21, ICC = 0.98, CV = 1.2). In assessing the validity of the ADL test the national players showed that they were significantly quicker in the ADL (mean diff = 0.41, $t = 5.32$, $p < 0.005$, CI = 0.25, 0.57, $d = 1.4$) the EX7m (mean diff = 0.19, $t = 6.72$, $p < 0.005$, CI = 0.14, 0.25, $d = 1.76$) and 505 (mean diff = 0.14, $t = 3.27$, $p < 0.005$, CI = 0.05, 0.22, $d = 0.86$) sub component tests compared to the club level players but not in the 7mLE (mean diff = 0.05, $t = 1.79$, $p = 0.08$, CI = 0.01, 0.11, $d = 0.47$). The data demonstrate that the ADL test was reliable in test retest situations and a valid predictor of level of sport participation because it discriminated between players of lesser ability (club) and higher ability (national) and can be used in a football setting to assess the main fitness components (explosive speed, leading speed and agility) which have been highlighted as important in the elite game.

Extending on this work, the aim of study 4 (Chapter 6) was to investigate the application of the A505 field test for the assessment of functional asymmetries of the lower limb. Measurement of the fastest time for each side was recorded along with the peak torque of the hamstrings and quadriceps measured on an isokinetic dynamometer. The data showed that there were significant differences recorded in three of the four categories of the dominant side movements, concentric extension (Mean difference = 44.18, $t = 5.70$, $p < 0.001$, CI = 28.4, 60.1, ES = 1.57), concentric flexion (Mean difference = 4.17, $t = 3.29$, $p = 0.003$, CI = 1.58, 6.8, ES = 1.12) and eccentric extension (Mean difference = 35.71, $t = 3.50$, $p = 0.001$, CI = 14.9, 56.5, ES = 1.18) with the eccentric flexion group showing non-significant differences (Mean difference = 2.68, $t = 1.73$, $p = 0.094$, CI = -0.5, 5.8, ES = 0.66). The non-dominant side showed significant differences in all four, concentric extension (Mean difference = 37.07, $t = 6.41$, $p < 0.001$, CI = 25.1, 49.0, ES = 1.51) concentric flexion (Mean difference = 4.14, $t = 2.70$, $p = 0.011$, CI = 1.0, 7.3, ES = 0.95), eccentric extension (Mean difference = 34.90, $t = 3.49$, $p = 0.002$, CI = 14.5, 55.3, ES = 1.18), and eccentric flexion (Mean difference = 2.20, $t = 2.27$, $p = 0.031$, CI = 0.2, 4.2, ES = 0.85). The results suggest that the use of the A505 field test can determine asymmetries during functional dynamic movements in elite youth soccer players when compared to isokinetic assessment and as imbalances may have functional consequences which can lead to injury, therefore there is a need to examine how best to correct these.

Using the subjects from the previous chapter the aim of study 5 (Chapter 7) was to examine the effect of isolateral plyometrics (PT) and strength training (ST) to correct bilateral imbalances in youth academy players. Players were separated into a PT or WT group and performed training over six weeks. The non-dominant leg improved in its performance in the A505 field test whilst there was no improvement in the dominant leg. There was no overall difference between the training groups in either the dominant ($f = 0.026$, $p = 0.619$, $CI = -0.043, 0.026$ s, $\eta p^2 = 0.013$) or the non-dominant leg ($f = 1.946$, $p = 0.179$, $CI = -0.064, 0.013$ s, $\eta p^2 = 0.093$). However this partial improvement decreased the bilateral A505 ratio and it can be postulated, as suggested in the previous chapter, that this would reduce the likelihood of injury in the players.

In summary, the work undertaken from the studies in this thesis provides novel information in relation to the measuring of match performance when using GPS and the application of this information to the programming of training programmes with elite youth soccer players. It has also examined and validated the use of a simple field test to highlight bilateral lower limb imbalances and possible training programs to improve the bilateral ratio and to maximise the development of youth players.

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**E hara taku toa It is not of my own
ite toa takitahi but the greatness
e nagari taku toa of those who
e toa takitini. have supported me.**

(Tori Reid, All Black Captain)

To my wife Claire

'When I walk beside her I am a better man' (Vedder, 2007)

G. Close	Legend
D. Doran	Kia Kaha
B. Drust	Appreciated
A Sparks	Stats God

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ADL	Adapted Draper and Lancaster
AFL	Australian rules football league
CEP95	Circle error probable at 95%
COD	Change of direction
dGPS	Differential global positioning system
MCS	Multiple camera system
FA	The football association
FIFA	The Fédération Internationale de Football Association
GPS	Global positioning system
HDOP	Horizontal dilution of precision
PT	Plyometric training
PZ	Prozone
WT	Weight training
7mEX	Seven meter explosive test
7mLE	Seven meter leading test
HI	> 4m/s
SPR	Sprint
HSR	High speed run
VHSR	Very high speed run

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

Association Football (soccer) is played by over 120 million people, watched by billions of spectators world-wide and culminates in the quadrennial FIFA World Cup. Identifying and developing elite youth players is a central tenant of club structures and can be considered multifaceted with the core motivation for youth development being at clubs without huge financial resources, as the additional revenue stream from the sale of players is of tremendous importance and this is particularly evident in England where it is routine for players to be transferred between clubs in multi-million pound deals. By highlighting talented individuals at a young age, clubs are able to focus their resources into maximising the opportunities of these players to progress and develop through the academy structure (Williams and Reilly, 2000). Developing home grown players also has the added benefit of generating a greater local fan base, as locally developed players or 'local heroes' play an important role in enhancing fan interest and in attracting a greater number of spectators to home games (Brandes *et al.*, 2008).

In addition to the local interest, National Associations have a vested interest in the development of quality youth players to fill the positions of their national teams. In England the establishment of regional academies has led to large investment in the long term development of youth players (Football Associations Charter for Quality Act, 1997; Elite Player Performance Plan, 2011) which follows a similar national policy in France, where a central academy aided in the success of the national team (European [2000] and World cup winners [1998]). However, with a vast annual investment of over 40 million pounds in English youth soccer academies, it could be argued that there is a limited investment return, with an average of only 25-30 players under 23 years of age entering the premier league each year (Sagar *et al.*, 2010). As such, a greater understanding of the developmental process may lead to a greater return on the substantial national investment. Youth development has been further highlighted by the European (UEFA) and World Governing bodies (FIFA) proposing legislation to force clubs into developing local talent by restricting the practice of the bigger clubs 'buying up the talent'. UEFA has introduced a rule requiring a minimum of 8 home grown players in a first team squad of 25 players (UEFA, 2008), and FIFA has suggested the '**FIFA 6+5**' rule (FIFA, 2008), where each club must field at least 6 players per match who are eligible to play for the national team.

At the elite adult level the physiological demands of soccer have been extensively examined allowing for physical attributes and match norms to be established (Reilly, 2003) which provide guidelines for the appropriate training prescriptions and allowing for individualised programs to be developed to

increase their effectiveness (Di Salvo *et al.*, 2006; Di Salvo and Pigozzi, 1998). Despite the large amount of information on the adult game, which has highlighted the importance of high intensity work, there is limited understanding of youth soccer (Harley *et al.*, 2010). Whilst there continues to be an increased financial investment it has not been extensively examined to determine the demands imposed by match play or the determinants required for the modelling of training regimens, which must focus on specific locomotor skills and movement types (Reilly, 1994). The progression stage between academy and first team (Under 18) requires closer examination as a greater understanding of the demands of the game would provide benchmarking information to aid in talent identification and development (Vaeyens *et al.*, 2013) This would allow training to be adjusted to deliver specific programs that match the demands of the game since scholarship soccer provides the link from youth to the adult game and is of vital importance in the progression of players to first team squads (Jennings *et al.*, 2010ii).

In recent years Global positioning systems (GPS) have been developed for use within a sports context and due to its portability they can be used within a range of sports and environments (Frencken *et al.*, 2010). This has permitted teams to collect physical performance data however there is limited examination of the reliability and validity of the collected data within the literature (Jennings *et al.*, 2010ii). Whilst GPS technology is used extensively within team sport, the methods employed for determining accurate capture conditions, such as the number of satellites and the Horizontal Dilution of Precision (HDOP), a measure of the quality of the data collected, has not been examined and rely on historical positional criteria established before GPS use in dynamic sports such as soccer.

Once essential physical components have been highlighted it is important to be able to test and monitor them, in elite adult soccer high intensity running (>5.5m/s) and agility have been emphasised as important. For players to be successful they must achieve high levels of physical skill and therefore a training regimen that improves important fitness requirements could have a profound effect on the levels of performance during matches. Only by maximising physical attributes will players progress through the grades to the elite level, for the player who is faster, stronger and more powerful than his counterparts will have a greater chance of success in the professional game (Mayhew *et al.*, 2004). Whilst the varying movements conducted during actual match play highlight the dynamic nature of soccer, the type of testing that is often performed does not specifically address the dynamic multi-directional complexity of the game movements that the players perform. In addition the testing procedure that is often employed can be time consuming as multiple tests are often employed which focus on one component of fitness e.g. sprint, agility, speed endurance tests. What is required is the

development and analysis of a soccer specific test that will characterise elite Academy scholarship players based on match specific data. This is important because it will provide physical pathway indicators for players to progress and compete at the elite adult level.

Of major concern within the academy establishment is the incidence of Academy injury rates which is higher than the professional equivalent and increases linearly with age (Price *et al.*, 2004). It has been suggested that isolateral imbalances are a major contributor of injury and that it is of importance to highlight these imbalances and determine training routines in which they can be corrected (Fousekis *et al.*, 2010). Jones and Bampouras (2010) have demonstrated that lower limb imbalances can be identified using a functional unilateral (leg press) tests, however of interest to the fitness coach and physiotherapist is if a field test can reproduce these results. Once highlighted best practice strategies to correct unilateral imbalances is of high importance and of interest is the role in which weight training and plyometric training exercises can play, as these two modes of exercise are commonly employed within an elite soccer setting, though there is limited examination of this within the literature. Jullien *et al.* (2008) in a training study examined the effect of strength and agility training over 3 weeks and found no difference between the two modes of exercise, however the limited time frame and the general circuit exercise protocol may have limited improvement and did not consider unilateral differences in the players. Hence there is a need to examine these two training procedures and their effect on the correction of unilateral imbalances.

It is paramount that soccer conditioning/coaching programs concurrently improve performance and reduce the likelihood of injury. Such programs need to take a holistic approach to youth development and what is lacking in the literature is the research that provides accurate information as to the steps and markers of how elite youth players develop into elite adult players whilst achieving these two training outcomes (Vaeyens *et al.*, 2013).

1.2 AIMS, OBJECTIVES AND STRUCTURE OF THESIS

The aim of this thesis is to quantify the workload and establish the demands of the game at the elite scholarship level and provide information for which bench marks can be set for the developing youth soccer players when compared to First team data. Having determined movement profiles, a sport specific anaerobic (speed) field fitness test will be established which focuses on the high intensity agility requirements of the game and more accurately examines on field performance and which can observe and determine left versus right side discrepancies in. A further aim will be to establish the optimum training prescription in order to correct the imbalances and hence decrease the likelihood of injury and improve performance.

The aims of this thesis will be achieved by the realisation of the following objectives:

- a) To establish the validity of GPS in soccer by comparing to Prozone™ and determining accurate capture conditions within the GPS software (Study 1).
- b) To characterise elite Under 18 scholarship soccer by determining work rates and positional demands of the game at the elite scholarship level (Study 2).
- c) To develop a specific field test for soccer which accurately focuses on the requirements of the game (Study 3).
- d) To examine if the field test developed in study three can determine unilateral performance discrepancies (Study 4).
- e) Examine the effect of plyometrics and strength training on correcting unilateral imbalances (Study 5).

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The Premier League™ is telecast to over 250 different countries and generates over £3 billion in domestic television rights and almost double this in worldwide revenue. Whilst this huge financial investment creates an environment in which clubs can attract and employ the best players in the world, unfortunately this limits the opportunities for the domestic youth players. A pivotal stage in youth development in England is the transition from academy to professional, and it is here that the major focus of player development should be concentrated (Cote, 1999), however current understanding of elite player development is limited (Mills *et al.*, 2012).

In this chapter the reader is initially presented with a background understanding of the types of match analysis tools that have been historically used and an overview of some of the contemporary methods of capture followed by a critical review of the studies within the literature. It will provide background that will aid in the understanding of the first study which examines the inter-change ability of two of the most widely used systems in soccer (Prozone and Global Positioning Systems). An analysis of what is currently known about Academy scholarship players (Under 18) match performance, arguably the most pivotal stage in a player's development will be examined (Williams and Ford, 2009) and the research examining the injury rates amongst scholarship players will be discussed with the current trends in injury prevention strategies researched, which will aid the reader when examining the chapters that look at bilateral imbalances and possible interventions to improve them.

Whilst elite youth soccer has received an increase in the amount of research in recent times and whilst there will always be the 'gifted' athlete, current research suggests that elite soccer players are largely 'built' not 'born' (Mills *et al.*, 2012). Whilst providing an extended introduction and rationale as to the nature of the studies undertaken in this thesis it will draw the reader to the conclusion that the approach to youth development needs to take a holistic approach in which there is an improvement in performance whilst limiting the likelihood of injury. Whilst these views have in the past been in conflict with each other it is the authors' intention to show that the aim of any training program should be to be continually looking for the safest and most successful way to develop young players to the highest level (Johnson *et al.* 2008).

2.2 PERFORMANCE ANALYSIS SYSTEMS

Historically, most sporting analysis has been through pen and paper checklists due to its ease and low cost, however inter-observer bias and error can be an issue in the collection of data and it would typically focus on actions that are easily defined and observed, more recently video has been used with varying degrees of detail to provide post-game analysis (Hughes, 2008). Whilst video analysis can reduce the error and bias associated with the notation system by providing coaches and players the opportunity to watch the performances again (possibly from multiple angles), it also allows for more detailed analysis to be performed. However the detail obtained is directly related to the amount of time that the analyst spends on the data. Hence the main problem with historical methods are that they are extremely time intensive and by the time that the data is obtained it is often too late to be of benefit for the coach and player before the next game. Therefore this type of analysis is commonly reserved for university studies and has little practical benefit for the coach (Hughes, 2008).

To develop sports specific training and conditioning programs, in any sport, an accurate and comprehensive understanding is required of the demands placed on the player (Maslovat and Franks, 2008). This can be further scrutinised to differentiate between positional requirements to further enhance physical, as well as technical and tactical training. In recent times a number of computer driven analysis programs have been developed using image processing algorithms to simultaneously track all the players, referees and the ball every tenth of a second (O'Donoghue, 2008). In the English premier league the most common system is Prozone™ (PZ), which is semi-automated and uses a minimum of six fixed cameras at the team's main stadium to capture the player's actions during matches and can provide technical and tactical data as well as physical statistics within 24 hours.

Whilst PZ will provide valid and reliable data (Di Salvo *et al.*, 2006) its major limitation is its lack of portability and as such whilst detailed quantitative data can be collected for match play there is no information of the training intensity or load-in-training. The expense of the system also limits its availability outside of First team soccer and at present the only time that it can be used with Academy players is if matches are played in the clubs stadium. It can be argued that the coach can monitor good and bad technical performance of the players through the week, however the physical efforts can be more difficult to monitor and quantify. A number of methods have been used to try and determine the physical workload during training with Impellizzeri *et al.* (2005) indicating that the external load, the organisation of the quality and quantity of the training, affects the internal physiological load along with the individuals characteristics. Measurements include using Rate of

Perceived Exertion (RPE) scales (Borg, 1982), measuring hormonal responses and levels (Fry *et al.*, 1991) and most commonly the monitoring of heart rate (HR) (Achten and Jeukendrup, 2003). Whilst all these quantities may provide indicators of training state they do not provide any information of the actual work that has been performed.

2.2.1 Global Positioning Systems (GPS)

2.2.1.1 History and development

Global positioning systems (GPS) were developed in the 1960s for use by departments within the US government, specifically the department of defence (DOD) and the National Aeronautics and Space Administration (NASA) (Noureldin *et al.*, 2013). The goal of these projects were to determine a highly dynamic local three-dimension position within a system that had a continuous global coverage in all weather conditions with a high level of accuracy and within a military (missile delivery, search and rescue) context with positioning accuracies achieved to within 22m in the horizontal plane (Kaplan, 2006). GPS relies on a constellation of 24 satellites orbiting at varying trajectories that combined criss-cross to cover to surface of the earth, at any one time there are only a fraction of these satellites visible and to determine the global position the GPS receiver unit uses a simple calculation of how long a signal from a satellite takes to reach it and by using the signal from three satellites, the position can be obtained using a synchronised clock (Noureldin *et al.*, 2013). However manufacturers using GPS units within a sporting context have programed software to examine data achieving a minimum of four satellites and use an arbortary measurement called the Horizontal Dilution of Precision (HDOP) to provide the user with estimation of the quality of the data.

Whilst the original use of GPS was limited to US government departments, the technology became commercially available in the early 1990s and its use has increased exponentially and now finds a wide variety of commercial applications (Noureldin *et al.*, 2013). The increase in commercial use can be attributed to a number of factors, including: (1) the cost of the receiver units has drastically reduced, (2) the size of the receivers has reduced and (3) the accuracy of the positioning and velocity data has increased (Noureldin *et al.*, 2013). In 2001, GPS technology was developed for use in a sporting context and since this time a number of commercially available systems have become available due to advancements in GPS technology which have allowed individual units to become smaller and more powerful (Kennedy, 2002; Petersen *et al.* 2009).



Figure 2.1: Brian O'Driscoll wearing a GPS device during the 2013 Lions tour to Australia

The development of commercial sporting GPS technology began with 1Hz units and limited software to accompany it, however since 2008 5Hz units have been available and the technology has been incorporated with tri-axial accelerometers to provide additional information and more accurate data by factoring in game impacts and ground reaction forces. These systems allow for individual workloads (distance covered and time/distance spent and different velocities) to be recorded and also allows for real time and spatial analysis opening up a number of applications in performance assessment (Williams and Morgan, 2009).

GPS within a sporting context has been developed and used in a variety of sports with the majority of the early scientific studies (Table 2.2) focussing on Australian Rules Football (AFL), which is most likely due to the production and development of the systems in Australia and the sports long history of sports science involvement (Coutts *et al.*, 2009; Edgecomb *et al.*, 2006). Initial studies examined the movement demands of the professional game (Wisbey, 2010) and determined the differences between elite and sub-elite players (Brewer *et al.*, 2010). However due to its portability and relatively low cost (compared to other match analysis systems) it has been used in a number of additional sporting contexts such as measuring the physical demands in Rugby Union (Cunniffe *et al.*, 2009) and beach soccer (Castellano and Casamichana, 2010). Gabbett (2013i) has used GPS to compare match performance in competitive and trial games and the same methodology has been used by Gabbett (2013ii) to examine Rugby League youth team performance. Waldron *et al.* (2013) used the system to examine fatigue and self-pacing strategies with interchange players in Rugby league.

Away from match day competition Hartwig *et al.* (2008) used the system to quantify the volume and intensity in youth rugby training and competition and in a similar vein Barbero-Alvarez *et al.* (2010) has used it to assess repeat sprint ability. Within professional sport in England GPS has become common place with most teams in rugby union, rugby league and soccer using one of the available models in their training. With the system becoming common place in soccer there is greater volume data being produced which focus on the return to play performance or the weekly workload of players (Barnes, 2012). What is evident is that due to the portability of the system, the ability to employ it with multiple users and the abundance of data that is generated through the software the amount of studies produced in the future will increase and due to the by-laws of the game restricting its use in competitive games this system remains a training ground solution.

2.2.1.2 Sources of Error

With all measurement tools there are various issues which can influence the accuracy of the data collected. To establish a global position, a satellite lock (SL) with three satellites will give an area which the receiver unit will fall within and the position of the satellites in the sky will determine the size and shape of the possible location area. For use in a sporting context a minimum SL of four is required to allow for a specific location to be calculated however in a dynamic sport this number may not be enough. Once a SL has been established there are still a number of possible sources of error that need to be accounted for so that valid and reliable data can be collected. These include (1) synchronicity, (2) the receiver unit, (3) signalling errors, (4) atmospheric conditions, (5) mask angle and (6) Ephemeris error (Steede-Terry, 2000; Bacci *et al.*, 2011).

To determine a global position, the GPS receiver unit uses a simple calculation of the time that a signal from a number of satellites takes to reach the receiver unit. An issue arises when the unit and satellite clocks are not in synchronicity and therefore the time of the signal cannot be accurately established. To reduce clock errors, improved synchronicity is performed by periodic control segment uploads, this requires a periodic recalibration of the timers of the satellite and ground based units. This reduces error immediately after the upload but it will gradually increase until the next upload (Conley *et al* 2006). The level of accuracy has improved as newer satellites have been launched with better performing clocks and improvements to the control segment (Yinger *et al*, 2003).

Historically the receiver unit could have had a number of limitations associated with it (Steede-Terry, 2000). From a technical aspect in the past some receivers could not track multiple satellites which would impact on the accuracy of the positional data due to the reduction of triangulation calculations. The design and unit quality was also a determinant in the lack of accuracy and within a sporting context this was exaggerated with the smaller units as the capture rate (Hz) and processing speed was reduced and this in turn decreased the precision of the data collected (Kennedy, 2002).

The main type of signalling error is referred to as ghost error (also termed multipath error) which occurs when the signal bounces or is reflected off larger reflective surfaces such as grandstands near the receiver (Steede-Terry, 2000; Bacci *et al.*, 2011). This type of error has been reduced with advanced contemporary software that filters out the second reflected signal and by doing so eliminating a significant source of the error (Conley *et al.*, 2006).

Ionospheric error is the unintentional degradation of the signal that can occur as the signal passes through the atmosphere with different weather patterns having an influence on the speed of the signal. Advances in software and signal analysis have developed so that sophisticated units can adjust for this source of error (Kennedy, 2002; Bacci *et al.*, 2011). A larger number of satellites positioned more centrally in the sky will reduce this error, however there are problems if all of the satellites are in a similar location (Conley *et al.*, 2006). The 'range rings' (the area that the receiver unit can be located in) that each satellite places the receiving unit in are based on error due to relative geometric position (Conley *et al.*, 2006). If the satellites are at right angles to one another and the unit then the geometric area will be less than if the satellites are all in a similar spacial alignment (Conley *et al.*, 2006). By using three satellites a general area of location can be determined, to establish greater accuracy a fourth satellite is required otherwise a discrepancy of 0.01 of a second would equate to a distance of 1860 miles (Steede-Terry, 2000). Therefore a minimum of 4 satellites are required to gain an accurate position.

Mask angle, that is often referred to when using GPS in stadium or built up areas, denotes an imaginary line that runs from the receiver unit though the top of any structure or object that restricts the vision of the unit to the open sky. It is measured in degrees and in comparison to the horizon, for example a mask angle of 20 degrees would limit the number of satellites to those seen above this angle when using the horizon as zero degrees. An example of this can be seen in Figure 2.2 where the satellite indicated by the arrow falls below the mask angle and therefore cannot be used as by the unit to calculate a global position within the stadium. A mask angle of zero degrees indicates that the entire

sky is available for the unit to see and that any available satellites can be used by the GPS unit. However this increases the potential for ionospheric error as the satellites low to the horizon are more likely to be influenced by atmospheric delay and multi path problems due to the greater distance that they have to travel through the atmosphere and whilst excluding them will reduce this error it will also limit the number of satellites that the receiver unit can use to establish its position (Conley *et al.*, 2006).

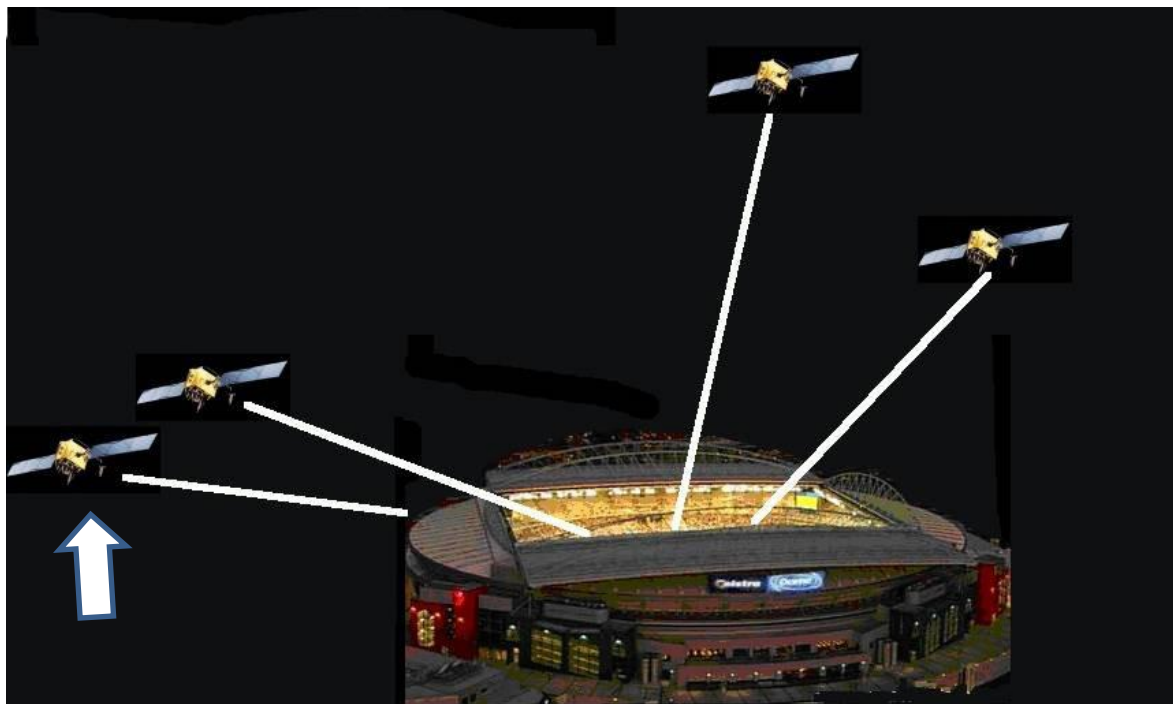


Figure 2.2: Example of how mask angle can restrict satellite signal due to use in a modern stadium or in built up areas.

Ephemeris error refers to the moon and sun's gravitational pull moving the satellite out of its orbit. This can be combated by having a number of ground based stations constantly transmitting data to the satellites (Steede-Terry, 2000). Differential GPS (dGPS) increases the accuracy of the receiver by using a second receiver that is placed at a known location and then any error can be calculated and applied to the second receiver that is collecting the required data (Terry, 2000; Kennedy, 2002).

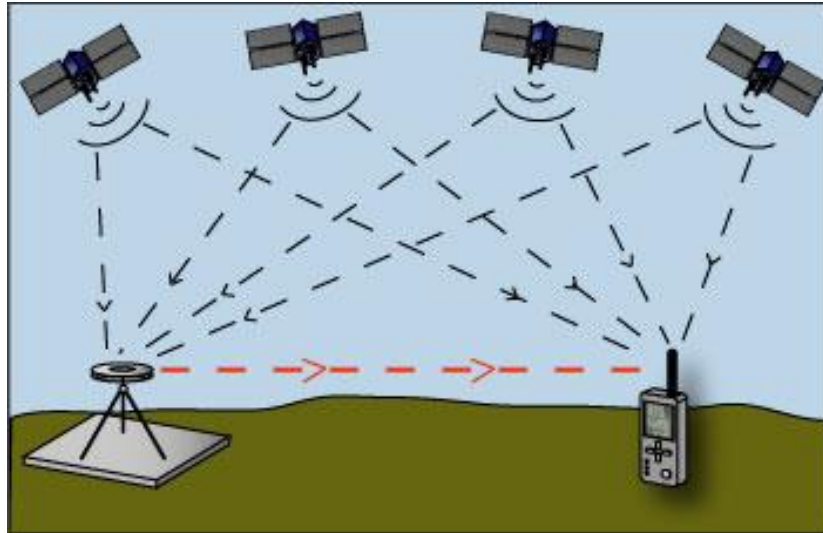


Figure 2.3: Example of Differential GPS (dGPS).

2.2.1.3 Horizontal Dilution of Precision

To quantify the quality of the signal received by the GPS unit by taking in to account all of the sources of error, Horizontal Dilution of Precision (HDOP) has been used as the industry standard (Jennings *et al.*, 2010i). It is used to determine the position of satellites in relation to the receiver unit and an arbitrary figure between 1 and 50 used, a score of 1 indicating that one satellite is directly overhead with the remainder of a large number of satellites equally spaced around the horizon. A figure of 50 would indicate that there are a limited number of satellites available and that they are clustered together on the horizon (Jennings *et al.*, 2010i). Obstructions that decrease the available sky hence increasing the virtual horizon, such as grandstands or use in built up urban areas, will limit the communication with satellites and the quality of the information gathered will decrease. In addition the dynamic nature of the satellite configuration from day to day will impact the capture conditions, and therefore the quality of the information gained may vary. At the present time the HDOP is the quantitative assessment tool used to determine the quality of the data obtained and is typically reported as the mean number, along with the mean satellite lock, of all the GPS units over the collection period (Jennings *et al.*, 2010i).

2.2.1.4 Tri-axial accelerometers

Contemporary designs of GPS units have seen the inclusion of tri-axial accelerometers which have been used in high contact sports (Rugby, Australian Rules) to provide the sports scientist with impact data such as body to body impact forces in tackles and ground impact forces from running and jumping (Young *et al.*, 2012). These additional measurement tools are sensitive enough to measure ground impacts and whilst they provide valuable information on acceleration and deceleration, each foot

contact can be incorporated into the data collected and used as an additional source to determine the distance covered. A number of companies have used this data to calculate the distance covered if the number of satellites required for velocity measurements drops below the minimum required (Catapult personal communication). There are however methodological issues associated with the use of accelerometers in this way as they are not firmly mounted to the body and are therefore highly susceptible to movement artefact and may dampen initial high velocity contact and are predisposed to noise during normal use (Pattriti 2004). As this method of distance data collection has not been examined within the literature it is not recommended that the data is used until it has been validated.

2.2.1.5 Reliability and Validity

A number of studies have been published which have assessed the reliability and validity of GPS (Table 2.1). Petersen *et al.*, (2009) used three different types of commercially available GPS units (1Hz and 5Hz) in examining cricket movements and found that there were differences between units and manufacturers and that the systems were valid and reliable in estimating longer distances of 600m to 8800m ($r = 0.99$) and lower speed activities of up to 5m/s (SEE = 0.4-3.7%), but that there were shortcomings in the analysis of short cricket specific sprinting activities which showed increasing error (SEE = 3-24%) for sprinting. However whilst they state that there is a time of day variation due to different satellite configurations and that sports scientists should take note and monitor the quality of the signal, the authors fail to report any such information during the collection of their test data and it is difficult to draw an accurate conclusion from their studies.

Grey *et al.* (2010) used a single subject wearing eight 1Hz GPS units over a 200m linear and non-linear course at four speeds, and found that there was an increase in error as velocity increased which was replicated in both linear (straight line) and non-linear (common patterns in field sports) conditions (LOA 2.6% - -13.4%), the recorded distance also showed greater error as the speed and complexity increased (COV = 6.04%). Jennings *et al.* (2010i) followed a similar format to Grey *et al.* (2010) but used 5 Hz units and had 20 players each wearing 2 units. They used a smaller (40m) linear and non-linear course and found that the between unit variability ($\pm 90\%$ CI) ranged from $9.9 \pm 4.7\%$ to $11.9 \pm 19.5\%$ for the straight line running movements and from $9.5 \pm 7.2\%$ to $10.7 \pm 7.9\%$ in the change of direction courses, recommending that players should wear the same unit in each training session to counter the effect of unit bias.

Duffield *et al.* (2010) also studied a single subject wearing two 1Hz and two 5Hz GPS units performing the court-based movement patterns of a tennis match and compared GPS to a VICON 3D motion capture system which measured at 100Hz. In a confined space, both 1 and 5Hz GPS devices under-reported the distance covered and as the speed increased so did the measurement error. In addition there was variability between similar devices that were capturing at the same rate which led to the same conclusion of Jennings *et al.* (2010i) that in a sport setting players should wear the same unit to avoid inter-unit error. Although Duffield *et al.* (2010) state that there were seven satellites acquired during the testing process there is no reporting of a minimum capture requirement used for the capture period or a reporting of the HDOP. The authors also acknowledge the dynamic nature of the GPS field, due to the continued improvements in both the software and hardware.

Coutts and Duffield (2010) collected data on intermittent exercises over a 128.5-m circuit which included walking, jogging, fast running, sprinting and standing still. Six 1-HZ GPS units were used in the study, which consisted of two each of three different models. The level of accuracy and reliability was acceptable for total distance (123.3 ± 8.3 , 126.2 ± 5.6 and 129.1 ± 8.2 m) and peak speeds (correlation with 20-m sprint time $r = -0.40$ to -0.53 , $P < 0.001$). Whilst the Coutts and Duffield (2010) indicated that there was an acceptable level of accuracy and reliability when assessing team sports movements they also warned that the level of reliability needed to be accounted for when interpreting GPS data.

Williams and Morgan (2009) examined the time of day and the effect of the use of GPS in a multi-purpose sports stadium with a single storey grandstand. The authors used 45 minutes of collected data at 9 points to determine the Circle Error Probable at 95% (CEP95), a measure of the dispersion range in which a radius of a circle will allow 95% of the data points to fall. As the GPS units were stationary a CEP95 score of 0 would indicate perfect accuracy. The authors found that there was a significant difference in the CEP95 between the 3 trials (1.3 ± 0.3 , 2.8 ± 0.9 , and 1.9 ± 0.8 m) and that this was negatively correlated to the number of satellites ($r = -0.784$). Williams and Morgan (2009) also found that as the units got to within 20m of the single story grandstand that the CEP95 increased above 1.5m and that the unit on the side-line showed a 10.2m CEP95 perpendicular to the grandstand. The same inverse relationship between number of satellites and the CEP95 that was established in part one of the experiment was again present ($r = -0.97$). These findings therefore suggest whichever method of data quality control is employed, the number of satellites is important and must be reported in any study employing GPS.

Table 2.1: GPS validation studies

Author	Overview	Sample Frequency	N° of Sats reported	HDOP	Conclusion
Schutz and Herren (2000)	Using GPS to assess speed	Not reported	Not reported	Not reported	In open sky accurate Differential 10x better than non-differential
Witte and Wilson (2004)	Accuracy of non-differential GPS to assess speed	1Hz	3 to 6	<5 to >40	Linear speed is accurate but sudden changes in velocity occur it is less accurate.
Witte and Wilson (2005)	To compare Wide Angle Augmentation System (WAAS) and differential GPS (dGPS) to GPS	1Hz	Mean 8 Range 4-10	Mean 1.2 (range 0.8-50)	Both WAAS units and dGPS are more accurate than GPS
Petersen <i>et al.</i> (2009) (Part 1)	Accuracy of GPS to monitor cricket movements	5Hz	Not reported	Not reported	Total distance acceptable Under estimate of high speed movements
Petersen <i>et al.</i> (2009) (Part 2)	Compare 3 different types of GPS unit	1 and 5Hz	Not reported	Not reported	Accuracy depended on brand
MacLeod <i>et al.</i> (2009)	Validity in measuring hockey movements	1Hz	Not reported	Not reported	Provides a valid tool for measuring speed and distance
Portas <i>et al.</i> (2010)	Accuracy of GPS to monitor Soccer movements	1 and 5Hz	Mean 7 Range 4-9	Mean 1.5	1 and 5Hz total distance acceptable 1Hz not acceptable for 180° turns
Barbero-Alvarez <i>et al.</i> (2010)	Assessing speed and repeated sprint ability	1Hz	Not reported	Not reported	Strong correlation between GPS and timed 15m and 30m. high variation in percentage decrement score in 7 x 30

Aughey and Falloon (2010)	Real time vs post game data	1Hz	Not reported	Not reported	Differences in distances in the speed zones and total distance.
Jennings et al. (2010i) p328	Validity and reliability of measuring team running patterns	1 and 5Hz	8.2 8.3 8.2	1.5 1.3 1.3	Long team sports distance acceptable Valid and reliable over slow speeds and higher sampling rates over longer efforts.
Jennings et al. (2010ii) P565	Variability of GPS in team sport movements	5Hz	8.5 7.8 8.4	1.2 1.1 1.1	Considerable variation in distance measured
Janssen and Sachlikids (2010)	Validity and reliability of measuring kayak velocity and acceleration using GPS accelerometer	5Hz	Not reported	Not reported	Accelerometer under reported velocity and acceleration and there was a time of day effect
Gray et al. (2010)	Measuring distance in team sports	1Hz	7	<2	Reduced validity in high speed non-linear movement patterns
Randers et al. (2010)	Comparing GPS with three other systems	1 and 5Hz	At least 3 satellites	Not reported	Large variation in the four different systems
Dogramaci et al. (2011)	Comparison of notational analysis to GPS	Not reported	Not reported	Not reported	Notational analysis valid and reliable and more accurate than GPS in some variables
Waldron et al. (2011i)	Using GPS to predict 30m speed	5Hz	Range 9-12	1.3	Systematic underestimate of 30m speed
Waldron et al. (2011ii)	Test-retest reliability and measurement of selected variables	5Hz	Range 9-11	1.2	GPS can be used to observe small changes in sprint speed. GPS and timing gates differ.

Harley <i>et al.</i> (2011)	Comparing GPS with Prozone	5Hz	>4	Not reported	Large variation in sprint distance.
Johnson <i>et al.</i> (2012)	Validity and reliability of GPS in measuring a simulated team sport circuit	5Hz	7.1	<3	GPS is capable of measuring movement demands performed at velocities <5.5 m/s, caution needs to be exercised when examining movements >5.5 m/s.
Varley <i>et al.</i> (2012)	Measuring instantaneous velocity in acceleration, deceleration and constant motion	5Hz and 10Hz	12	0.9	10Hz is 2/3 times more accurate than 5Hz and 6 times more reliable.
Marsland <i>et al.</i> (2012)	Identification of cross-country skiing movements using GPS	5Hz	Not reported	Not reported	Movement patterns can be identified from the acceleration and velocity data generated from GPS

Randers *et al.* (2010) compared two different GPS systems (MinimaxX and GPSports) with the addition of a video based time motion system and a semi-automatic multiple-camera system (MCS) (Amisco). The Amisco system performs in a similar way to PZ with multiple cameras based around the stadium recording players movements which is then analysed, however this system has not been validated within the literature. The 5Hz system (MinimaxX) recorded significantly greater distances than the 1 Hz system (GPSports) however, Randers *et al.* (2010) found that in high intensity running, sprinting, low-intensity running, and total running distance there was no significant difference between the two GPS systems. In comparing the MCS to the 1Hz GPS Randers *et al.* (2010) reported that the MCS recorded significantly greater values in all of the distance categories (total distance covered, high intensity running, sprinting, low-intensity running). When comparing the 5Hz GPS and the MCS there were significant differences between high intensity running, low intensity running and total distance running and non-significant differences between total distance covered and sprinting. By increasing the capture rate (1Hz to 5Hz) more comparable data was obtained between the GPS and the MCS, however a methodological error of Randers *et al.* (2010) study was that they did not report the number of satellites or the HDOP during the collection of the data and so it is difficult to directly compare the data or draw comparisons to systems that could produce a greater number of data points per second.

In an English based study Portas *et al.* (2010) compared data collected at 1Hz verses 5Hz in soccer specific activities. They found that the GPS units that sampled at higher rates were accurate, when compared to timing gates, for the total distance and during the less complex tasks but when the players performed turns of 180⁰ the accuracy decreased. However during a match these types of movements do not happen frequently and do not have a significant impact on the total work that the players perform (Portas *et al.*, 2010) but would be significant in game movements. In explaining the differences in accuracy between data and that which has previously been published, Portas *et al.* (2010) state that the differences in the satellite configurations has an influence. In Australasia a transitional satellite is used to link the units and satellites, whilst in Europe no transitional link is used, and that the additional sequencing in Australia may have an influence on the accuracy in the high speed data.

What is evident from the literature is that there are a number of studies that do not report the capture conditions in which the movement data was collected (Table 2.2). It is apparent is that as the sampling rate increases the accuracy of the data also improves (Jennings *et al.*, 2010ii; Macleod *et al.*, 2009; Portas *et al.*, 2010) however the historical criteria for collecting accurate GPS data (four satellites) has

not been examined within a sporting context. What are required are minimum recommendations for the collection of accurate data as currently the average number of satellites and the HDOP are reported for the collection period with little or no analysis of the conditions in which they were taken. However what must be appreciated is that the technology is new and that advances in the units and software is improving at a constant rate and that the literature may not be an accurate reflection of the accuracy obtained with current products, as there is a long term trend of excellence and improvement (Conley *et al.*, 2006).

2.2.2 ProZone™

2.2.2.1 History and development

ProZone™ (PZ) was founded and established in Leeds in 1998 specifically for soccer due to a lack of accurate and reliable performance analysis systems that would provide match information in a reasonable time frame. PZ Version 1 was released and used in a preseason friendly match involving Derby County FC in 1999 and by 2000 a number of Premiership clubs were using the system and the English National team used it in a match against Greece. In 2003 an updated version (Prozone Version 2) of the software was released with a further update in 2005 (Prozone Version 3). In 2012 PZ and Amisco amalgamated developing a global database of match and player recruitment data. At the present time over 100 clubs, leagues and federations use PZ which has seen it become the most widely used automated match analysis system in soccer.

The quantity of scientifically published research using PZ has largely been in soccer due to its historical links to the sport and its lack of portability and high expense. With the exception of its examination of Rugby League (Sykes *et al.*, 2009; Sykes *et al.*, 2011) the author is unaware of any other studies using PZ in sports.

Sykes *et al.* (2009) used the system to scrutinise the movement profiles of elite rugby league players over three games. The total distance covered as well as the percentage time spent in each of the seven preselected movement categories were analysed in attacking and defending as well as when the ball was in play in order to provide position-specific benchmarks for assessing match performance. Sykes *et al.* (2011) then examined and quantified the changes in locomotion rates throughout a match and found that by monitoring the decrease in high intensity running the coach would have a more effective way of detecting fatigue as opposed to monitoring the total distance.

A number of researchers have examined movement and activity profiles in elite soccer of the different European leagues with the recent focus of their attention on the high intensity activities during matches, with a particular interest in the sprinting profiles specifically the English Premier League (Bradley *et al.*, 2009; Di Salvo *et al.*, 2009), the Spanish League (Di Salvo *et al.*, 2007) and the elite European multi-nation European Champions League and UEFA Cup matches (Di Salvo *et al.* 2010) which have provided technical and fitness coaches with valuable match day information. With the increasing attention in sprinting the system has recently been used to divide sprinting into two different types, leading and explosive sprints (Di Salvo *et al.*, 2009).

Whilst players performance characteristics are captured and analysed Weston *et al.* (2007) examined the intensities of referees exercise during match-play work rate in FA Premier League games to see if first half exertion had an effect on second half performance. The authors reported that there was a decrease in performance in the second half but that further examination was required to determine whether reduced physical performances in the second half of matches are a consequence of referee fatigue, tactical strategies on behalf of the referee or reduced player match activities resulting in a slower tempo of match. The use of match data has also allowed for the comparison to field tests and Weston *et al.* (2009) found that the referees who recorded the best interval test heart rate and fastest 40-m time produced the best physical match performances.

In three further studies on referees, Weston *et al.* (2011i) examined the intensities of exercise during FA Premier League games of both referees and players. The data suggest that at the elite level, the referees running intensities were interrelated with those of the players and mimic the overall intensity of the match and when examining referees variability between match performance in the Premiership and Championship leagues, Weston *et al.* (2011ii) found that it was not dependent on referee age or experience. In the comparison of referees' performances at the start of the second half and the corresponding phase of the first half (0-15 min) and by comparing it to the players' performances during the same match periods Weston *et al.* (2011iii) found that physical match performance was reduced during the initial phase of the second half when compared with the first half in both referees and players with the referees performance due to a slower tempo of play. What is clear is that due to the restrictions of monitoring equipment, and the expense of the systems, in football these motion capture systems remain predominantly stadium solutions in soccer.

2.2.2.2 Reliability and Validity of ProZone™

There have been fewer scientific published studies using PZ than with GPS, most likely due to the high expense and lack of portability of the PZ system and therefore resulting in a limited number of users. However Di Salvo *et al.* (2006) examined straight line and multidirectional runs up to 60m at a range of different speeds (7 km/h, 11 km/h, 14 km/h, 19 km/h, 23 km/h and individual max) at 2 premiership grounds that had the system installed. The data obtained by PZ was compared to data collected from timing gates set up on the pitch and the two data sets were shown to have excellent correlation in the 60m and 50m runs ($r = 0.99$), the maximal 15m sprint ($r = 0.97$) and the maximal 20m sprint with right and left turns ($r = 0.96$). More recently Di Salvo *et al.* (2008) and Bradley *et al.* (2009) concurred in that PZ was accurate in its recording of movement in soccer and that it was highly accurate in quantifying match-related displacement velocities.

Table 2.2: Movement demands of sports using GPS.

Author	Overview	Sample Freq	Sats	HDOP	Findings
Hartwig <i>et al.</i> (2008)	Volume and Intensity in Adolescent Rugby	1Hz or not reported	Not reported	Not reported	<ul style="list-style-type: none"> • More information is required on adolescent athletes
Cunniffe <i>et al.</i> (2009)	Demands of Elite Rugby Union	1Hz	Not reported	Not reported	<ul style="list-style-type: none"> • Elite players run further and harder than previously thought
Gabbett (2010)	Demands of women's field hockey and training	5Hz	Not reported	Not reported	<ul style="list-style-type: none"> • Training did represent the physiological demands of competitive games
Castellano and Casamichana (2010)	HR and motion analysis in beach soccer	5Hz	Not reported	Not reported	<ul style="list-style-type: none"> • Intermittent high intensity sport with HR over 90% of max for half the time
Wisbey <i>et al.</i> (2010)	Movement demands in AFL football	1Hz	Not reported	Not reported	<ul style="list-style-type: none"> • Provided positional and changing physical demands
Brewer <i>et al.</i> (2010)	Comparison of elite and sub elite Australian rules football	1Hz	Not reported -min of 4	Not reported	<ul style="list-style-type: none"> • Elite players games had higher movement demands than sub elite players
Gabbett <i>et al.</i> (2012)	Demands of training and games of Professional Rugby league players	5Hz	Not reported	Not reported	<ul style="list-style-type: none"> • In games outside backs cover greater distances and forwards are involved in more tackles/collisions, which is not replicated in training.
Lythe and Kilding (2011)	Physical physiological demands in elite field hockey	1Hz	Not reported	Not reported	<ul style="list-style-type: none"> • Physically demanding sport with differences in physical position requirements

2.3 PHYSIOLOGICAL ANALYSIS OF SOCCER

2.3.1 Motion Profiles of Matches

As previously discussed the major historical issue with the analysis of match performance is that it is time consuming or labour intensive and in an academic setting this transpired to studies having a limited number of subjects (Di Salvo *et al.*, 2007; Hughes, 2008). The development of automated computer analysis methods has allowed for that there can be a greater number of matches and/or players analysed in a shorter space of time (Di Salvo *et al.*, 2007; Gregson *et al.*, 2010). Within the English game Bradley *et al.* (2009) used PZ to examine the positional demands and found that the wide midfielders covered the highest total distance (11535m) with the central defenders covering the least (9885m) and the other three designated positions full-backs, central midfielders and attackers covering 10710m, 11450m and 10314m respectively. The high intensity running above 4 m/s showed a similar trend with the wide midfielders covering the most distance (3138m) and the central defenders covering the least (1834m) with the other three positions full-backs, central midfielders and attackers covering 2605m, 2825m and 2341m respectively.

In examining the Spanish game Di Salvo *et al.* (2007) found that the central midfielders covered the most ground (12027m) and the central defenders covered the least (10627m) with the wide defender, wide midfielder and attacker recording distances of 11410m, 11990m and 11254m respectively. As with the Bradley *et al.* (2009) study, the Spanish counterparts also saw the wide midfielders cover the most high intensity distance (3171m) with the central defenders covering the least (1869m). The wide defenders covered 2784m, the central midfielders covered 2991m and the attackers covered 2708m.

Andrzejewski *et al.*, (2012) performed a similar analysis examining four games from a Polish team in the UEFA cup completion although they combined the wide midfield and central midfielders into one group and the wide and central defenders into one group. They found that the defenders covered 10932m total distance with 2416m of high intensity work. The midfielders covered a total distance of 11770m with 2980m of high intensity distance and the forwards attained 11377m total distance and 2811m high intensity.

The three studies presented here all show similar total distance and high intensity measurements and the general consensus within the literature and the applied sport science field was that total distance had remained constant over the period that automated analysis had been used and that it was the high speed, anaerobic activities that required a greater focus (Di Salvo *et al.*, 2010).

Di Salvo *et al.* (2009) performed a detailed analysis of the high intensity running activity, which they determined was speed greater than 5.5 m/s, completed by elite soccer players during match-play in the English premier league. Continued development of the automated analysis software allowed for a greater examination of the high intensity actions. Di Salvo *et al.* (2009) inspected the high intensity running distance and the total sprint distance both with and without the ball in addition to the type of sprint, leading or explosive, were performed. Wide midfield players recorded the furthest distance (1049m) in the very high intensity category (>5.5m/s) and central defenders (681m) the lowest distance. Di Salvo *et al.* (2010) expanded on this work in examining the sprint profiles of teams during the two international club UEFA cup competitions and found that whilst the positions showed similar percentages of leading sprints (76%) and explosive sprints (24%) the number performed varied with position and showed that wide midfielders performed 36 sprints followed by forwards (30), wide defenders (29), central midfielders (23) and central defenders (17) per game. In their detailed analysis Di Salvo *et al.* (2010) also showed that the large majority of sprints occurred over a distance of under 10m, with twice as many sprints in the 0 to 5m category.

The work of Di Salvo *et al.* (2010) and Bradley *et al.*, (2009) have provided a detailed examination of the elite men's game which gives additional evidence to the credence that high intensity work is important in the elite adult game and suggests that there may be a minimum threshold needed to be attained in order for success at the elite level. Additional unpublished data released by PZ (Appendix A) supports the contention that high intensity work is important for soccer as it reveals that since 2006 the total distance covered by teams has marginally increased from 108km to 110.2km however the proportion of very high intensity running (>5.5m/s) has increased from 8.7% to 11% with the number of sprints increasing by 82% and the total sprint distance increasing by over 50%.

2.3.2 Physiological responses to match play

Early studies examining the work rate in soccer established that both aerobic and anaerobic fitness was crucial for success due to the large total distance covered in a 90 minute match and a relationship was established between the distance covered and the players VO_{2max} (Smaros, 1980; Reilly and Thomas, 1976). The focus on VO_{2max} by sport scientists was further strengthened when Apor (1988), in examining the top four positions of a soccer league, correlated league position with VO_{2max} . Subsequently Bangsbo (1994a) and Helgerud *et al.* (2001) established that players use the aerobic system to produce 90% of the energy used in a match, which established a trend at this early stage of sport science in soccer training towards longer distance runs with trainers attempting to improve

players aerobic ability at the detriment of other components of fitness. Through a training study Helgerud *et al.* (2001) determined that by improving aerobic endurance players performance also improved anaerobic measures by increasing the number of sprints by 100% and the total distance covered by 1716m and this subsequently improved the number of ball touches by 24%.

When examining the breakdown of the different forms of speed locomotion activities Bangsbo *et al.* (1991) utilised video analysis to determine that walking was the most frequent which attributed for 40% of the time, whilst an additional 17% of the time the players were standing still. In the course of the match the players used low intensity running 35% with only 8% of the time being used for high intensity running. Earlier match analysis using video analysis also determined that of each of the anaerobic and aerobic elements contained three subcomponents. Such analysis deemed traditional long slow endurance type training inefficient and not specific to the sport as it did not include intermittent specific soccer movements such as acceleration and deceleration (Bangsbo, 1994iii; Reilly, 1997; Reilly and Bangsbo, 1998).

Whilst the majority of the energy in a game is derived from aerobic pathways, approximately 10% is from the anaerobic system and is used during bouts of intense exercise. Cable (1998) found that intense exercise lasted for approximately 7 minutes during a match which included sixty 2 second sprints which were in excess of 7m/s and in examining this further (Cable, 2002) established that the total distance covered while a player is exercising at a high intensity is as much as 1.8km however to be able to perform anaerobic activities, such as speed and speed endurance, players must have adequate aerobic capacity (Bangsbo, 1994a; Helgerud *et al.*, 2001; Cable, 2002). Both speed and speed endurance, are important within soccer as this can lead to both goal scoring and goal defending opportunities (Harrison, 2010). Dunbar and Power (1997) in examining the fitness levels of elite and sub-elite soccer players demonstrated that elite soccer players performance in short sprints was superior to that of sub-elite players highlighting the importance of anaerobic activities in soccer.

A number of authors have examined the work rates in soccer and established that there are different positional requirements within the game. Using heart rate (HR) Ali and Farraly (1991) found that midfielders achieved the highest mean HR followed by strikers and defenders in both a semi-professional and university population which was similar to Bangsbo *et al.* (1991) and their analysis of distance in Danish elite players which found that the Midfield players covered the greatest distance (11.4km) followed by the strikers (10.5km) and the defenders covering the least amount of ground (10.1km) which was obtained by counting steps per second and estimating distance and speed.

Whilst the scientific literature regarding motion analysis relates almost exclusively to adult players Stroyer *et al.* (2004) investigated the aerobic energy demands placed upon elite and sub-elite youth soccer players and similar to the results discovered in adult soccer players, defenders achieved the lowest mean heart rates however when comparing non-elite players they stood for longer and spent less time utilizing low intensity running and more time walking. Capranica *et al.* (2001) examined prepubescent soccer players heart rates and match demands and found that players walked for 38%, ran for 55% and stood still for 4% of the game. Compared to Stroyer *et al.* (2004), the standing and walking percentages are low and running appears to be very high, however this can be explained by single running category in the Capranica *et al.* (2001) study. Harley *et al.* (2010) in using GPS to monitor match profiles of youth players (Under 12, 13, 14, 15 and 16) found that in absolute terms the Under 16 group covered significantly more total distance, high-intensity distance, very high-intensity distance and sprint distance than the younger age groups ($P < 0.05$). However when the speed thresholds were normalized for each age-group using the mean squad times for a flying 10m and the data was considered relative to the players match exposure and there were few differences.

As the methods employed in the past were labour intensive this presented a time-detail continuum in which detail of the movement profiles of players could be provided but the time frame was prolonged or for a quick turnaround detail was limited (Hughes, 2008). The development of automated and semi automated analysis tools has allowed for more detail in a shorter time and has seen it become commonplace within the professional game in England.

Key components of fitness have been highlighted and tested in adult elite players (Jones and Helms, 1992), specifically demonstrating that high-intensity intermittent activity and the ability to jump and sprint short distances repeatedly is directly relevant to the high anaerobic nature of soccer (Reilly *et al.*, 2000; Mayhew *et al.*, 2004; McMillan *et al.*, 2005). Of the relevant studies which examined elite and professional soccer players most have been based using adult players and there are few studies which have examined the profiles of youth players (Gil *et al.*, 2010; Harley *et al.*, 2010).

Contemporary studies that have examined the youth population have generally provided physiological test measures that have been derived from both field and laboratory testing. Recently Wong and Wong (2009) provided physiological characteristics on youth team players using a five test battery of (1) maximal vertical jump, (2) isokinetic muscular strength testing, (3) VO_{2max} , (4) 1 rep max squat test, and (5) 30m sprint to test a national Under 16 team. They provide comparison data and recommend altering playing style without affording the reader with any match performance data. Mendez-

Villanueva *et al.* (2011) examined maximum running speed, acceleration and repeated sprint performance in 3 age groups (Under 14, Under 16 and Under 18) and showed a strong, and unsurprising, correlation between the three tested fitness components. Finally in what can be considered typical field testing, Vääntinen *et al.* (2010) measured 10m sprint, agility, counter movement jump in Under 12, Under 14 and Under 16 age groups and recommended that more research is required in order to develop tests that measure essential soccer skills in more game like situations.

Measurement of components of fitness that are specific to soccer are important in order to provide baseline information but can be considered a 'snapshot'. By examining the overall scores of a testing battery a more complete picture of the player can be established, however their relevance to 'on field' performance is difficult to measure and compare. Whilst this type of analysis can also provide data in the area of talent identification, such that a player on trial at the club can be given specific performance targets to catch up on (future projection of performance) and meet in order to stay in the academy structure. Any information that is reported is only cross sectional or of reference to specific age groups and no long term studies exist on the effects of preseason resistance training on improved sports performance in children and what is of importance is player performance in matches (Benjamin and Glow, 2003).

2.3.3 Match Profiles

In comparing field tests to actual match workload Castagna *et al.* (2010) examined level 1 of the Yo-Yo intermittent recovery test (Yo-Yo IR1), the Multistage fitness test (MSFT) and the Hoff test and compared to match performance in elite 14 year old players and found that the Yo-Yo IR1 and the MSFT were strongly related to the number of match activities. As such these field tests can be used in the prescription of training and for talent selection, however the age of the players (14 years old) make any long term projections tenuous at best as the anaerobic system may not be fully developed in the subjects.

Aslan *et al.* (2012) looked at the match performance of Under 18 university players using match analysis software and examined the metabolic cost of the game through blood analysis. They found that there was a correlation between blood lactate and distance covered and although the players covered different movement patterns according to the position that they were playing the physiological stress was similar. The distance covered in each of the speed categories was comparable to the literature however in order to collect blood sample the game was divided into 15 minute

sections with approximately three minutes rest, which would have had an impact of the rate of fatigue of the players. In addition the game was non-competitive which would have reduced the intensity of play, stress hormone level and ultimately the metabolic demand.

In one of the few studies which examined match performance of Under 18 players at an Academy, Buchheit *et al.* (2010), using players from the Aspire Academy in Qatar, found that the amount of running and high intensity running was position dependant in comparing to the field tests that they employed. However the total distance covered in the matches examined was only approximately two thirds of the distance that is recorded in the adults game and as such the population used may not be representative of all youth team soccer. It was also measured using 1Hz GPS which has been shown to give accurate total distance information in games play but limited in its recording of the high intensity work performed. The games organisation was different to the weekly youth league structure in England where the subjects were part of an academy which didn't play in a weekly league but had touring teams visit and played a number of games over a short period of time followed by an extended period of rest and training. These short periods of multiple games may have hindered the results due to the better players having a greater accumulation of fatigue and the use of lesser skilled players to combat this.

In an English Academy setting Harley *et al.* (2010) looked at Under 12 to Under 16 players and provided some baseline data which indicated a general trend of increasing distance and high intensity distance in the older age groups. However the mean total distance in the Under 16 age group was below the corresponding adult data, with the length of the games having an impact on this as it is 10 minutes shorter than Under 18 and adult matches, however the range of total distances recorded indicated that some of the players would be able to match to their adult equivalent. The speed zones were normalised to each of the players, so any direct comparison to any published adult data is limited and there was no reporting of the positions analysed. Of interest to the coach and sport scientist alike would be the distances covered in each of the velocities that are typically used within the PZ software in the Under 18 age group as these players are full time and involved in competitive leagues for the first time which would have provided information that was pertinent in comparison to the Adult game.

It has been shown that whilst the physiological demands of soccer have been examined through the monitoring of heart rates and video analysis, there are no data tracking the players as they progress from the youth (Academy) into the senior (Professional) game or the different high intensity anaerobic activity demands placed on them (Stratton *et al.*, 2004). Of the studies using youth players they

generally fall into 1 of 3 categories (1) the subjects used are not elite, (2) the studies are of a short duration or (3) they are cross-sectional in nature.

To the author's knowledge there are no studies that examine the match demands of elite Under 18 scholarship soccer players indicating a gap in the literature. What is required is a more comprehensive knowledge in the area of training and game load so that this would not only improve performance but would allow for the setting of programmes which could limit injury.

2.3.4 Speed and Agility testing

A number of contemporary studies have highlighted the importance of speed over short distances in the elite adult game (Di Salvo *et al.*, (2010); Bradley *et al.*, (2009) however what is lacking within the literature is the measurement and establishment of soccer specific testing criteria (Svensson and Drust, 2005). At any level soccer is considered an open skill due to its consistently changing environment, varying movements and multiple planes of motion (i.e. sideways and backwards) in addition to the unpredictable work rest periods highlights the dynamic nature of football (Ekblom, 1994., Reilly, 1997., Drust *et al.*, 2000). However it has been suggested that tests of both acceleration, over 10m, and max speed, which is achieved over distances of greater than 40m, should be established when testing soccer players (Mendez-Villanueva *et al.*, 2011). Buchheit *et al.* (2012) in attempting to simplify testing procedures in their assessment of where maximum speed occurred measured over 10 to 40m found that in Under 15 and 16 youth players the max speed occurred between 20-30m and 30-40m (~50% split).

In addition to inline running actions players also perform running movements which see them accelerate, decelerate and change direction before re-accelerating (Dellal, 2008) and Portas *et al.* (2010) has recognised and highlighted a number of movement patterns used within the adult elite game. In addition Little and Williams (2003) elude to a relationship between speed and agility when suggesting that both should be used in conjunction to provide a thorough indication of players speed capacity.

It has been suggested that agility training should involve both technical and tactical elements of the game which would include cognitive functions or tasks (Mujika *et al.*, 2009). Henry *et al.* (2012) state that better players have superior motor ability and recommends that agility training should contain feint and non-feint training through sports specific training or match situations as the feint is a unique skill. In their study, which was similar to Gabbets (2009), Henry *et al.* (2012) found that agility time

worsened when incorporating a feint which lengthens the movement time due to a second decision making component. Buchheit *et al.* (2012) in examining repeated sprints suggests that perception skills such as scanning and decision making should be considered in the testing and training of agility however the inclusion of reaction drills or cognitive components may be problematic when looking at physical components (Cone, 2012). When looking at the agility model proposed by Young *et al.* (2001) (Appendix E) it can be seen that agility is comprised of two main components which each have sub strands. These can be categorised as cognitive (perception and decision making) and somatic (physical characteristics and attributes). It may be therefore more accurate to term pre-planned movements as change of direction (COD) (Young and Farrow, 2006).

The examination of systems which use gates and lights to incorporate a reactive component has been suggested as a test for agility as it incorporates a decision and response aspect (Gabbett *et al.*, 2008; Gabbett and Benton, 2009). This concept has been further developed and has used full size video images to elicit a response from subjects in a move towards 'read and react' game-specific stimulus (Gabbett *et al.*, 2008). Gabbett *et al.* (2008) looked at a number of agility tests and a reactive test, and found similar scores in the pre planned movement but that the reactive test using an arrow or player on a screen differentiated between rugby league groups. They state that whilst linear speed and COD speed are significantly related, decision time was not related to COD meaning that pre planned and reactive tests are looking at 2 different qualities and should be highlighted in the player and trained accordingly. In testing rugby union players Green *et al.* (2011) highlighted the need to include straight line and pre planned moves as it is representative of game scenarios.

Young *et al.* (2011) following a similar methodology to Gabbett *et al.* (2008) used lit up arrows or video of players to illicit a response between two groups (elite vs club). The two groups showed no difference in time in the arrow condition, but did show a significant difference when the video of a player was used indicating the superiority of the elite group resides in their ability to perceive and use the information, or cues, of the simulated attacker changing direction. Whilst it may be argued that the difference in playing level between the two groups may have been too wide, local school vs national talent group, the interesting aspect of the study is that the school group performed better than the elite group in the pre-planned task and it was postulated that the agility test itself was not specific to the AFL sport as it had five turns and included a greater than 180 degree turn around a pole, so it may be that the test separated the groups due to its lack of specificity to the sport the elite group were involved in which generally requires movements of less than 90 degrees. This gives weight to the argument that agility testing needs to incorporate few turns and take less distance, and therefore

takes less time than is required in a number of commonly used tests. It may also indicate an ability of the national talent group to mask physical limitations by their ability to 'read' the game.

A number of authors have shown that agility performance is influenced by perceptual and decision making factors (Young *et al.*, 2011). Oliver and Meyers (2009) found that 10m sprint time and was a strong predictor of reactive and planned agility which contradicts the work of Sheppard *et al.* (2006). Mujika *et al.* (2009) showed a correlation between 15m sprint times and a 15m slalom course, but the specificity of the course to the sport could be called into question (3m lead in, 3 changes of direction and 50cm hurdle with 7m sprint). Farrow *et al.* (2005) noted that skilled players moved before the ball release and Gabbett and Benton (2009) when looking at agility with a reactive component noted that there is a 'speed accuracy' trade off so a reduction in the decision time resulted in a reduction in the accuracy of the response. Using club and academy players from Rugby union Green *et al.* (2011) further complicated the issue by finding significant differences in 10m and 30m sprint times as well as COD and reactive tests. Whilst Gabbett *et al.* (2008) found that speed over 5m, 10m, 20m and movement time was significantly different but the agility test did not produce significantly different results. Whilst the use of reactive tests using video screens and game situations may be shown to be valid, the expense and time consuming nature of the protocol makes it impractical even for elite players, what is clear is that agility is a complicated issue and a clear understanding and how to test and train for it is elusive (Young and Farrow, 2006).

2.4 INJURY RATES IN SOCCER

Despite its worldwide popularity and high rates of injury there are limited studies on injuries in soccer and efforts need to be made to identify high risk groups and prevent injury by identifying the factors and mechanism that play a part in the occurrence of injury in soccer players (Hawkins *et al.*, 2001; Rumpf and Cronin, 2012). An examination of the injury site and rates within the Premiership showed that over 85% occurred in the lower extremity, with 58% being classified as non-contact, which equated to an average of 1.3 injuries per player per season with an average of 24 days training and 1 game missed (Hawkins *et al.* 2001). The major conclusion from this work was that the training programs at clubs needed attention and in particular how these programs are modelled throughout the season in order to manipulate the risk and recovery of the players due to a high volume and intensity of games.

Within youth soccer, injury has been highlighted as a major reason for drop out and whilst there has been a number of studies examining recreational sports, little is known about injury at the high performance level (Steffen and Engebretsen, 2010). In a similar study to Hawkins *et al.* (2001), Price *et al.* (2004) investigated the injury rates in youth soccer players at soccer clubs in England in both training and match play and found that when examining the under 9 to under 19 age groups, the injury rate was 0.40 injuries per player per season with almost 22 training days and 2.31 games missed. The consequences of this are that skill acquisition and players development may be hindered due to training days missed. However the mean data may be misleading as the number of injuries increased linearly with age and as such the number of training days and games missed in the oldest age groups will be higher.

As with other studies examining soccer, the data from Price *et al.* (2004) showed that 90% of all injuries occurred in the lower limb with a large percentage occurring around the knee due to the rotational forces that act at the knee due to the high number of changes of direction over the course of the match. These data re-enforce Hawkins *et al.* (2001) opinion that there needs to be a greater focus on the day to day training that the players perform. The incidence and specifics of injury during locomotion where not specified, but as the mechanics of running, specifically accelerating and decelerating, are frequent actions within the sport they require further examination due to the high percentage of non-contact injuries (Price *et al.* 2004).

Within the analysis from Price *et al.* (2004) there was a reported higher percentage of dominant side injuries compared to the non-dominant side which Ekstrand (1982) suggests are due to the dominant side being involved in the contact aspects of the game (tackling). However non-contact injuries make up over 60% of all injuries which suggests that there are other mechanisms at work that require attention, such as strength deficits between the lower limbs which have been reported in soccer and implicated in injury (Fousekis *et al.*, 2010).

Moore *et al.* (2011) looked specifically at the mechanisms of the injury around the knee joint at Premiership academies over a five year period in the Under 9 to Under 16 age groups and found that there was an incidence rate of 0.71 knee injuries per player per season with 17 days and 2 games missed for each injury. Whilst the epidemiology of common knee injuries in youth is limited, the data of Moore *et al.* (2011) concurred with Price *et al.* (2004) in which they observed a linear increase in the number and severity of injury as players progressed through the age groups from Under 9 to Under 16 indicating a clear issue of growth and maturation in youth football players. Moore *et al.* (2011)

suggest that this is due to (1) an increase in the time in training and games, (2) the increase in the size and speed of players and (3) an increase in the aggression in older players; however at the present time we are unsure of the game demands of youth players. What is of particular concern is that the Premier league Elite Player Performance Plan (EPPP) reforms will increase the number of contact hours in training and could lead to a greater incidence of injuries to elite soccer players.

In reviewing injury occurrence in soccer Rumpf and Cronin (2012) highlighted the contact nature of injuries and the high percentage incidence of lower body, they also highlighted the need for complete rehabilitation from injury to limit the re-injury rate with programs that are progressive and suggest that the players can perform a range of tests before returning to play. Beijsterveldt *et al.* (2013) in acknowledging the high incidence of non-contact soccer injuries as amongst the highest in sports has suggested that despite the high rate, insufficient evidence is available on the efficacy of preventive training programmes on injury incidence which may be due to a lack of knowledge on the demands of the sport especially in youth. This suggestion was also echoed by Rumpf and Cronin, (2012) who suggest that specific screening programs should be developed which would help highlight at risk players and allow for a greater focus of a clubs resources. In order to do this a systematic assessment program that focuses on the lower limbs needs to be developed and applied in a soccer setting as there is a clear lack of information in this field.

2.4.1 Functional Screening

Historically injury assessment has focused on isolated fitness components at single joints or muscle groups such as flexibility and strength (Frohm *et al.*, 2012; Frost *et al.*, 2012) and whilst there has been a plethora of studies examining possible predictive indicators of injury there has not been a consensus established. Ostenberg *et al.* (1998) suggested that in order to return to activity after injury, functional tests should be used that represent the forces exerted in the match. They also reported that isokinetic testing was not correlated with 5 functional tests (1 leg hop for distance, triple jump, vertical jump, single leg raise, and a timed square hop) however these functional tests may not represent the forces associated with team sport. The use of dynamic assessment is usually performed in a clinical setting to assess a player's readiness to return to play after an injury and usually included a number of single leg hop tests which are designed to replicate the demands of the sport (Hamilton *et al.*, 2008). Due to the linear or vertical nature of the testing, and hence ease of assessment and reproducible results, these tests may not have been as sport specific as first envisaged. There is therefore a need to develop a field test that is easily administered and which has been based on the demands of the game.

Hewit *et al.* (2012) expanded on this early work and examined a number of single leg multi directional jumping tasks in order to assess lower limb asymmetry and reiterated the point that while vertical jumping has been used due to its ease of set up and administration it may mask possible left versus right side imbalances which may become evident in single leg tasks and that these single plane movements may not best represent the patterns of functional movement in sports players. Hewit *et al.* (2012) concluded that there was a lack of clarity when examining asymmetry and whilst most of the players involved in the study had 10-15% asymmetries, a focus on the force or distance measurements should be used as a threshold for intervention however the aim should be to minimise all imbalances. This injury phenomenon may be exasperated when increasing the number of games in a short space of time and by the contact nature of the sport since increasing fatigue may increase the likelihood of injury especially in the weaker limb.

In a move away from the ballistic single leg hopping tasks Cook (2004) suggested a seven movement test series aimed at identifying imbalances and suggested a number of methodologies to correct them. This early work has been refined by a number of authors and recently a number of functional movement tests have been suggested and shown to be successful in improving soccer players with asymmetries (Kiesel *et al.*, 2009). However there are a number of practical and methodological issues associated with using a screening battery of tests, Frisch *et al.* (2011) using Under 15 to Under 19 soccer players examined a wide range of variables in a preseason screening process which included strength testing, coordination, joint laxity, aerobic fitness, balance and explosive strength and found that there was no meaningful indicator of injury. However, there were several methodological issues with the study which limits the translation of these findings, for example the test screen process was only performed during the preseason and as such the performance of the players may have/will have changed through the season but with the time constraints of the testing process in season testing may not have been feasible. Associated with this time constraint is the use of laboratory tests which will not be possible for most soccer teams, therefore what is required is a 'functional' field based test

Jones and Bampouras (2010) examined single limb strength recorded on a leg press machine and compared to a number of functional jumping tasks and measures on an isokinetic machine and found that the leg press could determine isolateral imbalances between the dominant and non-dominant legs. They state that the assessing of lower limb imbalances should be assessed by the qualities that are prevalent in the sport and in the situation of soccer jumping and sprinting short distances is directly relevant to soccer (Mayhew *et al.*, 2004; McMillan *et al.*, 2005) and using single limb assessment is relevant due to locomotion being unilateral (Hewit *et al.*, 2012).

The development of testing measures that compare lower limb asymmetry have focused on specific fitness components and projected these results to the likelihood of injury and possibly reduction in performance however there are limited studies which have attempted to examine these fitness component imbalances through performance (Jones and Bampouras, 2010). Whilst it has been acknowledged that to prevent lower body injuries screening tools may be a crucial component, there is a need for the development of low cost tools and procedures that can be used in the field (Dallinga *et al.*, 2012). The coach, clinician or strength and conditioner needs to determine which variables are relevant to the sport and test appropriately (Hewit *et al.*, 2012) and to allow this it is essential that the specific demands of the game at the relevant level are reliably and accurately assessed.

2.5 SUMMARY

The transition from academy to the professional level is one of the key pivotal stages in the development of elite professional soccer players and our understanding of this process is incomplete (Mills *et al.*, 2012). Soccer at the highest level requires players to excel in a number of different components of fitness and of particular importance and interest is soccer agility and the ability to sprint short distances (McMillan *et al.*, 2005). There are few researchers who have provided a comprehensive detailed assessment of elite youth players and the vast majority of these studies have only examined specific aspects of fitness usually in a laboratory based setting (Mujika *et al.*, 2009; Wong, 2009; Huijgen, *et al.*, 2010). Moreover, whilst it has been shown that elite adult players have high levels of power (Cometti *et al.*, 2001) and strength (Wisloff *et al.*, 1998) in the lower extremity. The majority of information that is available on youth is dated, limited, and relates to non-elite soccer players (Malina *et al.*, 2005; Chamari *et al.*, 2005; Vanderford *et al.*, 2004; Tsolakis *et al.*, 2004; Faigenbaum *et al.*, 2002), therefore there is a clear gap in the literature which has consequences for the development programs of academy players.

Historically the development of players has been wholly in the form of improving soccer technique with very little focus on developing physical attributes. However, key fitness components have been identified and continue to increase the physical athleticism of players to such a level that it is just not enough for players to be technically proficient with the ball. The studies contained in this thesis are designed to further examine how an increase understanding of the match demands of youth soccer to allow the development of highly tailored training programs to maximise the development of youth players. The aim of any program should be to continually looking for the safest and most successful way to develop young players to the highest level (Johnson *et al.* 2008) and how to integrate a holistic approach to training is needed which looks to improve performance and reduce injury rates (Rumpf and Cronin, 2012).

CHAPTER 3

GENERAL METHODOLOGY

3.1 GENERAL METHODOLOGY

3.1.1 Location of testing and ethical approval

The comparison of GPS and Prozone (study 1) occurred at Goodison Park (Everton FC) with the examination of the Academy game analysis (study 2) occurring at a variety of premiership academies using the Everton Under 18 Scholarship players as subjects. The development of a sports specific test (study 3) and its subsequent use in the highlighting of isolateral muscle imbalances (study 4) and the corrective training (study 5) took place at the Al Ain Soccer Academy (Abu Dhabi, U.A.E). The ethical committee of Liverpool John Moores University approved all experimental protocols and procedures.

3.1.2 Participants

All of the subjects who participated in each study were young healthy males engaged in competitive soccer and the training and testing of this thesis was part of the conditioning schedule that they undertook as part of here development program at the Academy, the players had been involved in a structured academy program for a minimum of 2 years. All players participated on average in ~11 hours of training per week which typically involved two 30 minute weight sessions, 8 hours of soccer training over 5 sessions and 1 formal competition game. The soccer training sessions typically consisted of technical and tactical training and normally included a 15-minute warm-up, 20-minute technical training, 20-minute tactical training, 25-minute simulated competition, and a 10-minute cool down. A description of the subject's anthropometric characteristics is shown in table 3.1. All participants' over 18 gave written consent and those subjects under 18 had their parents written consent to participate after the details of the study had been fully explained and were made aware that they could withdraw at any time.

Table 3.1 Subjects mean (\pm SD) physical characteristics

	Study 1	Study 2	Study 3	Study 4	Study 5
Age (years)	17 \pm 0.8	16 \pm 0.9	16 \pm 0.9	16 \pm 0.9	16 \pm 0.3
Height (cm)	178 \pm 6	177 \pm 5	178 \pm 8	178 \pm 8	172 \pm 2
Body mass (kg)	73 \pm 3	71 \pm 3	70 \pm 3	70 \pm 3	65 \pm 4

3.1.3 Anthropometry

Subject's height and body mass was assessed prior to the start of each of the studies and was part of the academy monitoring. The subjects height and nude weight, plus shorts, was assessed using a dual height/weight stadiometer (SECA, Birmingham, UK).

3.2 GAME MOTION CAPTURE

3.2.1 Global positioning system (GPS)

All GPS data collection was performed using a 5Hz (Catapult, MinimaxX) GPS unit (figure 3.1). Prior to kick off the GPS units were switched on and left in the open for 10 minutes to attain a satellite lock as per the manufacturers instruction (figure 3.1). All the units had been previously calibrated by the UK distributor as per the manufactures instructions.



Figure 3.1: A Catapult GPS unit.

Subjects were fitted with a custom made vest that was worn under their playing shirt with a pocket that secured the GPS unit (88 x 50 x 19mm, 0.088kg) in the upper back between the shoulder blades (figure3.2). All players had used the motion capture system in training and in match play and were fully habituated and familiarized with the GPS system.



Figure 3.2: Location of the GPS unit in a specially designed harness

The GPS devices were switched off at the conclusion of the game the data was downloaded to a personal computer via a multi-unit docking port (Figure 3.3). The data stored included time, velocity, distance, position, direction, player load, Horizontal Dilution of Precision (HDOP), Figure of Merit, Number of satellites, individual satellite decibel (dB) strength, and individual satellite angle. Speed thresholds were determined by using Prozone equivalents (Table 3.2). The downloaded data was visually inspected using Sprint software (V 5.0) and then exported into Microsoft Excel for further analysis, which included the total distance in each speed zone, calculation of average number of satellites, and Horizontal Dilution of Precision (HDOP).



Figure 3.3: The GPS recharging and download docking station

3.2.2 ProZone™

Each player was monitored using an eight camera (Vicon Surveyor 236 cameras dome/SV FT-W23) computerised video match analysis system (ProZone Version 3.0, ProZone Sports Ltd1, Leeds, UK) which provided individual data. The cameras were mounted at the top of each stadium and positioned to allow the entire playing area to be seen by two cameras (Figure 3.4).

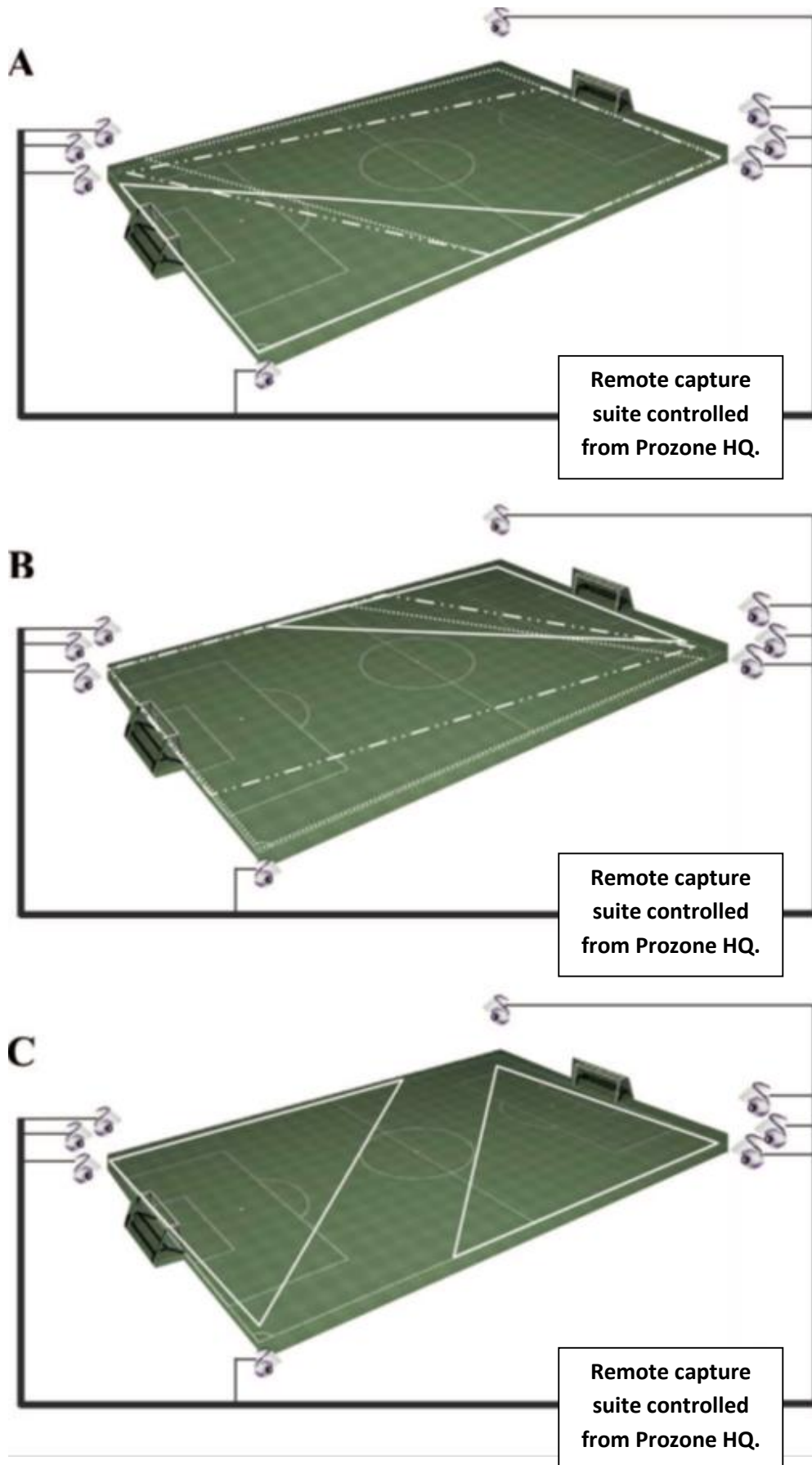


Figure 3.4: The eight camera ProZone™ setup, taken from Bradley *et al.*, (2009)

The signals received from the cameras were digitised at a sampling frequency of 10Hz and the captured data were analysed using match-analysis software (Stadium Manager, ProZone Sports Ltd1, Leeds, UK). The players' speed thresholds were coded into categories (Table 3.2), which are the default settings within the ProZone software. In addition a further category was calculated, high-intensity running which consisted of running, high speed running, and sprinting (running speed >4 m/s).

Table 3.2 Speed threshold limits (Di Salvo *et al.*, 2006)

Movement	Speed (km/h)	Speed (m/s)
Standing	0–0.6 km/h	0 m/s to 0.19 m/s
Walking	0.7–7.1 km/h	0.2 m/s to 1.99 m/s
Jogging	7.2–14.3 km/h	2m/s to 3.99 m/s
High Speed Running	14.4–19.7 km/h	4m/s to 5.49 m/s
Very High Speed running	19.8–25.1 km/h	5.5m/s to 6.9 m/s
Sprinting	>25.1 km/h	>7 m/s
High Intensity Running	>14.4 km/h	>4 m/s

3.3 Modified Speed/agility 505 test

The adapted speed/agility test used in studies three, four and five (Figure3.5) was based on the 505 test which was first proposed by Draper and Lancaster (1985). The subjects started by standing between the start cones (Position A) and sprint as quickly as possible between the cones (Position B) and place any part of the foot over the line at Position C, which was 12m away from the start subjects were then required to sprint back through the start cones (Position A). Timing gates are positioned at the Start/finish (Position A) and 7m away (Position B) at a width of one meter. The test provides 4 timings, (1) 7m acceleration, (2) 10m agility and (3) Flying 7m as well as a total time for completion. In addition the test can be repeated with the opposite foot touching the mid-line to provide a left/right comparison.

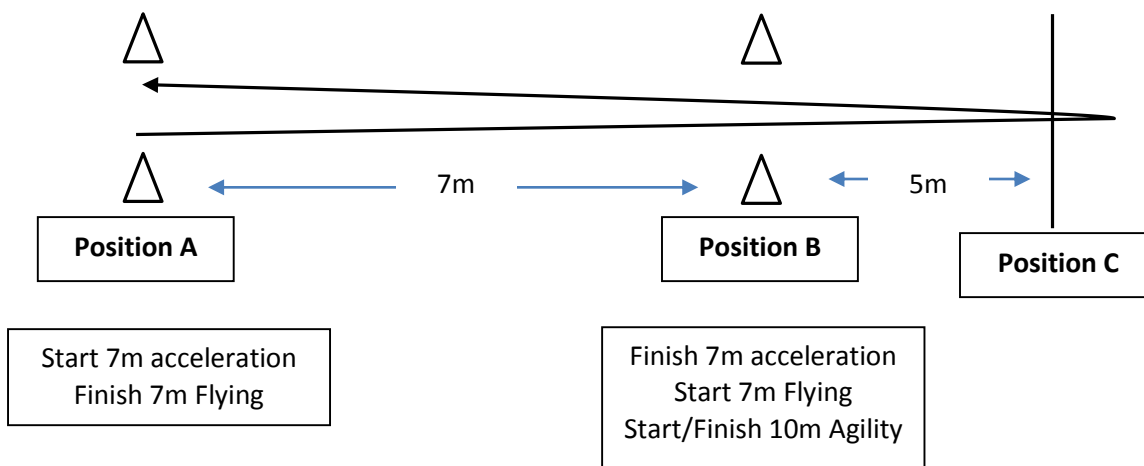


Figure 3.5: Diagram of the adapted 505- agility test.

3.4 Isokinetic Dynamometer

Muscle torque was assessed in study four (chapter seven) using an isokinetic leg dynamometer (Biodex System 3, Biodex Medical Systems, Shirley, USA). The test was designed to assess knee concentric flexion and extension movements and measurements were taken at 1.08 and 2.16 rad/s. All participants were familiarised to the procedures the week before testing which involved the same testing procedures as presented here. A Pilot study had determined that with this population one familiarisation session was adequate for reliable results (flexion at 1.08 rad/s ($p=0.64$), and 2.16 rad/s ($p=0.44$), extension at 1.08 rad/s ($p=0.31$) and 2.16 rad/s ($p=0.48$). A standardized warm-up of 10 minutes cycling and dynamic stretching exercises preceded the formal testing and the participants were allowed two sub-maximal and one maximal practice attempts at each test condition.

The subjects were seated on the dynamometer in an adjustable chair with the hip angle at approximately 90° , the upper body was stabilized with straps secured across the shoulder, chest and hips. A resistance pad was also positioned on the thigh, proximal to the knee joint, to localize the knee extensors and knee flexors. The axis of rotation of the dynamometer shaft was aligned with the axis of rotation of the knee joint, midway between the lateral condyle of the tibia and the lateral condyle of the femur. The cuff of the dynamometer's lever arm was attached to the ankle, proximal to the malleoli. These positions were recorded for each participant and standardized for subsequent trials. The range of motion was pre-set from 0° (flexed) to 80° (almost full extension) and a correction for gravity was made. At each test condition two submaximal warm-up movements were followed by

three maximal efforts. A rest of 20 sec. was allowed between consecutive efforts with 1 min between movements at different angular velocities. Verbal encouragement was given and the maximum score was recorded for each of the trials. All tests were performed on the subjects dominant and non-dominant legs which were determined through questioning on which leg they preferred when kicking a ball.



Figure 3.6: The Biodex isokinetic assessment chair.

3.5 Statistical Analysis

All data in are presented as means (\pm SD) with p values ≤ 0.05 indicating statistical significance. Prior to analysis all data were assessed for normality using standard graphical methods (Grafen and Hails 2002). To determine effect sizes a modified Cohen scale (d) was used to determine the standardized typical error (TE) of estimates (where 0.2 = small, 0.6 = moderate, 2.0 = large, and 4.0 = very large error), using the method of Hopkins (2012). All statistical analyses were performed using the statistical package for social sciences (SPSS, version 20, IBM, USA) unless otherwise stated.

CHAPTER 4

APPLICATION AND AGREEMENT OF GPS AND PROZONE[®] MATCH ANALYSIS IN SOCCER: A COMPARATIVE STUDY

GPS is becoming has become common place in professional sport to quantify the distances covered at different velocities and to employ this information in the monitoring of athletes and for use in the development of physical conditioning programs. What has not been established are the minimum measurement requirements to obtain valid and reliable data. The aim of this study was to compare 5Hz GPS and Prozone match data and to establish capture conditions to allow direct comparison of total distance and of distances in pre-determined speed zones.

4.1 Introduction

Identifying and quantifying movement patterns in team sports has traditionally been used by technical staff to review previous performances, and more recently by strength and conditioning coaches to develop valid sports specific training loads and intensities (Petersen *et al.*, 2009). Whilst the majority of performance analysis systems have historically been time motion studies or video based systems, the latter being time and labour intensive to analyse, there are now a number of GPS products that are becoming ever more popular (Frencken *et al.*, 2010). The use of individual GPS units in team sports can potentially give more comprehensive and accurate data that can be collected both in real time or analysed post game (Jennings *et al.*, 2010ii).

GPS systems that acquire data at 1Hz have been compared to timing gates within the literature and it has been established that at low running speed, total distance covered is accurate (Jennings *et al.*, 2010i; Portas *et al.*, 2010). However the measurement of high running speed or accelerations over short distances (<20m), both in a straight line and in those movements that have multiple changes of direction, the data become less valid and reliable (Petersen *et al.*, 2009). Mayhew *et al.*, (2004) and McMillan *et al.*, (2005) reported that the ability to repeatedly sprint short distances is directly related to the high anaerobic nature of soccer and that these high intensity actions are the most important in soccer. Petersen *et al.* (2009) have shown that these high speed movements may be missed with data acquisition rate set at 1 Hz, by measuring at a higher sampling rate of 5Hz it is possible to derive a more accurate picture of short high speed movements (Jennings *et al.*, 2010i; Portas *et al.*, 2010).

In addition to GPS, computerised, semi-automated, multi camera image recognition systems have been developed which use image processing algorithms to simultaneously track all the players (O'Donoghue, 2008). These systems are not portable but are useful during competitive soccer matches as the wearing of any measuring equipment by the players is prohibited by the world governing body (FIFA). The most common commercial system in use in England is Prozone® (PZ) and it is used to provide match data on physical and technical aspects of the game and has been proven to be valid and reliable (Di Salvo *et al.*, 2006).

At the present time the author is aware of only one study comparing the PZ and GPS systems (Harley *et al.*, 2011), although Randers *et al.* (2010) did examine similar technology these are not widely used within the game in England, and the conclusions drawn suggest that the two data sets may not be directly comparable as the GPS measured greater distances in total distance but under reported in

high intensity running (>4 m/s) and sprinting (>7 m/s). However there was limited examination of the satellite and HDOP capture conditions by Randers *et al.* (2010) which are generally reported as averages over the data capture period. As both systems are used extensively within the professional game in England, it is of direct interest to compare the two analysis tools.

The aim of this study was to compare data collected using a 5Hz GPS system (MinimaxX, Catapult) and the PZ match analysis system and to establish satellite and HDOP threshold limits within the GPS software to allow direct comparison between the two data sets with a focus on high intensity running (>4m/s).

4.2 Methods

The study took place mid-season due to the playing of competitive FA youth cup games at the clubs First team stadium, this fulfilled four criteria (1) that the game was played at a ground which had the PZ system installed, (2) the game was of a competitive nature so as to gain as accurately as possible data which represents typical match play, (3) the game was played with the best players available for selection, and (4) the game was not played early in the season where lack of fitness might influence the distances covered. The protocols were approved by the University Research Ethics Committee and the players and their parents were informed of the nature of the study and signed the written consent prior to the game. All the players had used the GPS system previously during training and competition games and were comfortable with the system. Players were free to withdraw from the study at any time.

Participants

Ten elite outfield youth team (Under 18) players (mean [\pm SD] age, stature, and body mass: 17 \pm .8years, 178 \pm 6 cm, 73 \pm 3 kg, respectively) from a premiership clubs academy participated in the study. Five of the players were in the second year of their scholarship and five were in their first year. These players had been involved in a structured academy program for an average of 6.3 years (range 4.4 to 8.7 years). In the previous 5 months the subjects had been exposed to a full time structured training environment that on average involved two 45 minute weight sessions, six 1.5 hour soccer sessions and 1 formal competition game per week. The soccer training sessions typically consisted of technical and tactical training and normally included a 15-minute warm-up, 20-minute technical training, 20-minute tactical training, 25-minute simulated competition, and a 10-minute cool down.

Procedures

This study followed the methodology and analysis procedures of Harley *et al.* (2011) when comparing the same two match analysis systems. Prior to kick off, 10 outfield players were fitted with a 5Hz GPS unit (MinimaxX, Catapult) in a custom made vest that was worn under their playing shirt with a pocket that secured the GPS unit in the upper back between the shoulder blades (Figure 4.1). The playing formation of the team comprised 4 defenders, 4 midfield players, and 2 forwards and the personnel and playing structure remained for the full game as there were no substitutions.



Figure 4.1: GPS unit and custom made vest

The game was played mid-week with an evening kick-off (7.30pm GMT) at a premiership ground that was fully enclosed with multi-level stadium on four sides, the stadium roof over-hang reached to within 10m of the side of the pitch and the average height of the grandstand was approximately 40m.

The players were also monitored by using an eight camera (Vicon Surveyor 236 cameras dome/SV FT-W23) computerised video match analysis system (ProZone Version 3.0, ProZone Sports Ltd1, Leeds, UK). The cameras were mounted at the top of each stadium and signals received from the cameras were digitised at a sampling frequency of 10Hz. The captured data were analysed using match-analysis software (Stadium Manager, ProZone Sports Ltd1, Leeds, UK). The system has been previously been independently validated to verify the accuracy of the data (Di Salvo, *et al.* 2006, Bradley *et al.*, 2009).

The GPS data was downloaded via a multi-unit docking port and visually inspected using Logan plus software (V 4.5.1a). The time that the 10th subjects GPS unit established a satellite connection and started to collect movement data was determined and used as the start point for data of all the GPS units. This process was repeated for the second half as the units lost the satellite connection during half time as the players were in covered changing rooms. The start points were determined as ten minutes into the first half and six minutes into the second half.

The two data sets, PZ and GPS, were synchronised and exported into Microsoft Excel. The total time of data collection for each half was determined as 36.36 minutes for the first half and 43.15 minutes for the 2nd half. The data was compared for each of the running intensities (Table 4.1) which are predetermined velocity zones within the PZ program. In addition High intensity running (sum of the 3 highest velocity groups, >4m/s) was also calculated as this is a common reporting feature within PZ reports. Within the GPS software a small amount of erroneous unallocated data is acknowledged for each player, which was typically less than 0.5%, this data was disregarded.

Table 4.1 Speed threshold limits

Movement	Speed (km/h)	Speed (m/s)
Standing	0–0.6 km/h	0 m/s to 0.19 m/s
Walking	0.7–7.1 km/h	0.2 m/s to 1.99 m/s
Jogging	7.2–14.3 km/h	2m/s to 3.99 m/s
High Speed Running	14.4–19.7 km/h	4m/s to 5.49 m/s
Very High Speed running	19.8–25.1 km/h	5.5m/s to 6.9 m/s
Sprinting	>25.1 km/h	>7 m/s
High Intensity Running	>14.4 km/h	>4 m/s

The subject's data was further analysed by examining it in 10 minute sub-divisions (15 to 25 minutes, 25 to 35 minutes, 35 to 45 minutes, 50 to 60 minutes, 60 to 70 minutes, 70 to 80 minutes, and 80 to 90 minutes) similar to the methodology of Harley *et al.* (2011). The data was reclassified by the subjects who averaged a satellite lock of over 4, 4.5, 5 and 5.5 and those subjects that averaged a Horizontal Dilution of Precision (HDOP), a figure indicating the accuracy of a global position, of below 4, 3, 2 and 1.8 for the ten minute period which were established by the author due to the minimum requirements of data points in each category for analysis.

In addition, the raw data from the Logan plus software was exported into Excel and the average number of satellites and HDOP for each player was calculated for each half and for each ten minute period. Correlations between the number of satellites and the HDOP were performed which allowed for secondary analysis and comparison of the two data sets to determine the parameters that produced data that was not significantly different from the PZ data in total distance and high intensity running (>4.0 m/s).

Statistical Analysis

To determine differences between PZ and GPS derived measures of speed and distance a Student paired t-test was used and statistical significance was fixed at $P < 0.05$. To examine the relationship between the capture conditions, number of satellites and HDOP, a Pearson's correlation analysis was performed. All statistical analysis was conducted using SPSS (version 20) with statistical significance set at $p < 0.05$. Following the methodology of Harley *et al.* (2011) paired t-test statistics were used to analyse differences between PZ and GPS for TD, HSR, VHSR, SPR, and HIR for each 10 minute period and the effect sizes were determined using Cohens (*d*) test.

4.3 Results

The capture conditions of the first and second half are illustrated in Figure 4.2 and demonstrates that in the first half the average number of satellites for the players was 4.6 and the HDOP was 3.7. In the second half the average number of satellites increased to 5.4 and the HDOP decreased to 2.02 per player. Both data sets were significantly different between the halves (satellite $P < 0.005$, HDOP $p < 0.005$) emphasising that the second half was superior to the first with regard to the capture conditions.

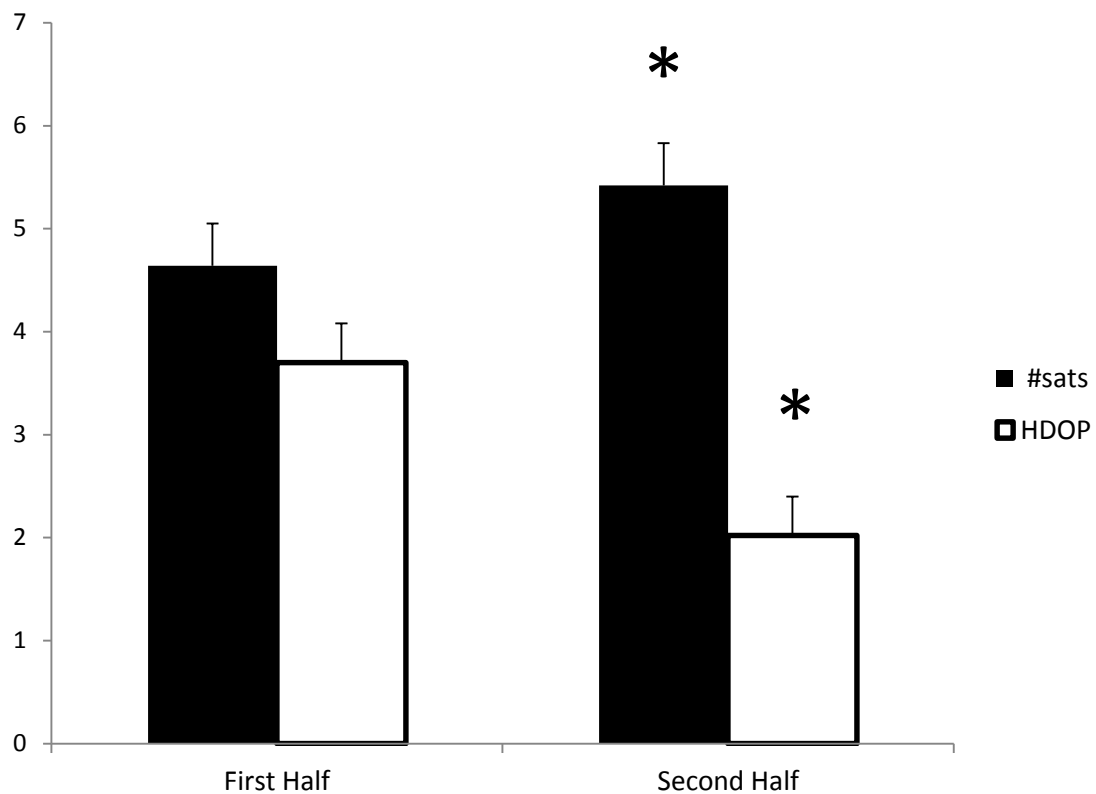


Fig 4.2: Average number of satellites and HDOP for each half. Data are Mean \pm SD (* indicates significantly different from first half).

The mean total distance recorded for each half using PZ and GPS can be seen in Figure 4.3. The distance recorded in the first half by the GPS was significantly greater ($p=0.004$) than the distance calculated by PZ for the same time period (4201m PZ v 4714m GPS) with all the players recording larger total distance from GPS data compared to the PZ data (range 23.4m to 1111m). There was no significant difference ($p=0.78$) between the GPS and PZ total distance data in the second half (4552m PZ v 4563m GPS).

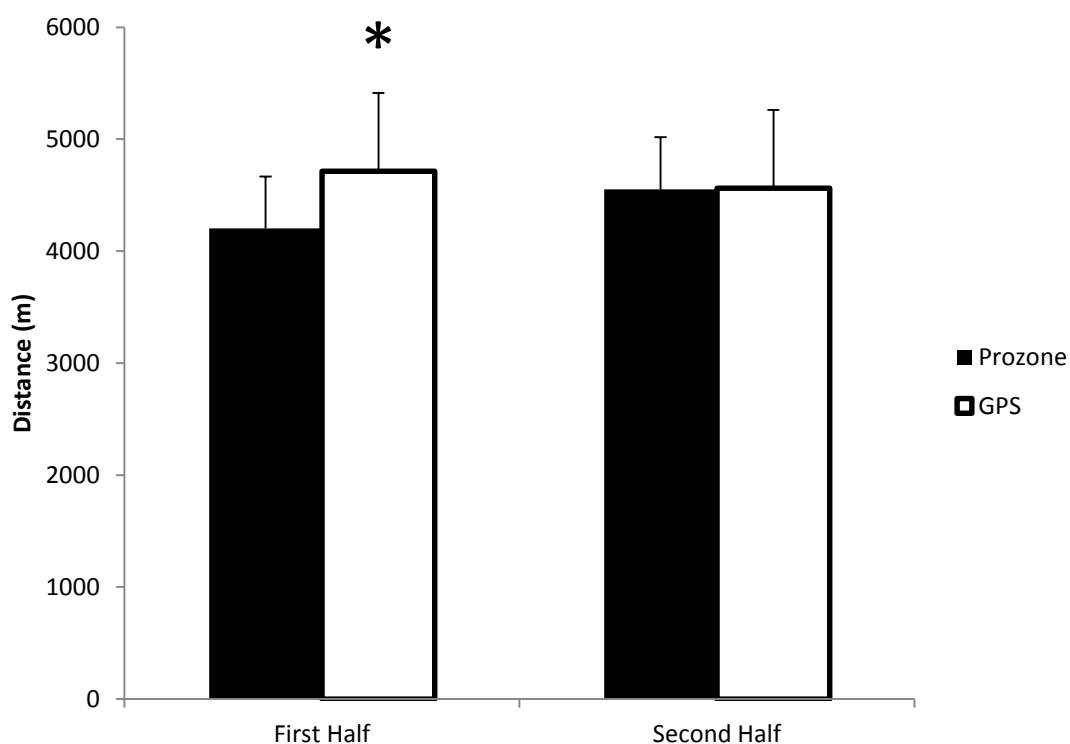


Fig 4.3: Total distance recorded from PZ and GPS for first and second half. Data are Mean \pm SD (* indicates significantly different from PZ data).

The distance for the first half speed zones can be seen in Figure 4.4. When examining the individual speed categories it can be seen that, as with the total distance covered, in the first half the GPS recorded significant differences ($P<0.005$) in four of the speed categories compared with the PZ data (sprints, Hi Int, jog and stand).

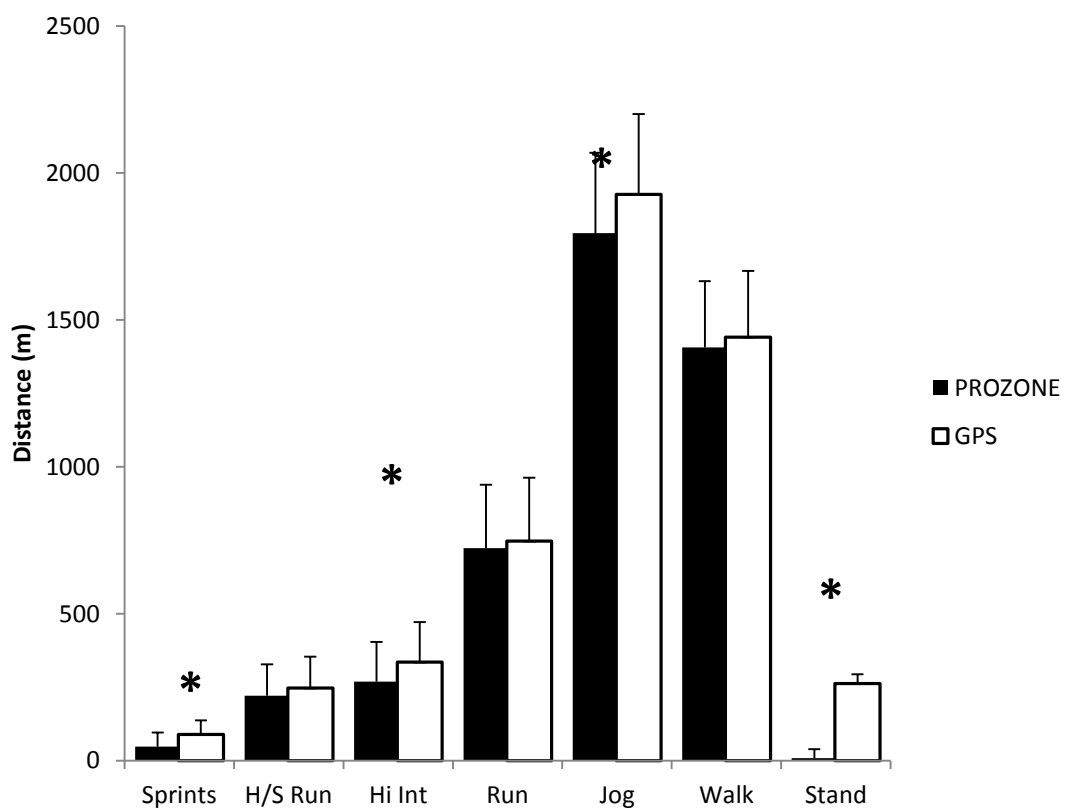


Fig 4.4: First half distance in each of the different speed zones for PZ and GPS. Data are Mean \pm SD (* indicates significantly different from PZ data).

The second half distance covered in each of the speed categories can be seen in Figure 4.5. The PZ recorded significantly larger differences in the sprint ($p<0.005$), high intensity ($p<0.005$), run ($p<0.005$) and walk ($p= 0.01$) and the GPS recorded a significantly greater distance in the stand ($p<0.005$) category.

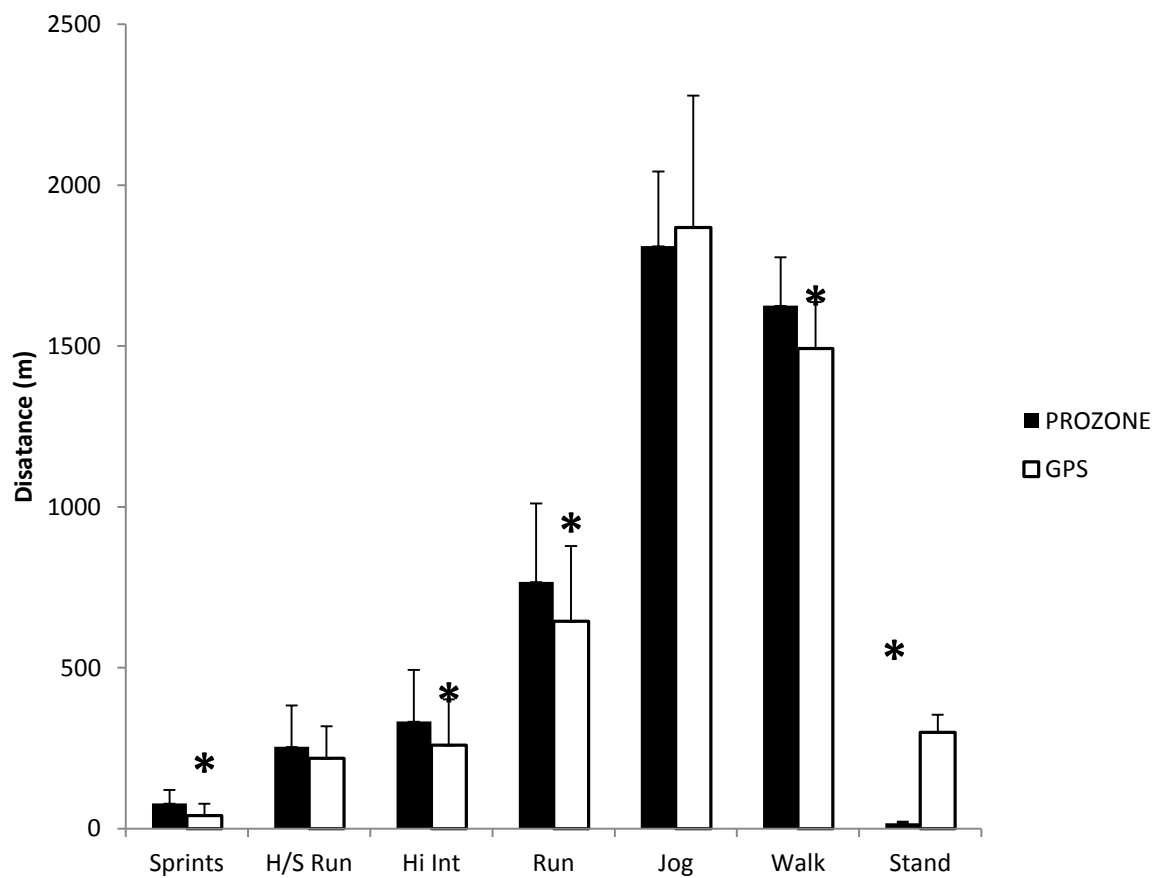


Fig 4.5: Second half distance in each of the different speed zones for PZ and GPS. Data are Mean \pm SD (* indicates significantly different from PZ data).

Total distance was not significantly different ($p>0.05$) between PZ and GPS for the second half (Figure 4.2) however within the individual speed categories there are significant differences between several of the groups (Figure 4.5). Examination of the average number of satellites and the HDOP of each of the players showed a relationship between the average number of satellites locked on to the GPS unit and the HDOP (Figure 4.6) and shows that there is a strong negative correlation ($r = -0.884$, $p < 0.001$) with nine of the ten subjects in the second half averaging over 5 satellites. The results suggesting that there is a five satellite threshold to which data can be considered improved for measurement of total distance.

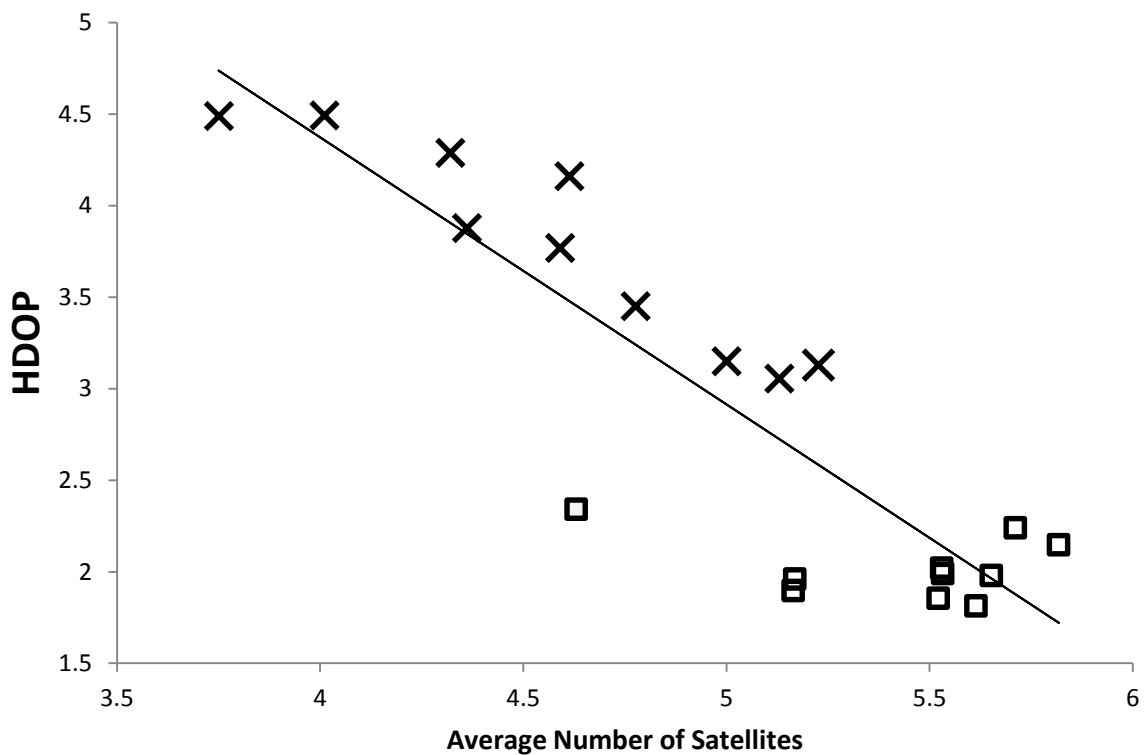


Figure 4.6: Correlation of number of satellites and HDOP. X is first half data.

Figure 4.7 shows the comparison of total distance PZ and GPS data when 12 players (three in the first half and nine in the second half) were reclassified to an average of over 5 satellites per half (range 5.00 to 5.82) there was no significant difference between the two groups ($p = 0.44$). There were eight players (seven from the first half and 1 from the second half) which averaged a satellite connection below 5 (range 4.32 to 4.78) which were significantly different ($p < 0.001$) from the PZ data.

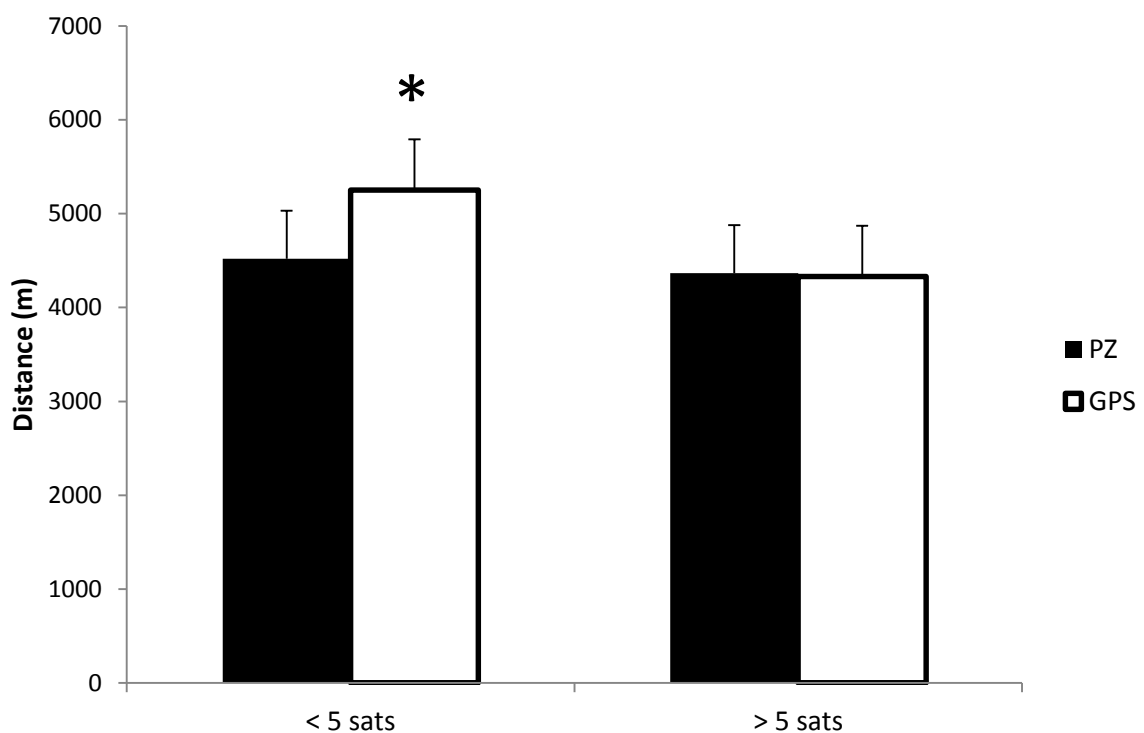


Figure 4.7: Comparison of recorded total distance covered by PZ and GPS when players averaged a satellite connection of five or more satellites. Data are Mean \pm SD (* indicates significantly different from PZ data).

Figure 4.8` shows the distance covered in each of the speed categories when a player averaged over 5 satellites. The GPS recorded significantly less distance than the PZ in four of the categories (H/S run, run, Hi Int, and walk) with the GPS recording a significantly greater total in the stand category.

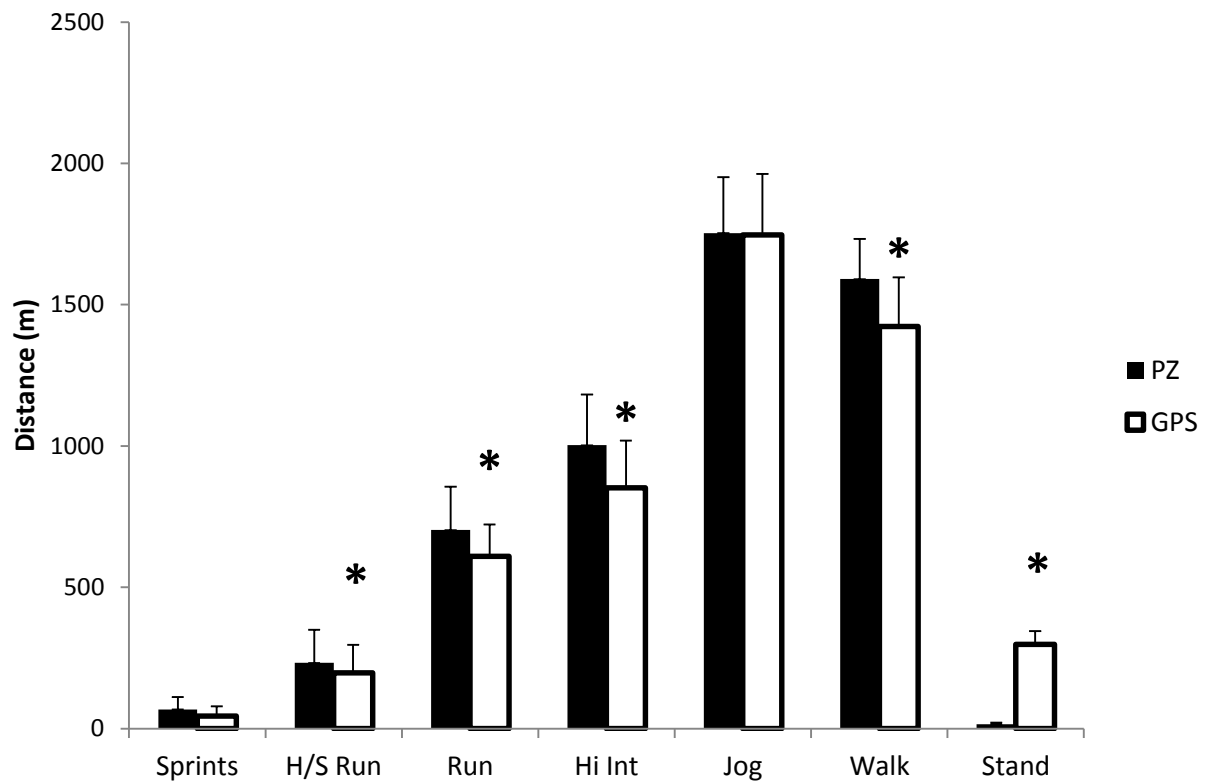


Figure 4.8: Distance of different speed zones for PZ and GPS when averaging five or more satellites. Data are Mean \pm SD (* indicates significantly different from first half).

In examining the correlation data (Figure 4.6) a minimum cut off limit of five satellites was used and a HDOP threshold of two selected, the data points that meet these two criteria were re-analysed. These criteria were selected as it was the highest satellite cut-off and lowest HDOP cut-off that allowed for eight subjects to be included in the subsequent analysis.

Figure 4.9 shows the speed categories, which were compared to the matching PZ data and no significant difference in the sprint ($p=0.11$) and high speed run ($p=0.47$) and the run ($p=0.051$). However the high intensity running (sum of the highest speed groups) showed significant differences ($p=0.03$). The Jog category showed a no significant difference ($p=0.61$) and the two slowest speed categories, walk and stand, did show significant differences between the PZ and GPS data ($p=0.02$ and $p<0.001$ respectively) however when combining these two lowest velocities there are no significant differences between the two systems ($p=0.43$).

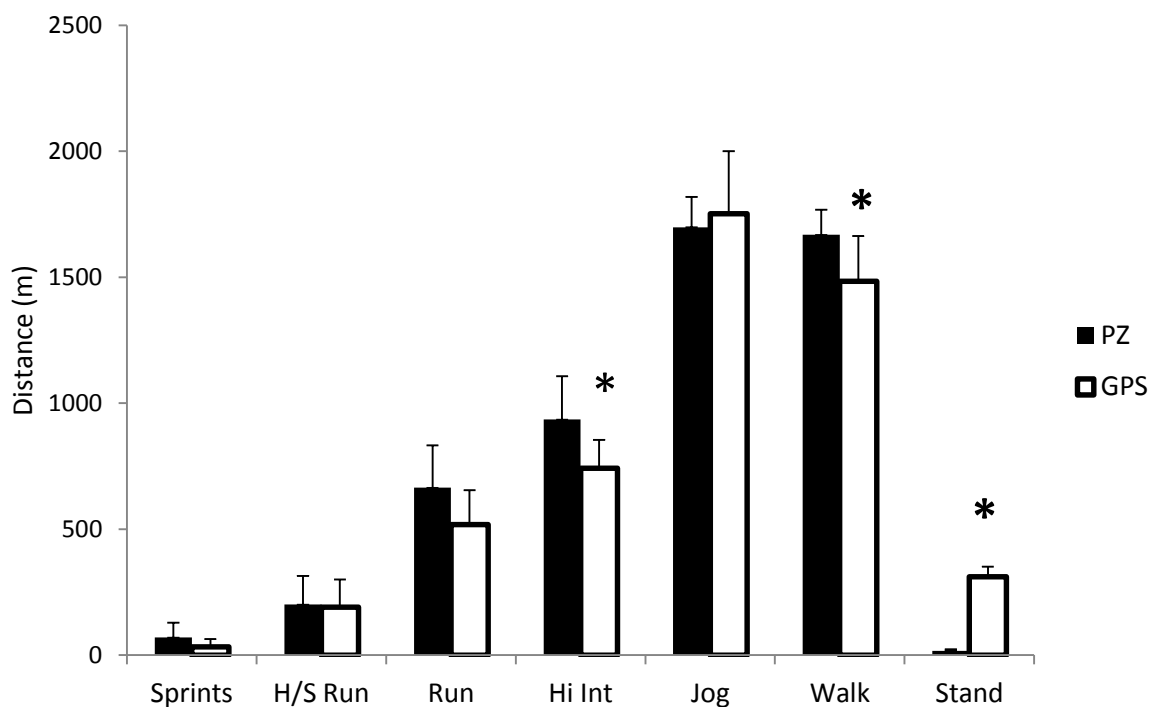


Figure 4.9: Distance of different speed zones for PZ and GPS when averaging five or more satellites and an HDOP of less than two. Data are Mean \pm SD (* indicates significantly different from PZ data).

n assessing the capture conditions it can be seen in Table 4.1 that the individual player percentage values for the HDOP and the number of satellites vary through the first and second half of the match. It can be observed that whilst there are players who average an HDOP of under 2, there are times when the number of satellites and the corresponding HDOP are small and large respectively. This can be seen with player 3 who averaged a HDOP of 1.81 but in over 11% of the data points had a HDOP over 2.5 and with player 7 who averaged a satellite lock of five but had 2.3% of the data points generated with three satellites and 27.3% of the data points generated by a satellite lock of only four.

Table 4.1: Percentage of HDOP value and number of Satellites for the first and second half.

		Player 1		Player 2		Player 3		Player 4		Player 5		Player 6		Player 7		Player 8		Player 9		Player 10	
HDOP	<1	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.3%
	1-1.5	0.0%	36.7%	0.0%	35.5%	0.0%	38.6%	0.0%	0.0%	0.0%	43.9%	0.5%	31.7%	0.0%	39.2%	0.0%	35.5%	0.0%	16.3%	0.0%	0.0%
	1.5-2	0.0%	14.1%	0.0%	37.7%	0.0%	40.0%	0.0%	81.0%	0.0%	24.3%	11.7%	32.8%	0.0%	40.2%	0.0%	15.9%	0.0%	55.7%	0.0%	55.8%
	2-2.5	2.4%	11.2%	16.0%	15.0%	13.7%	10.1%	2.7%	6.8%	0.0%	8.9%	11.7%	11.3%	3.2%	10.4%	1.2%	21.9%	0.0%	8.8%	2.6%	8.3%
	>2.5	97.6%	38.0%	84.0%	11.6%	86.3%	11.3%	97.3%	11.7%	100%	22.8%	76.1%	24.2%	96.8%	10.2%	98.8%	26.6%	99.7%	19.1%	97.4%	35.6%
	Ave		3.88	2.24	3.06	1.85	3.11	1.81	3.45	1.9	4.29	1.98	3.22	2.18	3.15	2.02	3.77	2.15	4.49	1.96	4.16
Satellites	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	2	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.3%
	3	9.0%	0.1%	0.1%	1.2%	0.7%	0.0%	1.1%	0.0%	5.5%	0.0%	1.5%	0.1%	2.3%	0.0%	2.5%	0.1%	24.7%	0.1%	4.0%	1.9%
	4	46.8%	2.8%	12.2%	6.9%	7.6%	2.5%	26.6%	5.1%	57.0%	2.9%	20.4%	2.4%	27.3%	7.6%	38.2%	2.3%	75.0%	8.3%	33.8%	34.5%
	5	43.4%	31.1%	62.1%	31.1%	60.0%	34.8%	65.9%	70.5%	37.5%	31.8%	56.4%	42.9%	55.4%	29.4%	56.7%	24.0%	0.0%	66.1%	59.3%	61.6%
	6	0.9%	58.0%	25.5%	58.8%	31.7%	61.3%	6.4%	23.9%	0.0%	62.5%	20.2%	53.6%	15.0%	61.7%	2.6%	62.7%	0.0%	25.4%	3.0%	1.7%
	7	0.0%	8.1%	0.0%	1.7%	0.0%	1.3%	0.0%	0.0%	0.0%	2.9%	1.5%	1.1%	0.0%	1.3%	0.0%	10.8%	0.0%	0.0%	0.0%	0.0%
Ave		4.36	5.71	5.13	5.52	5.23	5.61	4.78	5.16	4.32	5.65	4.94	5.42	5.00	5.53	4.59	5.82	3.75	5.17	4.61	4.63

The sub-dividing of each players data into 10 minute periods and subsequent correlation between HDOP and number of satellites can be seen in Figure 4.10 and shows that the capture conditions replicated those of the half data (Figure 4.6) with a strong negative correlation ($R^2 = 62$), a breakdown of each subjects HDOP and the number of satellites locked on can be seen in Appendix B.

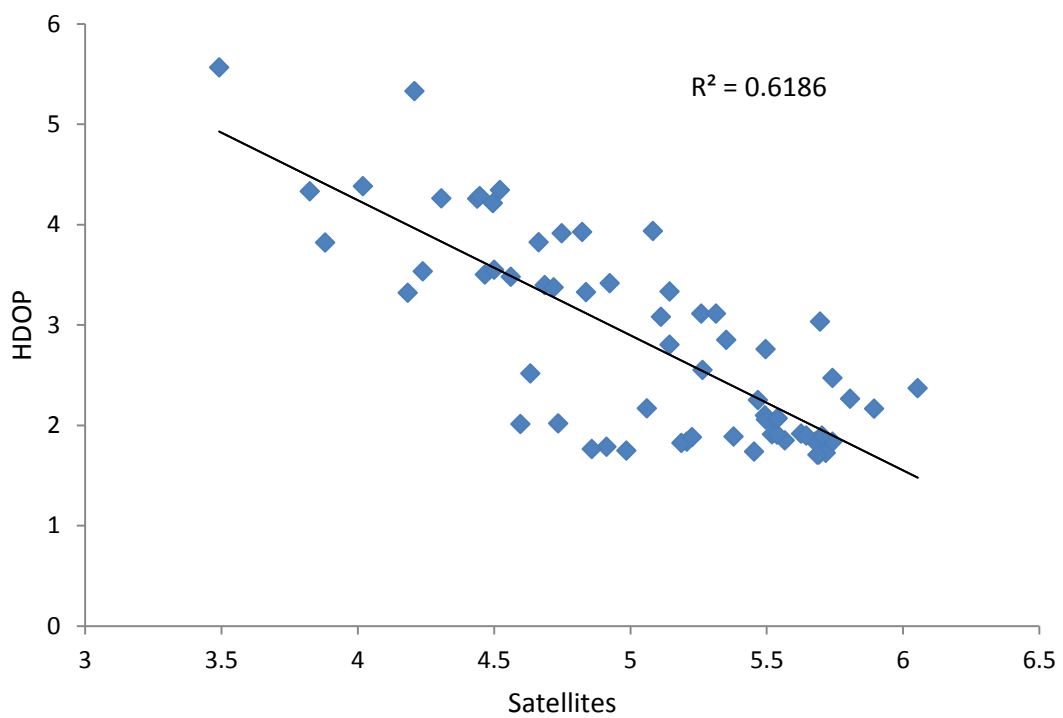


Figure 4.10: Correlation of number of satellites and HDOP.

Table 4.2: PZ and GPS performances (distance covered [m]) when using HDOP as the validation measure (* indicates significant difference between capture methods)

	PZ	GPS	<i>d</i>	<i>p</i>
HDOP less than 1.8				
Total distance (TD)	909 (± 118)	899 (± 151)	0.22	0.70
High speed run (HSR)	131 (± 69)	100 (± 39)	1.18	0.06
Very high speed run(VHSR)	41 (± 25)	39 (± 30)	1.19	0.73
Sprint (SPR)	8 (± 6)	8 (± 13)	0.02	0.97
High intensity running (HIR)	180 (± 94)	147 (± 64)	1.01	0.07
HDOP less than 2.0				
Total distance (TD)	1006 (± 154)	1005 (± 177)	0.02	0.941
High speed run (HSR)	150 (± 57)	124 (± 50)	0.88	0.0001*
Very high speed run(VHSR)	45 (± 25)	47 (± 41)	0.09	0.776
Sprint (SPR)	13 (± 12)	5 (± 9)	0.79	0.021*
High intensity running (HIR)	209 (± 77)	179 (± 71)	0.84	0.004*
HDOP less than 3.0				
Total distance (TD)	1163 (± 269)	1153 (± 293)	0.15	0.531
High speed run (HSR)	193 (± 80)	158 (± 67)	1.06	0.0001*
Very high speed run(VHSR)	62 (± 34)	54 (± 35)	0.42	0.080
Sprint (SPR)	17 (± 17)	9 (± 12)	0.74	0.003*
High intensity running (HIR)	272 (± 112)	224 (± 87)	1.20	0.0001*
HDOP less than 4.0				
Total distance (TD)	1175 (± 235)	1204 (± 278)	0.36	0.060
High speed run (HSR)	200 (± 75)	173 (± 68)	0.86	0.0001*
Very high speed run(VHSR)	65 (± 33)	58 (± 37)	0.36	0.064
Sprint (SPR)	18 (± 16)	14 (± 17)	0.30	0.112
High intensity running (HIR)	283 (± 108)	247 (± 97)	0.93	0.0001*

The re-categorised HDOP data can be seen in Table 4.2, the data was grouped into players who averaged an HDOP over the 10 minute capture period of less than 1.8, 2, 3 and 4. The less than 1.8 HDOP group showed that there was no significant difference ($p>0.05$) between any of the high intensity groups ($> 5.5\text{m/s}$) and the total distance ($p>0.05$) with the TD and SP indicating small effect sizes and the HSP, VHSP and HIR all showing large effect sizes. The groups of HDOP less than 2 and 3 showed significant differences in High speed run ($p<0.005$), Sprint ($p=0.02$ and $p=0.003$) and High intensity running ($p=0.004$ and $p=0.003$) and in the HDOP less than 4 group the high speed run ($p<0.005$) and the high speed running categories ($p<0.005$) showing significant differences.

The re-categorised number of satellites locked on data can be seen in Table 4.3, the data was grouped into players who averaged satellites of more than 5.5, 5, 4.5, and 4 over the ten minute period. In the number of satellites greater than 5.5 and 5 categories showed significant differences in four of the five speed groups (HIR $p<0.005$ and $p<0.005$, SPR $p=0.001$ and $p=0.002$, HSR $p=0.005$ and $p<0.005$, and TD $p=0.03$ and $p=0.02$ respectively) with only the very high speed group showing non-significant differences ($p=0.144$ and $p=0.0675$). There were significant differences (HIR $p<0.005$, SPR $p<0.005$, VHSP $p<0.005$, HSR $p<0.005$, and TD $p<0.005$) in all five categories in the number of satellites greater than 4.5 group. The over 4 satellite group showed significant differences in the total distance ($p=0.004$), high speed run ($p<0.005$) and high intensity running ($p<0.005$) groups. This data conflicts with the second half data in Figure 4.7 and suggests that a minimum of 5 satellites is not sufficient to obtain accurate total distance data.

Table 4.3: PZ and GPS performances (distance covered [m]) when using number of satellites as the validation measure. (* indicates significant difference between capture methods)

	PZ	GPS	<i>d</i>	<i>p</i>
Number of satellites > 5.5				
Total distance (TD)	1164 (±273)	1127 (±286)	0.76	0.030*
High speed run (HSR)	182 (±64)	152 (±56)	1.04	0.005*
Very high speed run (VHSR)	62 (±33)	50 (±34)	0.49	0.144
Sprint (SPR)	18 (±13)	6 (±8)	1.28	0.001*
High intensity running (HIR)	262 (±102)	208 (±71)	1.36	0.000*
Number of satellites > 5.0				
Total distance (TD)	1149(±244)	1121 (±243)	0.56	0.0205*
High speed run (HSR)	184 (±69)	153 (±56)	0.97	0.0002*
Very high speed run (VHSR)	59 (±30)	50 (±34)	0.44	0.0675
Sprint (SPR)	16 (±15)	8 (±12)	0.79	0.0017*
High intensity running (HIR)	258 (±96)	211 (±78)	1.16	0.0001*
Number of satellites > 4.5				
Total distance (TD)	1176 (±243)	1199 (±286)	0.29	0.0001*
High speed run (HSR)	200 (±78)	173 (±74)	0.79	0.0001*
Very high speed run (VHSR)	65 (±33)	57 (±37)	0.37	0.0001*
Sprint (SPR)	16 (±16)	13 (±17)	0.25	0.0001*
High intensity running (HIR)	281 (±108)	243 (±103)	0.87	0.0001*
Number of satellites > 4.0				
Total distance (TD)	1187 (±229)	1237 (± 286)	0.54	0.004*
High speed run (HSR)	205 (±286)	184 (±75)	0.62	0.001*
Very high speed run (VHSR)	66 (±32)	62 (±39)	0.15	0.400
Sprint (SPR)	16 (±16)	15 (±17)	0.13	0.458
High intensity running (HIR)	287 (±105)	261 (±108)	0.60	0.004*

4.4 Discussion

The aim of this study was to compare data from a 5Hz GPS and the PZ motion capture and analysis system and establish threshold limits within the GPS software to allow direct comparison between the two data sets with a focus on total distance and high intensity running (>4 m/s). When examining the complete data of each half (Figure 4.2) there was a significant difference in the total distance recorded between the two systems in the first half although no significant difference in the total distance in the second half.

The 12% total distance over-estimation in the first half in this study conflicts with the results of Jennings *et al.* (2010i) who found on a sport specific circuit with a pre-determined distance that the 5Hz GPS underestimated in measuring total distance. Conversely, Petersen *et al.* (2010), also using a 5Hz GPS system, found a 3% over-estimate in walking and striding but a 20 to 40% under estimate in sprinting. Grey *et al.* (2010) concurred and found overestimates in total distance when using 1Hz GPS of up to 5.25% over a 200m linear course and an underestimate of up to 19% in a non-linear course. When extrapolated out to the distances recorded in each half in this study it is possible that the slow speed linear overestimates would account for the multi-directional underestimates, and partly explain the overestimation of the first half total data, as the majority of movements in soccer are linear in nature and of a low speed (Portas *et al.*, 2010).

The second half total distance, in contrast to the first half data, was not significantly different to the PZ. Examining each of the players individual capture data and calculating the average number of satellites and HDOP for each of the halves it was established that in the first half only three players averaged a 'lock' in excess of five satellites and all the players had an HDOP over 3.0. In the second half nine of the players averaged over five satellites and seven had a HDOP under 2.0 (Figure 4.6) indicating that there were improved capture conditions in the second half due to the larger number of satellites visible to the units, hence the increased accuracy of the total distance second half GPS data when compared to the PZ data.

In examining the speed categories, the GPS distance covered was significantly different to the PZ in four of the groups in the first half (Figure 4.4) and five of the groups in the second half (Figure 4.5). This is comparable to a number of studies that have concluded that high speed movement patterns are not captured effectively with the 5Hz system, possibly due to the equipment not being sensitive enough to capture the short high speed movements associated with soccer (Grey *et al.*, 2010, Jennings *et al.*, 2010i). Harley *et al.* (2011) found that GPS over estimated when measuring total distance and

under estimated distance in the speed categories above 4 m/s. The results in this study concurred with regards to the speed categories but not the total distance in the higher quality capture conditions of the second half.

To more closely examine high intensity running (>4 m/s) the methodology of Harley *et al.* (2011) was applied and the first half data was divided into three groups (15 to 25 minutes, 25 to 35 minutes, 35 minutes to half time) and the second half into four groups (50 to 60 minutes, 60 to 70 minutes, 70 to 80 minutes, 80 minutes to full time) and the total distance and the distances across each of the high intensity (>4m/s) speed zones compared. The use of 10 minute capture groups as opposed to the 15 minute time frame that Harley *et al.* (2011) used was to produce a greater number of data points and limit the change in capture conditions which was observed in the first half data (Appendix B). This change in capture conditions may have occurred due to the changing nature of the satellite constellation or the dynamic positional changes that occur in soccer. Analysis of the smaller time frames showed that there were occasions that some of the speed categories were comparable (Table 4.2 and Table 4.3) across the different analysed capture conditions (number of satellites and HDOP) but the only situation that all high intensity running categories (>4m/s) and TD where not significantly different was the group that averaged a HDOP under 1.8 (Table 4.2).

Within the literature there are a number of studies that have examined the validity of GPS and concluded that the total distance and the low velocity (<5m/s) measurements are accurate (Petersen *et al.*, 2009; Jennings *et al.*, 2010i; Jennings *et al.* 2010ii; Schutz and Herren.,2000; Witte and Wilson 2004; Barbero-Alvarez *et al.*, 2010; Portas *et al.*, 2010; and Grey *et al.*, 2010). However Schutz and Herren (2000), Petersen *et al.* (2009) and Barbero-Alvarez *et al.* (2010) did not report the capture conditions (number of satellites and HDOP) and as has been established in this study the capture conditions can vary greatly and have a large impact on the quality of the data obtained, therefore the accuracy of the data and conclusions are difficult to draw comparisons with and should be considered with caution. As previously discussed the study by Grey *et al.* (2010) only measured at 1Hz and as such the differences in results could be due to different software and hardware employed in the study (Jennings *et al.*, 2010ii). In the study by Witte and Wilson (2004) the authors used equipment that could be considered highly restrictive as it had to be mounted on a helmet and carried in a backpack and the technology and the accompanying software has moved on considerably since this study and so drawing comparisons, again is difficult.

There are however three contemporary studies that have assessed the validity and reliability, using the same GPS reporting format as in this study which documented the HDOP and number of satellites. Jennings *et al.* (2010ii) found that in a sport specific course there was a variability of up to 11.1% between 2 units worn by the same player and recommend that same player used the same unit all the time. Jennings *et al.* (2010i) found that the total distance covered was less than 10% of the actual recorded distance. Where change of direction was determined, whilst sprinting, using a gradual (10m with 90° turns) a 12.9% underestimation was observed, application of tight turns (5m with 90° change of directions) resulted in an underestimation of 15.8% and there recommendation was to limit the use of the GPS system for establishing total distance. Portas *et al.* (2010) used soccer specific movement paths and concluded that there was a movement threshold (180° turn) at which the 5Hz system data becomes compromised, one reason for a difference in the accuracy of the high speed data in the Portas *et al.*, (2010) study compared with studies from Australia (Jennings *et al.* 2010i and Jennings *et al.* 2010ii) is possibly due to the different satellite configurations in the two countries. In addition, the satellite constellation may be denser over Europe due to the greater commercial demands in this highly populated area compared to the relatively sparsely populated and extremely vast landscape in the southern hemisphere.

A number of studies have used the minimum of 4 satellites as a prerequisite for data inclusion which is based on historical accuracy requirements looking at a global position and not at velocity and acceleration. As such it may be seen as a limited threshold limit however there are a number of papers within the literature using GPS which fail to mention the capture conditions. The early work of Schutz and Herren (2000) used bulky Equipment that travelled in a car next to runner and whilst they acknowledge that it was Differential GPS (dGPS), ie using base on earth to filter noise out of signal, the satellites and HDOP were not reported. Brewer *et al.* (2010) in comparing elite and sub elite Australian rules players and Castellano and Casamichana (2010) examining the movement profiles of beach soccer players again failed to report the number of satellites or HDOP and Wisbey *et al.* (2010) who looked at movement demands of AFL player, whilst acknowledging that GPS technology had superseded traditional coded time motion analysis, failed to report the number of satellites or the HDOP but did state that if there were less than 3 satellites then the data was disregarded. What is apparent is that many studies rely on historical minimum requirements and there are a limited number of studies looking at the capture conditions.

The reporting of the capture conditions has historically been in the form of the average number of satellites and HDOP over the collection period. What has been highlighted in this study that is of particular concern is the dynamic nature of these capture conditions over a relatively short time frame. Not only was the difference notable from the first half to the second in this study (Figure 4.3) but also in the way in which less favourable conditions can be 'washed out' when averaging data. Examples of this can be seen in Table 4.1 with player ones first half satellite data showing that 9% of the data was recorded when only three satellites were visible and yet the data averaged over four satellites for the half and would therefore be included in a number of contemporary studies. Even if the minimum was increased to five satellites Player seven, who averages 5 satellites across the time period, shows that 29.6% of data collected was under the 5 satellite threshold. When examining the HDOP data a similar phenomenon occurs, player 3 indicates that they are extremely close to the 1.8 HDOP recommended but there are 11.3% of data collected above a HDOP of 2.5 and if the minimum of 2 HDOP is used, as suggested by Jennings *et al.* (2010i) then player 5 shows almost 23% of data is collected above 2.5 HDOP. Therefore additional validation measures need to be incorporated when assessing the quality of the data capture conditions which profile and map the number of satellites and the HDOP through the match. The results from this chapter would suggest that capture data tables are produced, or at a minimum the graphed HDOP and satellite data is eyeballed, to observe any erroneous data that maybe 'hidden'.

In a similar comparison study comparing GPS and a commercially available automated match analysis system (Amisco), Randers *et al.* (2010) determined that the GPS system underestimated significantly in 4 of the 5 speed categories. The results and conclusions must be questioned as the study has a number of fundamental methodological issues. For example the HDOP was not reported, and the authors methodology states that the data can be collected with a minimum of 3 satellites which is fundamentally inaccurate as the manufacturer advises that a minimum of 4 are required and whilst the authors conclude that any comparison of results between different match analysis systems should be done with caution if they had been more methodical in there collection the data could have been compared with more precision. It is possible that the inclusion of data with a low number of satellites was due to the data being collected in an enclosed stadium which severely limited the number of visible satellites.

The recorded player GPS distances can be considered as the product of a number of factors which collectively increase the size of the error measured. With non-differential GPS receivers, the signal is solely reliant on calculating the time between unit and satellite, however a slight discrepancy can equate to a larger recorded error. Therefore a larger number of satellites serve to reduce the measurement error. In addition, atmospheric conditions can slow a signal down, so by improving the satellite positions in the sky (i.e. having the satellites located above the receiver unit) reduces the amount of atmosphere the signal has to travel through (Steede-Terry, 2000, Conley *et al.*, 2006). Furthermore, improved units and analysis algorithms can more accurately filter atmospheric interference as well as most of the ionospheric error (Kennedy, 2002).

Consideration should also be given to the capture rate of the systems as a possible reason for a difference in recorded high speed distance. PZ captures data every 0.1 second and GPS at 0.2 of a second, as seen in studies which compare capture rates of 1Hz and 5Hz the level of accuracy improves with the faster capture rate (O'Donoghue, 2008; Portas, *et al.* 2010). A system examined by Frencken *et al.* (2010) which recorded at 1000Hz found that the distance error was under 2% in a sprinting multi-direction test of 25m. The improvement in the quality of the data can be seen in the 1Hz and 5Hz GPS comparison studies that show improvement with higher sampling rates [Petersen *et al.*, (2009) Jennings *et al.*, (2010i), Jennings *et al.*, (2010ii) and Grey *et al.*, (2010)]. In addition the PZ system can guarantee 8 cameras with a fixed field of vision and with GPS this is not always the achievable.

The way in which the information is collated and categorised may also be a reason that the GPS underestimates the high intensity work. Appendix C shows the capture requirements within the GPS software and it is likely that these criteria are different to the category classes within the PZ software which uses instantaneous trigonometry measurements which does not required a minimum threshold of time to log high speed movement. This may also provide a 'blurring' of the categories when comparing across the systems which can be seen in the in the significant differences of the walk and stand conditions across the two technologies but when comparing the sum of the two modes there are non-significant differences (Figure 4.9). However it is difficult to compare the systems more accurately as the algorithms and methods of determining speed within these industrial systems is of a commercially sensitive nature (Witte and Wilson, 2004).

4.5 Conclusion

This study has confirmed and extended the work of Harley *et al.* (2011) and compared GPS and PZ data and determined that data capture at 5Hz can provide accurate representation of movement patterns during soccer specific activity. This study has reported GPS data in a new and novel way and the data suggest the 5 Hz GPS system is accurate in a stadium situation (i.e. underreporting by 10%) in recording total distance when the units have an average satellite 'lock' of 5 or more for the recording period of a half. For the accurate assessment of high velocity running (>4m/s) an HDOP of less than 1.8 is required and this provides valid data that allows for a direct comparison with PZ data. However, such a conclusion must be framed within the caveat that there are a number of capture conditions that must be fulfilled. The number of satellites and the HDOP need to be reported when collecting data from GPS units, however more detail is required above the basic average number of satellites and HDOP as recommended by others (Jennings *et al.* 2010ii).

CHAPTER 5

ACTIVITY PROFILE IN ELITE YOUTH SCHOLARSHIP SOCCER

Within the literature the measurement of activity profiles of elite Under 18 scholarship players in competitive games is limited. As this has been highlighted as a fundamental period in the development process of youth players it is important that this information is determined. Using the GPS data capture conditions established in Chapter 4 the aim of this study was to use GPS technology to quantify and report the movement profiles of elite Under 18 scholarship players and compare the high intensity movement profiles with those of first team players within the same club. This will aid in the development process as it will highlight areas of physical discrepancy between the developing player and that of the elite adult player that can then be a focus on by the fitness training staff.

5.1 Introduction

The development of automated computer analysis programs in recent years has allowed for an increased focus and analysis of the physical demands of elite soccer match play (Bangsbo, 1994i; Bangsbo, 1994ii; Bangsbo, 1994iii; Ekblom, 1986; Balsom, 1994) and whilst the high cost of these methods has restricted their use to First team soccer games (Di Salvo *et al.*, 2010) the development of sport specific GPS units has allowed for the closer examination of youth team matches. The activity demands imposed during match in elite youth players, in particular high intensity activities is relatively sparse (Reilly *et al.*, 2000; Buchheit *et al.*, 2012). This paucity of data is in part due to the labour intensive methods employed, with few researchers providing a comprehensive assessment of workload (Wong, 2009). The majority of youth information available is dated, limited and applicable to non-elite soccer players only (Malina *et al.*, 2005; Chamari *et al.*, 2005; Vanderford *et al.*, 2004; Tsolakis *et al.*, 2004; Faigenbaum *et al.*, 2002). Of those studies that have examined match profiles in youth team soccer, most have used groups of lower age groups or examined non-elite players (Harley *et al.*, 2010; Aslan *et al.*, 2012). Recently with the development of sports specific global positioning systems (GPS) the ability to quantify the physical characteristics of training and match play is more accessible to these populations (Jennings *et al.*, 2010i).

The introduction of the Elite player performance plan (EPPP) in England to facilitate increased development of youth players indicates there is a need for a greater focus and understanding of the movement profiles of Under 18 games due to its direct importance in linking the academy program to the first team (Williams and Reilly, 2000). In addition, whilst general movement patterns are important to acquire within the professional game there are a number of physical characteristic that differentiate between the positional requirements at the elite level (Andrzejewski *et al.*, 2012). This data is multi-faceted in that it is required for talent identification, by fitness coaches to facilitate the development and prescription training and to monitor the training and match loads (Harley *et al.*, 2010). Harley *et al.* (2010) expand further and state the importance of assessing both absolute and relative match activities across age groups is required for the accurate prescription of training drills that are specific to the age group and the individual player involved.

Data from the Premier league™ shows that the total distance covered ranges between 10 and 14 km which are similar to lower league examples (Bradley *et al.*, 2009). However it has been shown that the difference between elite and non-elite soccer players is the high intensity distance covered (>4 m/s) and the very high intensity distance covered (>5.5 m/s) as the ability of players to sprint short distances repeatedly is directly relevant to the high degree of anaerobic contribution in match play and as such warrants further examination given the importance attributed to high intensity actions in soccer (Mayhew *et al.*, 2004; McMillan *et al.*, 2005; Bradley *et al.*, 2009).

Therefore the aims of this study were to quantify match play intensity according to outfield playing position in elite youth soccer at a scholarship (Under 18) level as anecdotal observations suggest that there are variations in the work rate. It is hypothesised that there will be significant differences between the outfield positions in the elite youth soccer and significant differences in total distance and high intensity running when compared to First team players.

5.2 Methods

This study included 11 Under 18 games and took place during the second half of the season. The games were competitive and were included in the premier league academy structure. The protocols were approved by the University Research Ethics Committee and the players and their parents were informed of the nature of the study and signed the written consent prior to the game. All the players had used the GPS system previously during training and competition games and were comfortable with the system. Players were free to withdraw from the study at any time.

Participants

Over the course of the data collection a total of fourteen elite outfield youth team from a premierships clubs academy structure (Under 18) players (mean [\pm SD] age, stature, and body mass: 16 \pm .9years, 177 \pm 5 cm, 71 \pm 3 kg, respectively) participated in the study with a mean [\pm SD] number of games of 8.6 \pm 3. Four of the players were in the second year of their scholarship, five were in their first year and four were from the Under 16 academy team and one was from the Under 15 academy team. These players had been involved in a structured academy program for an average of 5.1 years (range 3.9 to 8.7 years). In the previous 5 months the subjects in their first or second year had been exposed to a full time structured training environment that on average per week involved two 45 minute weight sessions, six 1.5 hour soccer sessions and 1 formal competition game. The soccer training sessions typically consisted of technical and tactical training and normally included a 15-minute warm-up, 20-

minute technical training, 20-minute tactical training, 25-minute simulated competition, and a 10-minute cool down. The players from the under 15 and 16 teams had been involved in a similar structure with the exception of the volume of soccer sessions which numbered four per week and typically took place in the evening.

Procedures

Prior to kick off for each competitive youth team match, 10 outfield players were fitted with a 5Hz GPS unit (MinimaxX, Catapult) in a custom made vest that was worn under their playing shirt with a pocket that secured the GPS unit in the upper back between the shoulder blades. Only the data of players playing 4-4-2 (4 defenders, 4 midfield players, and 2 forwards) were collected and analysed and any players that were substituted were not included in the study. All games were played at 11.00am on a Saturday morning and played on training fields that were free of tall structures and trees.

After the completion of the game the GPS data was downloaded via a multi-unit docking port and visually inspected using Logan plus software (V 4.5.1a). Within the GPS software a small amount of unallocated data is acknowledged for each player this was typically less than 0.5%, this data was disregarded. In addition, the raw data from the Logan plus software was exported into Microsoft Excel, visually inspected, and the average number of satellites and Horizontal Dilution of Precision (HDOP) for each player was calculated for each half. This allowed for secondary analysis and comparison of the data set to determine the capture conditions (average number of satellites and HDOP). Any players that did not meet the data collection requirements that were established in Study one (Chapter 4) throughout the half were disregarded. The players were grouped according to position as (1) central defenders (CD), (2) wide defenders (WD), (3) central midfielders (CM), (4) wide midfielders (WM), and (5) forwards (FW) in keeping with the position criteria of Di Salvo *et al.* (2010).

Speed and Movement Categories

Using pre-defined speed zones that are used by Prozone to quantify players movement profiles the following categories and speed thresholds were used: standing (0 – 0.19 m/s), walking (0.2 – 1.99 m/s), jogging (2 – 3.99 m/s), running (4– 5.49 m/s), high-speed running (5.5 – 7 m/s), and sprinting (>7 m/s). High-intensity running consisted of running, high-speed running, and sprinting (>4 m/s). Very high-intensity running consisted of high-speed running and sprinting (running speed >5.5 m/s). The inclusion of High-intensity running and Very high-intensity running were included as they are frequently used in the applied field to quantify the effort and load of the game on the players.

The maximum speed attained in each position was recorded and the rate at which sprints were attained was examined and categorised into leading, sprints which were achieved with an acceleration rate less than 2 m/s and explosive, sprints speeds that were reached when an acceleration rate was greater than 2 m/s.

Statistical Analysis

Data for between positional differences was analysed using a One-way ANOVA. Statistically significant differences between mean were identified using the Games-Howell post hoc test, due to the unequal numbers of participants in each group. A Kruskal-Wallis test was used for data that was identified as being non-parametric and in the event of a significant difference post hoc assessment was assessed using a Mann-Whitney test. Effect sizes were calculated as r (Rank biserial correlation) for a Mann-Whitney U test range for this is -1.00 to +1.00 with a value of 0.00 suggesting no effect. All assessments of normality and inferential statistical procedures were performed using IBM SPSS v20 for Windows (SPSS Inc., Chicago, IL, USA). Statistical significance for all tests was regarded as $p < 0.05$.

5.3 Results

Total distance

Total distances covered (Figure 5.1) were significantly different between positions and analysis ($f_{4,97} = 8.01$, $p = 0.000$, $\eta^2 = 0.26$). The WM covered the greatest distance ($11369\text{m} \pm 1234\text{m}$ [range 14290 – 9079m]) which was significantly more than the FW ($10334 \pm 940\text{m}$ [range 11461-7148]) (mean diff = 1334.6 m, $p = 0.006$, CI = 301.7, 2367.5, $d = 1.05$), the CD ($9805 \pm 989\text{m}$ [range 12143 – 8488m]) (mean diff = 1563.8 m, $p = 0.001$, CI = 522.8, 2604.8, $d = 1.13$) and the WD ($9673 \pm 1232\text{m}$ [range 12465 – 6596]) (mean diff = 1695.38 m, $p = 0.001$, CI = 579.9, 2810.7, $d = 1.12$) with all three exhibiting very strong (>1.00) effect sizes (d). The CM (10752 ± 1068 [range 11630 – 7390]) was not significantly different to any of the other positions examined. In relative time this equates to 106.6 m/min for CD, 105.1 m/min for WD, 116.8 m/min for CM, 123.6 m/min for WM and 109.3m/min for FW.

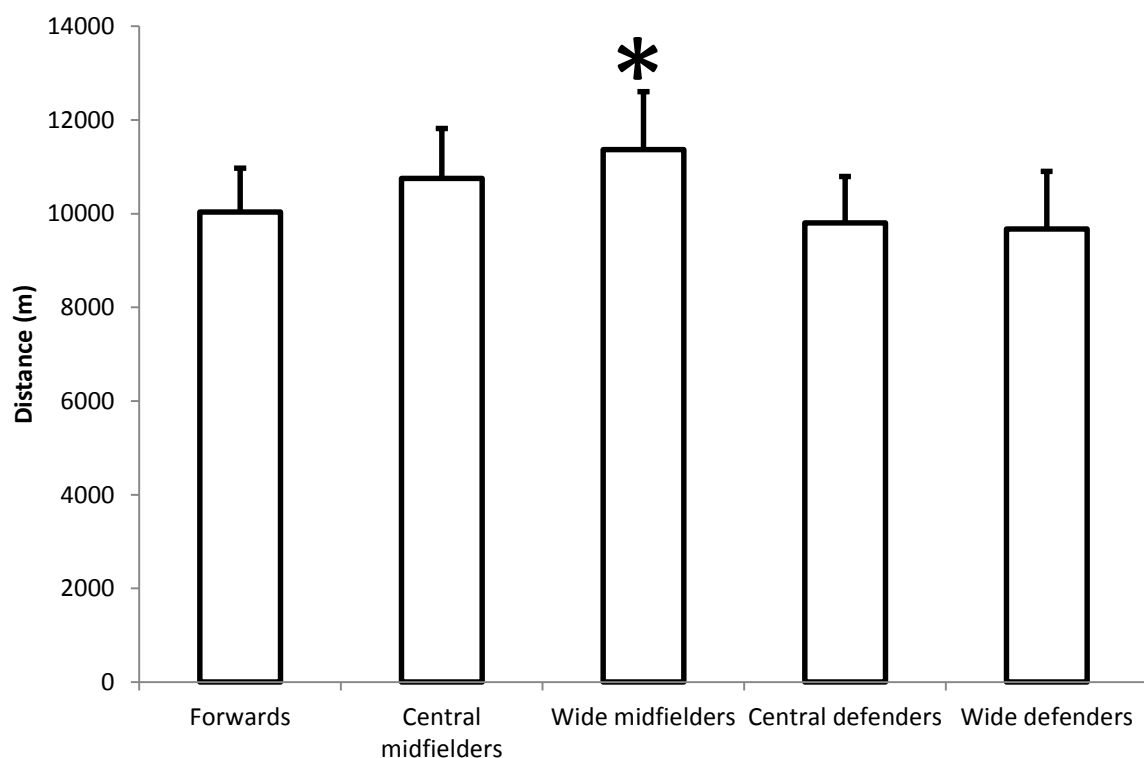


Fig 5.1: Total distance covered in the match by position. Data are mean \pm SD. (* significantly different to CD, FW and WD).

High intensity distance

The high intensity distance (>4 m/s) covered (Figure 5.2) was greatest in the WM group (2787 ± 805m [range 4627 – 1137]) followed by the CM (2519 ± 398m [range 3242 – 1876]), FW (2324 ± 347m [range 3006 – 1608]), WD (1953 ± 477m [range 2945 - 1251]) and CD (1799 ± 366m [range 2494 – 1286]). There was significant differences between positions ($\chi^2 = 35.772$, $p = 0.000$, $\eta^2 = 0.37$) with the FW significantly different to the WM ($U = 103.0$, $p = 0.015$, $r = 0.46$), CD ($U = 55.0$, $p = 0.000$, $r = 0.71$) and WD ($U = 100.5$, $p = 0.005$, $r = 0.52$). The CM was significantly different to CD ($U = 31.0$, $p = 0.000$, $r = 0.82$) and WD ($U = 75.0$, $p = 0.002$, $r = 0.60$) and there was a significant difference between WM and CD ($U = 46.0$, $p = 0.000$, $r = 0.77$) and WD ($U = 81.0$, $p = 0.000$, $r = 0.63$). The Mann-Whitney effect sizes (r) indicating that there was a substantial effect in all calculations.

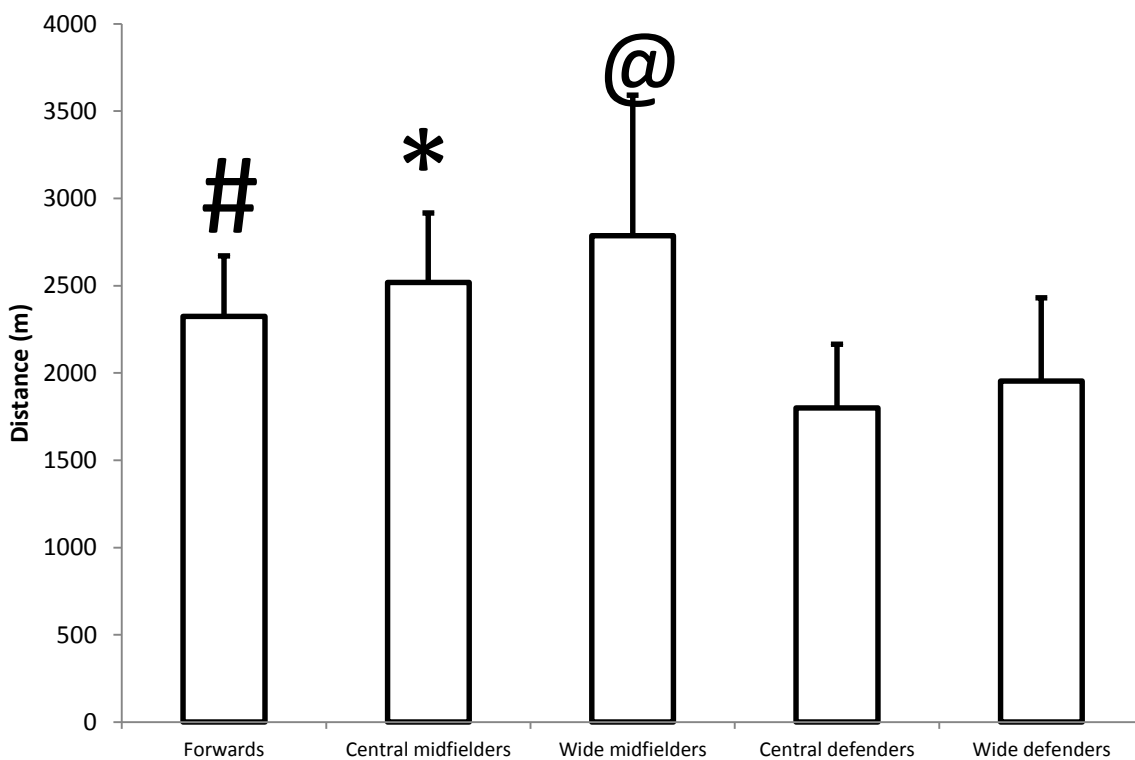


Figure 5.2: High Intensity Distance (speed >4 m/s). Data are mean ±SD. (# significantly different to WM, CD, and WD; * significantly different to CD and WD; @ significantly different to CD and WD).

Very High intensity distance

The very high intensity distance (>5.5 m/s) covered (Figure 5.3) data showed significant difference between positions ($f_{4,97} = 5.317$, $p = 0.001$, $\eta^2 = 0.19$). The FW group ($804 \pm 155\text{m}$ [range 1070 - 478]) covered the most distance at this intensity followed by the WM ($663 \pm 259\text{m}$ [range 1152 - 165]), the CM ($656 \pm 214\text{m}$ [range 1212 - 368]), the WD ($588 \pm 181\text{m}$ [range 1014 - 354]) and the CD ($532 \pm 151\text{m}$ [range 842 - 320]). The FW covered significantly greater distance to the CD (mean diff = 271.8 m, $p = 0.000$, CI = 131.4, 412.3, $d = 1.33$) and the WD (mean diff = 215.8 m, $p = 0.002$, CI = 65.9, 365.7, $d = 1.08$) with both showing a very strong effect size.

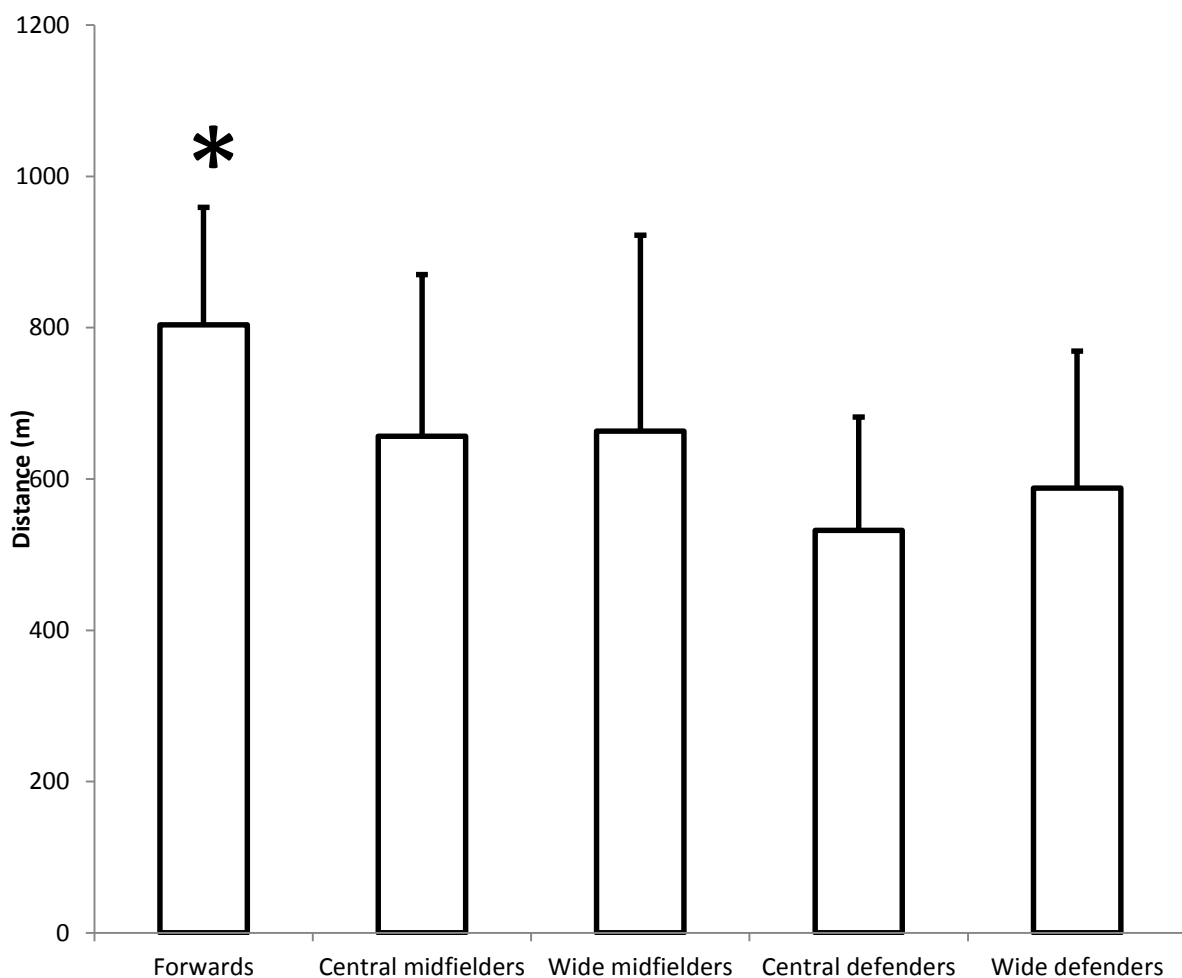


Figure 5.3: Very High intensity distance (>5.5 m/s) covered in the match by position. Data are mean \pm SD. (* significantly different to CD, WD).

Sprint distance

Figure 5.4 shows the sprint distance data, as determined by any speed greater than 7 m/s. The FW covered the greatest distance ($184 \pm 63\text{m}$ [range 351 – 91]), followed by the CD ($119 \pm 58\text{m}$ [range 227 – 17]), the WD ($112 \pm 49\text{m}$ [range 242 – 20]), the WM ($109 \pm 69\text{m}$ [range 257 – 11]) and the CM ($97 \pm 67\text{m}$ [range 293 – 13]). There was statistical difference between positions ($\chi^2 = 18.680$, $p = 0.001$, $\eta^2 = 0.19$) and post hoc analysis indicated that there was a significant difference between the FW and CM ($U = 47.0$, $p = 0.000$, $r = 0.71$), WM ($U = 82.0$, $p = 0.002$, $r = 0.57$), CD ($U = 93.0$, $p = 0.006$, $r = 0.51$), and WD ($U = 76.0$, $p = 0.001$, $r = 0.64$) with a large effect size.

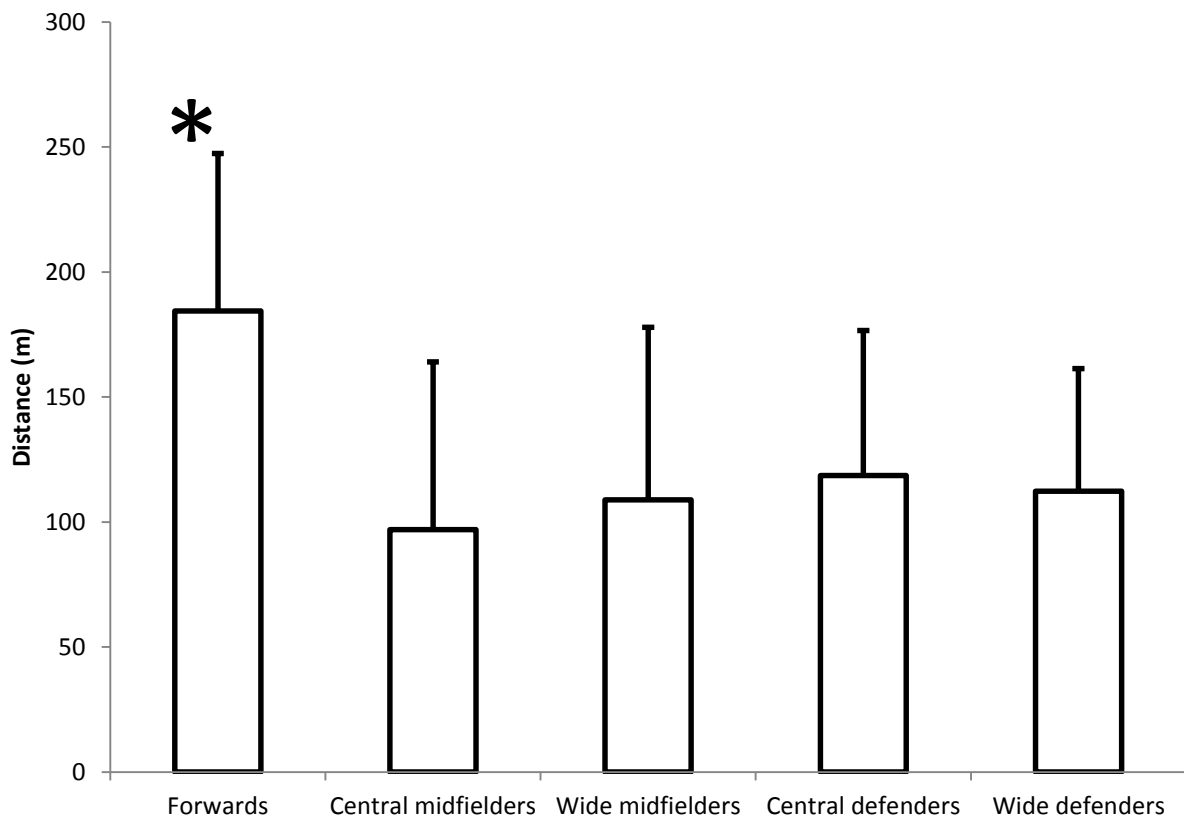


Figure 5.4: Sprint distance (>7m/s) covered in the match by position. Data are mean \pm SD. (* significantly different to CM, WM, CD, WD).

Number of run, high speed runs and sprint efforts

Figure 5.5 shows the number of efforts in each of the high intensity speed zones (run > 4 m/s, high speed run >5.5 m/s and sprint >7 m/s). All playing positions showed a significant decrease in the number of actions as the speed increased ($f_{3,293} = 6.21$, $p = 0.000$, $\eta^2 = 0.46$). In the run criteria (>4 m/s) the WM performed the most runs (141 [range 212 – 88]) followed by the CM (135 [range 156 – 91]), FW (120 [range 155 – 83]), WD (110 [range 144 – 58]) and CD (109 [range 142 – 89]). There was statistical difference between positions ($f_{4,97} = 9.581$, $p = 0.000$, $\eta^2 = 0.29$) with post hoc assessment suggesting that there was a significant difference between CM and CD (mean diff = 26.3 runs, $p = 0.001$, CI = 8.9, 43.8, $d = 1.17$), and WD (mean diff = 25.3 runs, $p = 0.004$, CI = 6.4, 44.2, $d = 1.04$). There was also significant differences between the WM group and CD (mean diff = 32.6 runs, $p = 0.001$, CI = 11.4, 53.9, $d = 1.15$) and the WM group and WD (mean diff = 31.6 runs, $p = 0.002$, CI = 9.2, 54.0, $d = 1.07$).

In the high run category (>5.5 m/s) the FW had the most efforts (48 [range 67 – 31]) with the CM [range 60 – 27] and the WM [range 72 – 15] both performing 42. The WD (36 [range 54 – 22]) and the CD (34 [range 52 – 23]) made a similar number with only a 2 per game average difference. There was statistical difference between positions ($f_{4,97} = 5.191$, $p = 0.001$, $\eta^2 = 0.18$) with the FW significantly different to the CD (mean diff = 14.1 runs, $p = 0.000$, CI = 5.9, 22.4, $D = 1.07$) and the WD (mean diff = 11.4 runs, $p = 0.004$, CI = 2.9, 19.9, $d = 1.03$). In the sprint category the FW performed the most sprints in a game (12 [range 20 – 5]) with the remaining positions CM (7 [range 17-2]), WM (8 [range 15 – 1]), CD (9 [range 16 – 2]), WD (7 [range 14 – 2]) all indicating similar values. Statistical difference between positions ($f_{4,97} = 5.875$, $p = 0.000$, $\eta^2 = 0.20$) was established and post hoc analysis indicating that the FW were significantly different to CM (mean diff = 5.0 runs, $p = 0.003$, CI = 1.4, 8.6, $d = 1.11$), WM (mean diff = 4.6 runs, $p = 0.015$, CI = 0.7, 8.5, $d = 0.95$), CD (mean diff = 3.8 runs, $p = 0.035$, CI = 0.2, 7.5, $d = 0.88$), and WD (mean diff = 5.0 runs, $p = 0.001$, CI = 1.9, 8.2, $d = 1.19$).

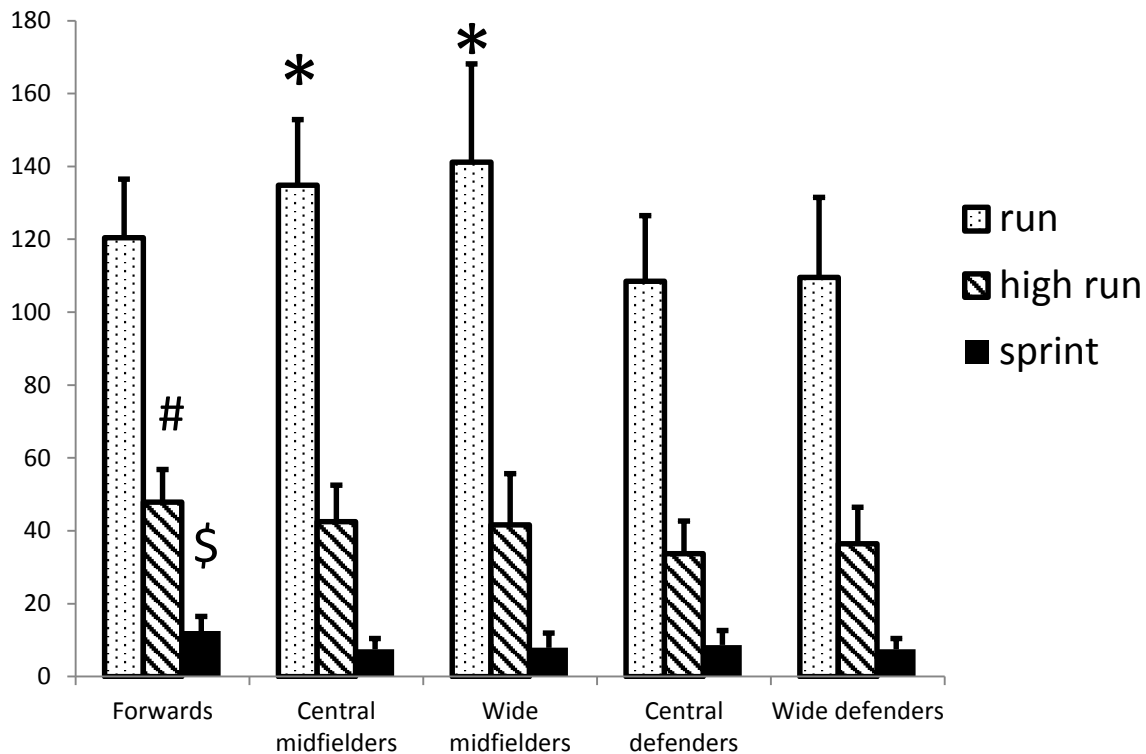


Figure 5.5: The average number of efforts above 14.4 m/s by position. Data are mean \pm SD (* significantly different to CD and WD. # significantly different to CD and WD. \$ significantly different to CM, WM, CD, WD). The three speed categories were all significantly different.

Sprint Distance

The sprint distance of each position was calculated and presented as a percentage (Figure 5.6), all positions indicated significant differences between the four distance measurement categories ($p < 0.001$). Post-Hoc testing indicated that in the 0-5 distance the FW ($p < 0.01$) and CD ($p < 0.05$) were significantly different to the WM, CM, and WD positions ($U = 83.0$, $p = 0.000$, $r = 0.61$, $U = 81.0$, $p = 0.000$, $r = 0.57$ and $U = 78.0$, $p = 0.000$, $r = 0.57$ respectively). In the 5-10 category the WM was significantly different ($p < 0.001$) to the other 4 positions which was repeated in the 10-40 category ($p < 0.001$). There were no significant differences ($p > 0.05$) in the 40+ category. The Across 4 of the 5 positions over 50% of the sprints were over 10m, the WM recorded 49% of sprints over 10m. Most positions made sprints of 5 to 10m within the 30% to 40% of the time range with again the WM the only exception recording a higher percentage of 45%. All positions made less than 10% of their sprints under 5m or over 40m.

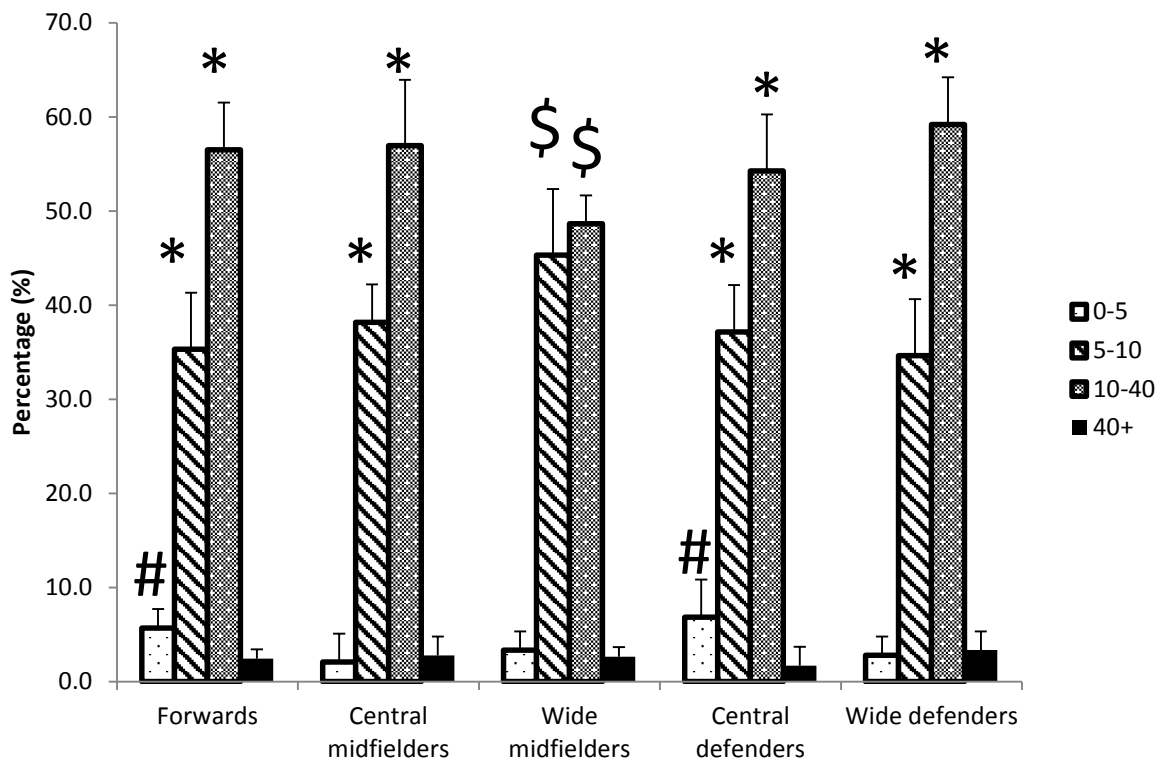


Figure 5.6: Percentage of sprint distance by position. Data are mean \pm SD (* significantly different to other positional distance covered, # significantly different to CM, WM and WD, \$ significantly different to FW, CD, CM, WD)

Maximum Speed and type

All positions attained speeds over 9 m/s with the FW attaining the top speed of 9.6 m/s which were not significantly different ($f_{4,293} = 4.635$, $p = 0.65$) to the other positions (Table 5.1). In addition, the rate at which sprint speed was achieved was also recorded and categorised as a leading or explosive action. Of the Sprints recorded across all positions 34% were explosive (greater than 2 m/s acceleration) and 66% were leading (less than 2 m/s acceleration) which were not significantly different ($f_{4,293} = 6.372$, $p = 0.87$) and ($f_{4,293} = 7.945$, $p = 0.73$) respectively between positions.

Table 5.1: Mean (\pm SD) maximum speed and type of sprint recorded by position.

	Forwards	Central midfielders	Wide midfielders	Central defenders	Wide defenders
Max Speed (m/s)	9.6(\pm 2)	9.4(\pm 1)	9.5(\pm 2)	9.1(\pm 2)	9.1(\pm 1)
Explosive Sprint (Number)	7.2(\pm 1.2)	3.6(\pm 0.6)	4.3(\pm 0.8)	4.7(\pm 1.1)	4.6(\pm 1.4)
Explosive Sprint (%)	34	36	33	32	33
Leading Sprint (Number)	13.9(\pm 1.8)	6.5(\pm 1.2)	8.9(\pm 1.9)	10.0(\pm 1.1)	9.2(\pm 1.6)
Leading Sprint (%)	66	64	67	68	67

5.4 Discussion

The purpose of this study was to assess the movement demands of elite scholarship soccer players in order to provide a base of knowledge from which to build a comprehensive framework which will allow soccer and fitness coaches to establish norms to aid in the development and progression of players from the academy into the first team squad.

The total distance covered by the five positions in this study was recorded as 51643m, which is comparable to the distances recorded by Bradley *et al.* (2009), who examined players from the Premiership (2005-06 season) and recorded a total distance of 53894m. The WM position in this study covered the greatest distance (11369m), followed by the CM (10762m) which again is in agreement with Bradley *et al.* (2009) who also found that the WM covered the most distance (11535m) followed by the CM (11450m). This is to be expected as midfielders are involved in attack and defence and hence have a greater physical responsibility than the backs and the forwards (Reilly, 1976).

The WD in this study covered the least distance ($9673 \pm 1232\text{m}$) which is surprising due to the role that this position plays during periods of attack by providing width and crossing the ball into the penalty area from wide positions (Harrison, 2010). Bradley *et al.* (2009) found that WD ($10710\text{m} \pm 589$) covered more distance than both CD ($9885\text{m} \pm 555$) and FW ($10314\text{m} \pm 1175$). This discrepancy is possibly due to the age of the players who played in this position during this study; in the majority of games for which data was collected players from the under sixteen (U16) and under fifteen (U15) teams were used. It may be concluded that these younger players did not have the physical attributes to match their older counterparts, it is conceivable that the younger players in this study tactically 'played it safe' and kept their formation during the game and as a consequence this is not a true representative figure of the position of WD for Under 18 games (Reilly *et al.*, 2008). Maturation of the players was not examined and this may have been influential in the distances covered within the different speed zones and can be considered a limitation of this study. An additional possibility is that as the U18 games are longer in duration than the U15 and U16 games the players may have been pacing themselves in order to last the full 90 minutes. Whichever scenario is relevant the author is confident that the WD data captured in this study is not representative of Under 18 games.

The CD distance covered in this study ($9805 \pm 989\text{m}$) is comparable to that of Bradley *et al.* (2009) which recorded a distance of $9885\text{m} (\pm 555)$ and again highlights the possible unreliable values recorded for the WD in this study as it would be expected for the WD to surpass the distance of the CD. One reason for this is the possibility of the CD being used for attacking corners (which were not recorded) and as such if there were a large number in the oppositions half this would see the CD making a number of runs to get into the oppositions goal box and to return to a defensive position. Likewise the total distance of the FW is comparable between Bradley *et al.* (2009) and this study $10314\text{m} (\pm 1175)$ v $10034\text{m} (\pm 940)$ respectively).

Harley *et al.* (2010) examined the distance covered in games with the Under 15 and Under 16 age groups and found that Under 15 players covered 6016m which equates to 118 m/min and Under 16 players covered 7672m equating to 115 m/min this compares to the overall value of 10328m (112 m/min) in this study, showing a significant difference in distance covered however a reduced meters per minute measurement. However the Under 15 players only averaged 51 minutes per game and the Under 16 players only averaged 71 minutes per game and the use of 'rolling subs' was allowed possibly reducing the effect of accumulated fatigue due to the greater and more frequent rest periods. In addition, Harley *et al.* (2010) examined one game for each player at the age of 16 and the psychological impact of wearing the GPS may have artificially inflated the distance and speed covered

in a one-off trial due to an increased awareness of the players mindful of staff playing closer attention to the physical efforts of the recorded game, so an accurate picture may only emerge when a greater number of games are analysed. In addition positional differences were not reported making it difficult to draw comparisons to the values in this study and the normalised speed zones make it difficult for direct comparison to first team players data.

It has been suggested that to assess youth players, relative group derived speed norms should be used. This study used the same speed zones as those used with first team players (Harley *et al.*, 2010), as it is not the authors contention that age related norms are not valuable, as it has been shown that producing individual norms may be more beneficial to the sports science body (Abt and Lovel, 2009), but with the ever greater focus on youth players for the first team, it would be remiss to hold them to a different set of standards and as such the Author would recommend that age related and individualised norms are used with younger age groups but that the Under 18 age group are compared to the First team data.

High intensity activity is of interest as sprint and repeated sprint performance have been highlighted as important to success in elite soccer (Impellizzeri *et al.*, 2008 and Rampinini *et al.*, 2007). A number of authors have examined the movement and activity profiles of players during soccer matches, most notably Reilly and Thomas (1976) and Bangsbo (1994). However more recent studies have provided a greater insight to the movement demands of soccer and it is now widely accepted that the physical and physiological demands of the game have increased over the past decade (Bradlet *et al.*, 2009; Di salvo *et al.*, 2010).

The intensity zones that were used in this study are the same that are applied within the Prozone software and are similar to those reported in the literature (Rampinini *et al.*, 2007). Comparing the high intensity running (>4 m/s) with Bradley *et al.* (2009) shows, that whilst individually the recorded distances covered were lower, they shared similar values across all playing positions with the exception of the WD which recorded 25% less distance, this is to be expected with the results of the total distance which has been explained above. The very high intensity (>5.5 m/s) showed a greater discrepancy in the distance covered across all positions when compared to the Premier league data. The youth team players covered between 88% (CD) and 55% (WM) of the high intensity distance of the data recorded by Bradley *et al.* (2009) and this trend was highlighted further when looking at the sprinting distance (>7 m/s) which saw ranges of 78% (CD) to 31% (WM) of the distance covered.

The lower recorded number of high intensity movements may be explained by a under reporting from the GPS system (Jennings *et al.*, 2010i). However, Portas *et al.* (2010) suggested that a 5% threshold is used when examining Soccer specific activities and whilst the author considers that the capture conditions developed in Study 1 confirmed and extended those used by Portas *et al.* (2010). It is possible that not all of the very high intensity data was obtained in this study however even by using the 5% threshold the Under 18 player's very high intensity data is considerably less than the first team averages and anecdotal evidence supports this contention with feedback of players who have trained with the first team and comment that it is 'sharper' and quicker with less time on the ball and the difficulty to create space due to being closed down quickly. All pointing to the assertion that the Under 18 players need to improve their acceleration over short distances (less than 10m) and not their maximum speed.

In a study by Aslan *et al.* (2012) which examine players of a similar age, but not ability, found that out field players covered 9900 (\pm 840m), which is a mid-range value of this study and recorded very high intensity distances of 325 (\pm 72m). However positional differences were not examined and each half was separated into thirds with a 3 minute interval so that lactate measurements could be made, this would have facilitated more favourable conditions for very high intensity actions and therefore there is limited value in comparing this study with the present one as the effect of accumulated fatigue would have been reduced.

In examining the very high intensity movements of teams in the European cup club competitions, Di Salvo *et al.*, (2010) examined the number of sprints ($>$ 7m/s) and found that WM players had the highest values (36) followed by a similar number for the WD (30) and FW (30), with the CM (24) and CD (17) with the least. This study found that CM, CD and WD recorded the same number of sprints (9) whilst the FW recorded the most (12) and in contradiction to Di Salvo *et al.* (2010), the WM recorded the least (8). One possible reason for this large difference in the recorded numbers, apart from the large difference in level, between European games and Under 18 games, is that the level of opposition is also not reported. Opposition activity will have an impact on the style of play and the tactical formation as will the score through the game, the level of competition and environmental factors (Reilly, 1996). It is possible that at the youth level, success can be attributed to putting quick players up front and that the final positions of players have not yet been determined. Anecdotal evidence suggests that there is some movement of position even after players move on from the Academy. It may be argued that the games analysed were not physically demanding enough and as such the players were not required to perform with any greater intensity, however within the games

used there were a number of elite 'A' grade games, which can be classified as local derby and games against historically strong academies with only one game in which a 3 goal margin was achieved by half time.

In addition to the number of sprints Di Salvo *et al.* (2009) examined the type and distance of sprints. The type of sprint was categorised in as leading, where the sprint speed was reached by a gradual acceleration from standing, walking, jogging or running while entering the high-speed run category during the previous 0.5s time period or explosive, where the sprint speed was reached by a fast acceleration from standing, walking, jogging or running without entering the high-speed run category during the previous 0.5s. All positions recorded approximately 76% leading sprints (Di Salvo *et al.*, 2010), which is similar to the data obtained in this study that found that 66% of the sprints were leading. The distance of the sprints performed by the elite youth players across all the positions was similar and showed that over 50% of the time, except for the WM (48%) they were between 10 and 40m. The 10 to 40m distance category used in this study was possibly too wide for the current population but when examining the data of Di Salvo *et al.* (2010) the majority of the sprints occurred under 5m highlighting a shorter faster movement pattern in elite adult players.

The Top speed recorded by the Under 18 players (Figure 5.7) is comparable across the positions and indicates that all the players have the physical capacity to run above the 7 m/s sprint threshold highlighted by the PZ software, however the ability to replicate these high velocity movements appears to be absent in this age group.

The main goal of Academy soccer is to produce players to progress to the first team and it is prudent to examine their performance profile (Appendix D). This shows similar values to those within the literature except for the CM which recorded almost 100m more high intensity meters per game than the premier league average and almost twice the recorded difference of those measured in the Under 18 games. This may show a playing methodology which uses the CM as a greater attacking option, (i.e as an extra FW) and as such should be implemented throughout the clubs technical and tactical training philosophy and needs to be at the forefront of any Long Term Athlete Development at the club.

5.5 Conclusions

The information collected in this study should provide a starting point from which to base physical conditioning programs to improve elite youth players on field performance. It has highlighted that there are significant differences between movement categories and across playing positions in elite youth soccer. This study has also highlighted that whilst total distance is similar with First team players, elite youth players do not perform as much very high intensity work in games and that this is an area that the developing players need to focus on improving as the distance of high intensity running is related to training status (Krustrup *et al.*, 2003). The maximal speeds recorded were comparable to first team players indicating that the players were physically able to perform high intensity actions. However the data shows that the number of sprints performed is less than first team players and the average distance covered is also longer than first team players from the same club. Highlighting that the acceleration profiles need to receive the greatest attention at Under 18 level for there to be successful progression at the elite level.

CHAPTER 6

RELIABILITY AND VALIDITY OF A NEW SPEED AND AGILITY TEST FOR SOCCER

The adapted Draper and Lancaster test

Chapter 5 highlighted that whilst Under 18 players could achieve similar total distances and maximum speeds to first team players but that they did not achieve the same high intensity distances or perform similar movement patterns, specifically those of explosive sprints, of first team players in competitive matches. In order to develop this physical component a fitness test needs to be established that focuses on short acceleration profiles and has an agility component to it which has been previously highlighted as important for football players. By developing a football specific test using the movement profiles highlighted by the previous study, specifically incorporating explosive and leading sprints with an agility component requiring one change of direction, youth players weaknesses can be highlighted, specific training protocols implemented to improve performance and their progress can be monitored.

6.1 INTRODUCTION

Fitness testing serves a wide range of purposes which include athlete profiling, the highlighting of an individual's strengths and weaknesses and examining training effects (Cone, 2012). Due to the complex nature of soccer and the wide ranging fitness components required to play successfully there are a large number of tests, both laboratory and field based, that have been suggested for use (Svensson and Drust, 2005). However the use of a battery of tests becomes problematic when attempting to schedule into the playing calendar, especially in-season when the focus is on the technical and tactical development of the players. This is further highlighted by the instruction of most testing procedures for the subjects to limit their activity for 24 to 48 hour prior to the testing (Cone 2012). Therefore what is required is a simple test that focuses on the most important aspect of the game using minimal equipment and time that can be replicated with different testers.

It has been established that the movement patterns and key components of fitness in both elite and sub – elite (adult) soccer players is of an intermittent, high intensity nature, consisting of standing, walking, jogging and sprinting while decelerating, accelerating and changing direction and as such soccer, at any level, is considered an open skill due to its consistently changing environment (Bangsbo, 1994., Reilly, 1997., Drust *et al.*, 2000, Reilly *et al.*, 2000). Whilst soccer players can cover in excess of 12km in a match the previous chapter (chapter 5) has shown it is the high intensity movements of greater than 7 m/s which have been shown to have the greatest influence on the result (Mendez-Villanueva *et al.*, 2011). Speed is therefore an important component of fitness and recent game analysis has shown that this can be further defined as leading, characterised by a gradual acceleration typically with the player already in motion, and explosive, characterised by a fast acceleration from usually standing or slow walk start (Di Salvo., *et al* 2010). Both modes should be tested due to the high proportion of each in the professional game and whilst maximum speed is important it is acceleration over a short distance which is fundamental to success (Taskin, 2008). Historically in soccer the average reported distance of high speed running has been shown to range between 15m to 40m and last 2 to 4 seconds which has corresponded to speed being typically measured over varying distances of 10 to 40m (Ekblom, 1994; Bangsbo *et al.*, 1991). Contemporary studies have suggested that the current average distance is 7m which is reported by ProZone™ data from Premiership matches and European club competitions (Bradley *et al.*, 2009; Di Salvo *et al.*, 2010).

In addition to speed Sheppard *et al.* (2006) have emphasised agility as essential in team sports and whilst acceleration and maximum speed are important it is the ability to change direction with a minimal loss of balance or speed which is of high importance. Reilly *et al.* (2000) and Bangsbo *et al.* (1994) concur and state that turning, sprinting and changing pace are skill critical to soccer and that agility is the most discriminating factor when examining physical attributes of elite and non-elite soccer players, in North America this is commonly referred to as first step quickness and is the ability of the player to create separation from the defender and establish space.

A number of tests have been developed to examine and measure speed agility, the most common being the Illinois agility test and the T-test (Haj Sassi *et al.*, 2009). However the analysis of the movement profiles associated with elite soccer in the previous chapter indicates that in the large majority of the recorded instances there is only 1 decisive movement, or change of direction, from the player preceding or during a high intensity run. This is of interest as a number of agility tests commonly include multiple changes of direction (Illinois 9, T-test 4, and four line sprint 3), as such it can be argued that these tests, whilst valid assessors of agility, are not specific to assess agility in soccer. As well as the number of change of directions the total distance of the test needs to be examined as the T-test is completed over 40m, the Illinois Agility test over 60m and the four line sprint test over 30m and as previously discussed the majority of sprints occur under 10m with a mean distance being 7m.

Draper and Lancaster (1985) developed a single testing protocol that assessed two agility measurements, (1) 505 and (2) Up and Back, a 30m test consisting of a 15m sprint with a 180 degree change of direction and 15m sprint, with the total time recorded (Up and Back) and the time 5m before the 180^o turn and 5m after the turn recorded (505). The 505 test has been shown to be a valid test of agility due to its significant correlation with acceleration however the Up and Back test was dependant on acceleration and maximum velocity and was therefore deemed not relevant in the assessment of agility. It is the author's contention that an adapted Draper and Lancaster test (ADL) could be used to measure (1) leading speed (2) explosive speed and (3) agility.

Therefore the purpose of this study was to (1) adapt the Draper and Lancaster test (ADL) to soccer specific distances (2) determine the test-retest reliability of the test, and (3) investigate the ability of the test to discriminate between different levels of players by comparing the results between club and national level soccer players.

6.2 METHODS

Based on the match analysis and literature review from the previous chapter the ADL was proposed to reproduce the sprint and agility movements that were highlighted as important at the senior elite level (Draper and Lancaster, 1985). This incorporated an Up and Back test (UAB) and the 505 test that have been previously used to examine agility, however the distance between the start of the UAB and the 505 was reduced to 7m and recorded as both explosive and leading speed.

Participants

A total of 32 elite outfield youth team (Under 16 and Under 17) players (mean [\pm SD] age, stature, and body mass: $16 \pm .7$ years, 173 ± 1 cm, 67 ± 5 kg, respectively) from a Professional Soccer club academy participated in the study. The players had been involved in a structured academy program for a minimum of 2 years. Nine of the players were considered elite for the purposes of this study as they were members of their respective age group national teams. All players participated on average in \sim 11 hours of training per week over 5 sessions and 1 formal competition game which typically involved two 30 minute weight sessions and 8 hours of soccer training. The soccer training sessions typically consisted of technical and tactical training and normally included a 15-minute warm-up, 20-minute technical training, 20-minute tactical training, 25-minute simulated competition, and a 10-minute cool down.

Procedures

The first phase of this study aimed to establish the relative and absolute reliability of the ADL test. Each subject completed the ADL test twice separated by at least 72 hours. All subjects were familiarized with the ADL protocol before data collection and after a standardised warm-up which included 15mins jogging, dynamic stretches, short sprints with change of direction and deceleration, a minimum of 5 minutes of rest after the warm-up to allow adequate recovery.

The second phase of the study investigated the validity of the test by comparing the sprint and agility results between elite and non-elite players. For the purposes of the study elite players were defined as youth who were selected for the National team and non-elite were defined as club level players.

Adapted Draper and Lancaster test

The ADL test (see chapter 3) consisted of 1 maximal effort which was run in an 'up and back' practice with 1 change of direction of 180°. The subject began with both feet behind the starting line in a staggered stance and at their own discretion sprinted forward to a line 12m in front of them, passing between timing gates at the start and 7m from the start, they placed part of one of their feet (individual choice) over the line, turned 180° and sprinted back through the start/finish timing gates. The times were electronically recorded (Brower Timing Systems, Utah, USA) to the nearest hundredth of a second and the tripods set at a height of 0.75m and placed 1m apart to limit the width of the 'running lane' which ensured that the player made a sharp 180° turn. All of the testing took place outside on a synthetic pitch at the soccer clubs Academy training complex. The timings recorded were defined as an (1) explosive sprint (start to 7m), (2) Agility (7m timing gate to turning point and back), (3) leading sprint (7m timing gate to finish) and (4) total time.

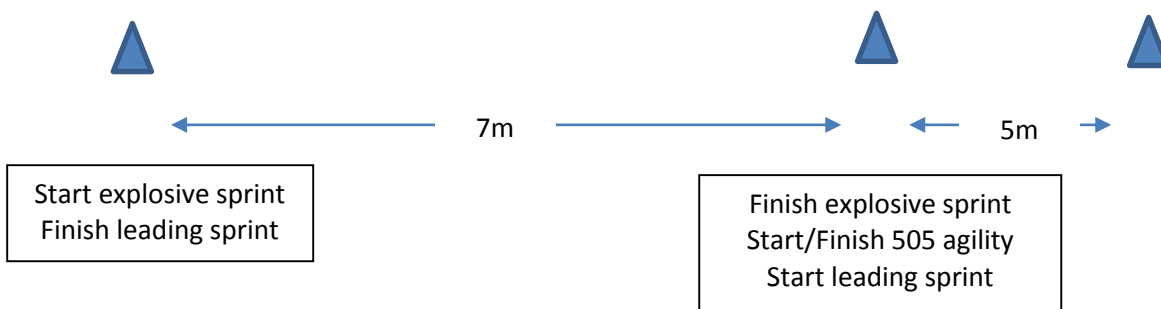


Figure 6.1: Diagram of the adapted Draper and Lancaster (ADL) test.

Statistical Analysis

Comparisons between the trials for each component of the test were initially determined using a paired t-test. A modified Cohen scale was used to determine the standardized typical error (TE) of estimates (where 0.2 = small, 0.6 = moderate, 2.0 = large, and 4.0 = very large error), and the coefficient of variation (CV) was also calculated using the method of Hopkins (2012). Assessments of the strength of the relationships within sections of the trials and the trial total time were made using intraclass correlation coefficients (ICC). Multiple linear regression, using the enter method, was performed in order to assess which component of the trials (LE7m, 505, EX7m) had largest influence on overall trial performance (Total). Statistical significance for all tests was regarded as $p < 0.05$. Assessments of normality and inferential statistical procedures were performed using IBM SPSS v20 for Windows (SPSS Inc., Chicago, IL, USA) and Microsoft Excel 2010 (Microsoft Corp, Seattle, USA) was used for all other calculations.

6.3 RESULTS

There were no test-retest significant differences between any of the component sections of the protocol (Table 6.1). The total time of the ADL proved to be highly reproducible along with the three individual tests 7M EX, 505, 7M LE which was indicated by small TE, strong ICC and very low CV data.

Table 6.1. Reliability analysis summary

Statistic	LE7m	505	EX7m	Total
Test 1	1.36 ± 0.07	2.41 ± 0.12	1.77 ± 0.11	5.54 ± 0.23
Test 2	1.35 ± 0.08	2.42 ± 0.13	1.76 ± 0.12	5.53 ± 0.28
Mean Difference (s)	0.005	0.004	0.001	0.012
T	0.83	0.54	0.12	1.18
Diff Sig	0.42	0.59	0.91	0.25
CI (s)	-0.03 to 0.04	-0.05 to 0.06	-0.05 to 0.05	-0.10 to 0.13
ICC	0.932	0.964	0.979	0.985
TE	0.38	0.28	0.21	0.17
CV (%)	1.6	1.3	1.2	0.7

In assessing the validity of the ADL test the national players showed that they were quicker in all four tests (Table 6.2) compared to the club level players, significantly so in the 7m EX (mean diff = 0.19, t = 6.72, p < 0.005, CI = 0.14, 0.25, d = 1.76), 505 (mean diff = 0.14, t = 3.27, p < 0.005, CI = 0.05, 0.22, d = 0.86) and Total (mean diff = 0.41, t = 5.32, p < 0.005, CI = 0.25, 0.57, d = 1.4) tests, however in the 7m LE test the difference was not significantly different (mean diff = 0.05, t = 1.79, p = 0.08, CI = 0.01, 0.11, d = 0.47).

Table 6.2 Multiple Regression Analysis Summary.

	Predictor Variable	Time	Beta	Significance
Club	LE7m	1.36 ± 0.07	0.449	p < 0.001
	505	2.44 ± 0.11	0.937	p < 0.001
	EX7m	1.81 ± 0.08	0.632	p < 0.001
	Total	5.63 ± 0.18		
National	LE7m	1.31 ± 0.07	0.381	p < 0.001
	505	2.30 ± 0.09	0.457	p < 0.001
	EX7m	1.61 ± 0.06	0.237	p < 0.001
	Total	5.22 ± 0.2		
Total	LE7m	1.34 ± 0.08	0.255	p < 0.001
	505	2.40 ± 0.12	0.492	p < 0.001
	EX7m	1.75 ± 0.11	0.518	p < 0.001
	Total	5.52 ± 0.26		

In the club level players total completion time was significantly predicted by the Le7m, 505 and Ex7m time ($F_{3,21} = 134.71$, $p < 0.001$, $r^2 = 0.95$). This regression model shows that the best overall predictor of performance in this group of players was the 505 time (Table 6.2). Multiple regression also illustrated that total completion time was significantly predicted from Le7m, 505 and Ex7m time in the national level players ($F_{3,21} = 12121.01$, $p < 0.001$, $r^2 = 1.00$), but in this case the regression model showed that the best overall predictor of performance was the EX7m time. When these groups of players were combined Le7m, 505 and Ex7m time also significantly predicted total completion time ($F_{3,27} = 1155.18$, $p < 0.001$, $r^2 = 0.99$), with the best overall predictor of performance again being the EX7m time.

6.4 DISCUSSION

The purpose of this study was to assess the reliability and validity of the ADL field test in academy soccer players. The detailed analysis of soccer in Chapter 5 has highlighted the requirements of elite adult players and determined that (1) explosive sprinting ability, (2) leading sprinting ability and (3) agility are all required at the elite level. As such the reliability of the components of the ADL field test in a test retest situation has been demonstrated (Table 6.1) with high correlations for total time and the three sub-components. The high correlation was evident with both the club and national level players, indicating that the test can be used across a number of playing levels within soccer to discriminate between club and national level players and demonstrates its proficiency to distinguish between players of different ability in a youth population of elite academy soccer players. (Table 6.2).

Whilst straight line speed has been shown to be important in soccer, historical testing has included distances of up to 40m (Svensson and Drust, 2005) which is over four times longer than the average distance covered by elite adult players (Di Salvo *et al.* 2008). In a similar vein the tests which have been developed and used which examine agility often contain a number of changes of direction and are over distances which are not representative of soccer (Haj-Sassi *et al.* 2011). Whilst it has been shown that there are a large number of varied movements in football it is important to examine actions and test the components of agility that are important for the soccer performance of the individual (Svensson and Drust, 2005; Portas *et al.*, 2010) and in examining the validity of any field test it is important that the test itself represents as closely as possible the match performance in a competitive setting (Hopkins *et al.*, 1999). This is the first field testing which has attempted to assess players by directly linking testing procedures to the conditions of the modern game determined by PZ analysis.

Mendez-Villanueva (2011) state that acceleration is the most important speed quality in soccer and it has been established in the previous chapter that there were two types (leading and explosive) that were utilised in both European football and at the academy level. The ADL test has successfully incorporated both into a single test and has normalised the leading sprints by introducing a five meter lead in distance that the players will perform at maximal speed/intensity. Gore (2000) has suggested that speed testing should include start speed (10m), acceleration speed (10-20) and composite speed (0-20m), however Di Salvo *et al.* (2009) and the authors GPS data (Chapter 5) does not support this extended sprinting range as only a small percentage of high intensity activities cover this distance. In addition the most relevant patterns should be included and these should mimic the most taxing movements (Hopkins *et al.*, 1999) with an awareness that the additional muscular actions required in change of direction require a higher glycolytic contribution (Dellal *et al.*, 2010). Whilst it would be difficult and time consuming to provide testing data on all the different variable movements and distances the inclusion of the most dynamic movement (180° turn) is warranted as it is the most taxing for the player and hence was included within this studies testing procedure.

Due to its unique distance (7 meters) it is difficult to compare the results obtained in this study to the literature, however the mean time of 1.61 (\pm 0.06) seconds for the national players over 7m would appear to be comparable to the 10m time of 1.92 (\pm 0.06) which Lopez-Segovia *et al.* (2011) measured in Under 21 amateur players. However, when accounting for the age difference the players in this study could be seen as a quicker group. Buchheit *et al.* (2012) provided data of Under 15 (1.85 seconds) and Under 16 (1.79 seconds) players over 10m which would seem to be slightly quicker than the subjects in this study. However it is possible that the National players were starting to slow down or had self-determined a speed in which they felt that they could complete the deceleration phase and turn at. This is possibly demonstrated with the club level players who, whilst having a significant difference in the EX and 505, did not show a difference in the 7mLE indicating that they self-limited the speed at which they completed the first two aspects of the test. This movement action/profile is important in soccer because of the ability to close down attackers. Of interest would be a linear test over 7m with a unlimited deceleration period as this may add further evidence to the sport specific nature of the test and highlight the deficiency's in the lesser skilled group. The 505 test followed the same procedures as performed in the literature and with a mean time of 2.3 (\pm 0.091) seconds which is comparable to the adult elite rugby league players that Gabbett *et al.* (2008) measured who recorded time of 2.39 sec.

Little and Williams (2003) elude to a relationship between speed and agility when suggesting that both should be used in conjunction to provide a thorough indication of players speed capacity. However caution must be employed when designing movement specific testing drills especially with agility training as its important that fitness coaches don't become football coaches and try and replicate football drills with an agility component as this will end up diluting the focus of the fitness element and allow other components of the sport, for example ball manipulation skills, to influence the results.

Within the majority of sport science settings, the lack of equipment, time and space are underlying issues (Cone 2012) with usually two sets of timing gates being the norm and used to record sprint times over designated distances. The advantage of the ADL test is that it records a number of components of fitness in one effort that has been shown to be relevant to the movement profiles of football and due to the simplicity of the test and the time it takes for a player to complete, it can be included within the in-season training calendar with minimal disruption to the coaching process.

An additional advantage of the ADL is that it provides for position specific testing in that the coach or sports scientist may choose one aspect to focus on, for example it may be argued that an attacker/forward relies on sprint speed with motion before the maximal effort due to the positional requirements and as such the 7mLE would become the focus which may also have implications for talent identification. Further investigation may also look to the starting position and add a turn and sprint with the start of the 7mEX as this would be of interest to the defending start position, however this has potential for diluting the overall testing procedure and may not provide any additional information to the coach. However whilst performance testing can provide valid and important information it needs to be at the forefront of the tester and coaching staffs mind that no field test will determine performance during match play, due to the complex nature of the sport and the large number of physical parameters which are difficult to isolate (Svensson and Drust, 2005). Green *et al.*, (2011) acknowledged that using known and unknown tests will give strength and weaknesses in physical and cognitive elements and will allow the more accurate prescription for the strength and conditioning coach in the area of agility training.

Cone (2012) has suggested that an additional advantage of the 505 test is that limb asymmetry may be assess which would allow for a more effective assessment of return to play capability in previously injured players, it may also allow for a sport specific assessment in healthy players and highlight 'at risk' athletes.

6.5 CONCLUSION

To conclude the ADL test was found to be reliable in test retest situations and a valid predictor of level of sport participation because it discriminated between players of lesser ability (club) and higher ability (national). It can be used in a football setting to assess the main fitness components (explosive speed, leading speed and agility) which have been highlighted as important in the elite game and predictive of physiological differences between academy and elite players. This is of interest to the strength and conditioning coach and the sports scientist as traditionally speed testing has been performed over varying distances (10-40m) from a standing start and agility has been assessed using longer distances using multiple changes of direction.

CHAPTER 7

CAN THE 505 FIELD BASED FITNESS TEST HIGHLIGHT ISOLATERAL IMBALANCES?

It has been suggested within the literature that an advantage of the 505 test is that limb asymmetry may be assessed. Whilst this would allow for a more effective assessment of return to play capability in previously injured players, it may also allow for a sport specific assessment in healthy players and highlight 'at risk' athletes. Using the test developed in Chapter 6 the aim of this study was to examine the contention that bilateral imbalance between dominant and non-dominant lower limbs could be identified using the 505 fitness test, which would have implications for assessment and subsequent injury prevention programming.

7.1 INTRODUCTION

The goal of any training or development program is to increase player performance whilst simultaneously reducing, or minimising the likelihood of injury. This is more prevalent in youth soccer as the time devoted to skill acquisition and development can be severely reduced by injury (Price *et al.*, 2004). In youth players the role that injury prevention plays is key due to the added complexity of the developing body through puberty and the increased workloads that the Academy structure places on those players that are selected for full time training. There is the added variable that those players that are often seen as skilful enough will be accelerated through the age group teams and as such can be playing and training at levels which are, from a volume and intensity perspective, in advance of what their peers are doing.

In comparison to other team sports within the adult population, soccer has a higher incidence of non-contact injury due to the nature of the mechanical loads and the loading pattern, which are exerted on the body in an asymmetrical fashion (Fousekis *et al.*, 2010). Hawkins *et al.* (2001) found that within the professional game in England there were 39 injuries per club, and that each of these injuries led to an average of 4 matches being missed per season. Of the total injuries 87% occurred in the lower extremity with the majority of these occurring on the dominant side highlighting a need for unilateral assessment. Price *et al.* (2004) in examining academy players found similar results with 90% of all injuries occurring to the lower limbs with the dominant side again receiving the most treatment and a trend which showed an increasing likelihood of injury in the older age groups. Of particular concern is that injuries amongst youth soccer players are increasing and strategies need to put in place to attempt to prevent and control the incidence of these injuries and reverse the trend (Brito *et al.*, 2012).

Strength is essential for injury prevention as well as performance improvement (Bangsbo, 1994). In soccer, due to asymmetric movement patterns, imbalances between the two lower body limbs has been implicated in injury rates (Fousekis *et al.*, 2010). As such unilateral testing has been suggested to be a priority due to several factors including; a) highly unilateral nature of soccer, b) dominant vs non-dominant limb imbalances observed to increase with soccer playing experiences, c) limb asymmetry greater than 15% is associated with lower extremity injury, d) most injuries effect single limb, e) unilateral testing allows for the more effective development of return to play criteria via either comparison to uninjured leg or/and comparison to pre-injury results (Cone, 2012). Highlighting soccer

specific injury risk factors in the adult population has received wide examination, but only recently has youth soccer received the same attention (Frish *et al.*, 2011).

In assessing bilateral differences a number of test criteria have been suggested with flexibility, or passive joint range, receiving an abundance of scrutiny (Frost *et al.* 2012). Strength testing has also received attention due to its importance in the performance outcome of the sport and it is now seen as important as endurance (Requena *et al.*, 2009). However due to the expense and time consuming 'gold standard' testing protocols of isokinetic dynamometry it is impractical for the vast majority of fitness coaches and medical personnel (Jones and Bampouras, 2010). A number of 'functional tests' and screening protocols have been suggested which examine the quality of the players movement, as opposed to the individual fitness components (Frohm *et al.*, 2012; Dallinga *et al.*, 2012; Frost *et al.*, 2012), nevertheless the relationship between laboratory based and functional testing is still developing (Requena *et al.*, 2009). There have been limited studies examining performance and its relationship to bilateral strength imbalances and as lateral movements and accelerations are important this area requires greater attention due to the undesirable nature of isolateral imbalances (Jones and Bampouras, 2009).

As seen in the previous chapter, the ADL test has been shown to be a reliable assessor of speed and agility in academy soccer players and it has been suggested that the 505 component of the test, due to its unilateral nature, would provide an effective assessment of the existence of limb asymmetry although this contention has not been established (Cone, 2012). The aim of this study to assess if the 505 test can determine bilateral muscle imbalances between the dominant and non-dominant lower limbs in elite youth soccer players when compared to isokinetic data.

7.2 METHODS

Based on the validity and reliability of the A505 test from the previous chapter an adapted 505 test (ADL) was proposed to reproduce the sprint and agility movements that were highlighted as important at the senior elite level (Draper and Lancaster, 1985).

Participants and Procedures

A total of 32 outfield youth team (Under 16 and Under 17) players (mean [\pm SD] age, stature, and body mass: $16 \pm .7$ years, 173 ± 1 cm, 67 ± 5 kg, respectively) from a Professional Soccer club academy participated in the study. The players had been involved in a structured academy program for a minimum of 2 years. All players participated on average in \sim 11 hours of training per week which typically involved two 30 minute weight sessions, 8 hours of soccer training over 5 sessions and 1 formal competition game. The soccer training sessions typically consisted of technical and tactical training and normally included a 15-minute warm-up, 20-minute technical training, 20-minute tactical training, 25-minute simulated competition, and a 10-minute cool down.

All subjects were familiarized with the A505 protocol before data collection. After a standardised warm-up which included 15mins jogging, dynamic stretches, short sprints with change of direction and deceleration, a minimum of 5 minutes of rest after the warm-up to allow adequate recovery.

Adapted 505 test

The A505 test consisted of 4 maximal efforts, two each side with the fastest time (s) for each side recorded. A comprehensive explanation of the testing protocol is described in the General Methods section (Chapter 3.3).

Isokinetic testing

Isokinetic assessment was performed as described in the General Methods section (Chapter 3.4) A functional ratio of knee extension was calculated using the eccentric peak torque of the eccentric hamstrings recorded at 2.016 rad/s and the concentric quadriceps recorded at 1.08 rad/s (Iga *et al.*, 2009) this enabled the examination of the effects of soccer on the muscle strength balances about the knee joint.

Statistical Analysis

To determine differences between positions a Student paired t-test was used and statistical significance was fixed at $p < 0.05$. All statistical analysis were conducted using SPSS (IBM, version 20).

7.3 RESULTS

The differences in the dominant and non-dominant legs during the agility test can be seen in Table 7.1 which shows the agility times for all the players tested (total) and the breakdown into the expertise level (National or club) that was used in the last chapter. It can be seen that the Club level players displayed a significant difference (8.11%) between dominant and non-dominant lower limbs, whilst the national level players showed a no significant difference between lower limbs (4.43%). The combination of the two groups showed a significant difference (7.08%) with the non-dominant side being the slower for all three groups.

Table 7.1: Comparison of the dominant and non-dominant time to completion (s) of the A505 agility test. . (* indicates significant difference, between dominant and non-dominant, # indicates significant difference between club and national players where $P < 0.05$).

	Dominant	Non-Dominant	Imbalance (%)	P-Value	T-Value	CI	Effect Size
CLUB							
AGILITY (505)	2.44±0.13	2.66±0.12	8.11	0.000*	9.18	0.20, 0.27	1.38
NATIONAL							
AGILITY (505)	2.30±0.13#	2.41±0.14#	4.43	0.001*	5.01	0.06, 0.16	0.85
TOTAL							
AGILITY (505)	2.40±0.13	2.59±0.13	7.08	0.000*	9.35	0.15, 0.23	1.08

There were significant differences between the dominant legs of the CLUB when compared to the NATIONAL (Mean difference = 0.14, $t = 3.27$, $p = 0.003$, CI = 0.05, 0.22, ES = 1.33) and TOTAL (Mean difference = 0.04, $t = 1.20$, $p = 0.235$, CI = -0.03, 0.10, ES = 0.33) players and the non-dominant legs of the CLUB (Mean difference = 0.007, $t = 1.75$, $p = 0.086$, CI = -0.01, 0.15, ES = 0.49) and NATIONAL (Mean difference = 0.25, $t = 5.21$, $p < 0.001$, CI = 0.15, 0.34, ES = 1.37). There was also significant differences in the dominant limbs in the NATIONAL players (Mean difference = 0.10, $t = 2.23$, $p = 0.032$, CI = 0.01, 0.19, ES = 0.86) and the non-dominant limbs (Mean difference = 0.18, $t = 2.97$, $p = 0.005$, CI = 0.06, 0.30, ES = 1.15) when compared to the TOTAL group

Table 7.2: Isokinetic comparison of the dominant and non-dominant lower limbs. (* indicates significant difference, between dominant and non-dominant, # indicates significant difference between club and national players where P <0.05).

	Dominant (N.m)	Non-Dominant (N.m)	Imbalance (%)	P Value	T Value	CI (N.m)	Effect Size (d)
CLUB							
CON EXT (1.08rad/s)	175±27	159±20*	10.00	0.000	6.08	10.6, 21.6	0.65
CON FLEX (1.08rad/s)	91±3	94±4*	-3.63	0.000	5.31	2.2, 5.1	0.99
ECC EXT (2.16rad/s)	195±28	216±27*	-9.85	0.000	42.54	19.8, 21.8	0.71
ECC FLEX (2.16rad/s)	94±4	91±3*	4.00	0.000	10.81	2.8, 4.2	0.92
NATIONAL							
CON EXT (1.08rad/s)	203±20#	196±12#	3.48	0.065	2.14	-0.6, 14.8	0.44
CON FLEX (1.08rad/s)	95±5#	99±5#	-3.58	0.067	2.12	-7.7, 0.3	0.73
ECC EXT (2.16rad/s)	230±19#	250±20*#	-7.99	0.000	19.47	17.6, 22.4	0.93
ECC FLEX (2.16rad/s)	97 (±12)	93 (±14)*#	4.00	0.000	6.93	2.7, 5.3	1.06
TOTAL							
CON EXT (1.08rad/s)	183 (±28)	170 (±25)*	8.11	0.000	6.13	9.0, 18.1	0.50
CON FLEX (1.08rad/s)	92 (±4)	96 (±4)*	-3.61	0.000	5.41	2.2, 5.1	0.81
ECC EXT (2.16rad/s)	204 (±30)	225 (±30)*	-9.00	0.000	45.67	19.7, 21.5	0.65
ECC FLEX (2.16rad/s)	95 (±4)	92 (±3)*	4.00	0.000	12.94	3.1, 4.2	0.92

The isokinetic assessment of the CLUB and NATIONAL players can be seen in Table 7.2 and shows that there were differences recorded between 3.63% and 10% between the lower limbs. The data showed that there were significant differences recorded in three of the four categories of the dominant side movements, concentric extension (Mean difference = 44.18, t = 5.70, p <0.001, CI = 28.4, 60.1, ES = 1.57), concentric flexion (Mean difference = 4.17, t = 3.29, p = 0.003, CI = 1.58, 6.8, ES = 1.12) and eccentric extension (Mean difference = 35.71, t = 3.50, p = 0.001, CI = 14.9, 56.5, ES = 1.18) with the eccentric flexion group showing non-significant differences (Mean difference = 2.68, t = 1.73, p = 0.094, CI = -0.5, 5.8, ES = 0.66). The non-dominant side showed significant differences in all four, concentric extension (Mean difference = 37.07, t = 6.41, p <0.001, CI = 25.1, 49.0, ES = 1.51) concentric flexion (Mean difference = 4.14, t = 2.70, p = 0.011, CI = 1.0, 7.3, ES = 0.95), eccentric extension (Mean difference = 34.90, t = 3.49, p = 0.002, CI = 14.5, 55.3, ES = 1.18), and eccentric flexion (Mean difference = 2.20, t = 2.27, p = 0.031, CI = 0.2, 4.2, ES = 0.85).

Table 7.3: The dynamic knee ratios Concentric measured at 2.16 rad/s and Eccentric measured at 1.08 rad/s. (* indicates significant difference, between dominant and non-dominant, # indicates significant difference between club and national players where P <0.05).

	Dominant	Non-Dominant	Imbalance (%)	P Value	T Value	CI	Effect Size
CLUB							
H _{ecc} /Q _{con}	0.55±0.07	0.58±0.07	6.15	0.000*	4.49	0.02, 0.04	0.42
H _{con} /Q _{ecc}	0.48±0.06	0.44±0.05	6.6	0.000*	6.43	0.02, 0.04	0.54
NATIONAL							
H _{ecc} /Q _{con}	0.48±0.05#	0.48±0.04#	0.7	0.560	0.61	-0.01, 0.02	0.07
H _{con} /Q _{ecc}	0.42±0.04#	0.40±0.04#	3.15	0.067	2.12	-0.02, 0.04	0.31
TOTAL							
H _{ecc} /Q _{con}	0.53±0.07	0.55±0.07	4.64	0.001*	3.55	0.01, 0.03	0.47
H _{con} /Q _{ecc}	0.46±0.06	0.43±0.05	5.7	0.000*	6.41	0.02, 0.04	0.64

7.4 DISCUSSION

The aim of this study was to investigate the application of a unilateral field test for the assessment of functional asymmetries of the lower limb. The results show that the A505 indicated an overall difference of 7.08% in which the club level players showed a 8% difference and the national players showed a 4.43% difference between lower limbs (Table 7.1). This compares to a difference of between 3.63 and 10% in the isokinetic tests with the club players, a 3.88 and 7.99% difference in the national players which equated to between a 4 to 9% difference overall (Table 7.2).

Both the club and national level players follow the same trend with regard to the strength of each leg in concentric and eccentric muscle actions about the knee joint. The dominant leg (main kicking leg) is shown to be stronger in concentric contractions during extension and eccentric contractions during flexion with the non-dominant leg stronger during concentric flexion and eccentric extension movements. A possible reason for the difference between the lower limbs in soccer players is due to the way in which each limb is used. The dominant leg is predominantly used during high velocity kicking movements and as such the knee extension muscles are conditioned for concentric movements whilst the non-dominant leg is used to support the body weight, stabilise the joints and resist torque generated by the kicking leg and this conditions the knee extensors in eccentric conditions (Rahnama *et al.*, 2005).

However whilst the trend was similar the Club level players only reported significant differences between legs during the concentric extension and the eccentric extension, with the national level players showing significant differences in lower limbs in the eccentric extension (Table 7.2). This is in agreement with Rahmana *et al.* (2005) who found that during knee flexion the preferred leg was weaker than the non-preferred leg and may indicate that the playing standard of the national level players used in this study were similar to those English players used in the Rahmana *et al.* (2005) study.

The method of assessing and calculating the ratios in this study was the same as that proposed by Iga *et al.* (2009). Whilst Aagaard *et al.* (1998) has proposed a valid, reliable and widely used protocol to calculate hamstring/quadriceps ratios we concur with Iga *et al.* (2009) that the high speed eccentric assessment protocol caused discomfort with a number of players when pilot testing and that the data collected was therefore invalid due to it not being maximal. In addition by adopting the same methodology it also allowed for a direct comparison between the subjects in this study and those in the Iga *et al.* (2009).

Examination of the muscle ratio data (Table 7.3) show that the ratios for the H_{ecc}/Q_{con} range between 0.47 and 0.57 with the club level players showing a significant difference between the dominant and non-dominant legs (6.15%). In comparison to the data in Iga *et al.* (2009) this compares to be low as they calculated a figure of approximately 0.70 across the three groups that they tested (Control, conventional trained soccer players and resistance trained soccer players) and they did not find any iso-lateral differences within the subjects. The H_{con}/Q_{ecc} data was more representative of that reported in the literature with no significant differences between lower limbs and a ratio figure of between 0.39 and 0.46 which compared to between 0.42 and 0.50 in Iga *et al.* (2009).

The interest in the muscle ratio about the knee joint is due to the suggestion that the over development of the quads places a greater strain on the hamstring and as such contributes to injury

(Greco *et al.*, 2012), which may highlight the club level players data in this study as being important in the area of injury prevention. Of interest in the study by Iga *et al.* (2009) whilst there were no reported differences in the ratios at the speeds replicated in this study when examining the ratios at greater velocity the differences became more pronounced most likely due to the muscles about the knee joint adapting to the specific demands of the game, this was a limitation of our study due to time constraints that there were not multiple speed assessments but of the test procedure.

Within the literature the author is aware of only two studies which have examined unilateral asymmetries in elite youth soccer players both of which both suggest that the loading patterns in soccer are detrimental to the muscle balance patterns of the lower limb (Iga *et al.*, 2009; Daneshjoo *et al.*, 2013). Iga *et al.* (2009) concurs with Rahmana *et al.* (2005) and suggests that it is the loading in soccer which negatively adjusts the balance of the hamstring and quadriceps muscle groups in knee extension during high speed movements due to the preference of one leg for the ballistic kicking movements which was evident in this study. This was anecdotally observed as the group of players involved with this study were also involved in a number of screening assessments of which included landing and balance tasks and it was highlighted that the non-dominant leg outperformed the dominant leg, most likely due to its use as the bracing or standing leg when kicking the ball. Iga *et al.* (2009) findings also support the use of strength training in youth team players training to correct imbalances as they found that players within a training program that included strength training had greater peak torque values but also lower level of observed imbalances when compared to those players who did not include strength training. Daneshjoo *et al.* (2013) has also highlighted this area of discrepancy due to the different level of play, age and gender in the subjects in using subject from

a range of different sorting backgrounds Jones and Bampouras (2010) state that the lack of a homogeneous group as the reason that their data was not more explicit in highlighting iso-lateral differences, therefore future studies need to be more stringent in the recruitment of subject and groups need to be matched accordingly.

Contrary to the observation within the present work, Iga *et al.* (2009) report no significant differences between the dominant and non-dominant legs with regard to the balance of strength about the knee. However, given imbalances that may manifest in adult players (Rahnama *et al.*, 2005) such imbalances must evolve over the soccer players early playing career; such consideration should be addressed more fully in the long term player development models currently implemented.

In examining adult soccer players Rahnama *et al.* (2005) did not report any significant differences in their data on peak torque over 3 speeds during concentric knee extension or during eccentric actions although the preferred leg did record larger values in all conditions. During concentric knee flexion the only difference in the four conditions was a significantly stronger non-dominant leg at the 2.09rad/s speed, which is possibly erroneous data as slower and faster speeds did not indicate a difference. When examining ratio data a conventional Hamstring/Quadriceps ratio indicated no significant difference but in the calculated Dynamic control ratio there was a significant difference reported. However Rahnama *et al.* (2005) subject group of 41 players included elite and sub elite players and they did not state the number subjects in each skill level or indicate if there were differences between the two groups. Hence conclusions are difficult arrive at as there have been a number of studies, including this one, in which the level of play has highlighted discrepancies in iso-lateral differences.

Whilst isokinetic testing for peak torque and the hamstring/quadriceps imbalance ratio used in this study, and historically, is commonly used there is contemporary data indicating that it is not a valid predictor of injury (Zvijac *et al.*, 2013). A number of studies have sort other means of injury prediction and have examined iso-lateral differences in flexibility, strength and jumping tasks as well as through the use of screening tools such as the Functional Movement Screen (FMS). Jones and Bamouras (2010) found similar differences in a variety of jumping tasks, leg press and isokinetic testing but did not find a significant relationship and suggest that each of the imbalances were independent of each other which leads to the proposition that testing should be as sports specific as possible.

Jones and Bamouras (2010) elaborate further and suggest the field test is more functional with multiple joints and agonist and antagonist actions which is the opposite to the isokinetic chair which isolates one muscle group about 1 joint. The field test also looks at different aspects of the strength used in sport with regard to power and reactive strength and also looks at a number of other components of fitness such as speed and agility which require strength but in a sports specific way and whilst field tests don't provide agonist/antagonist imbalances, left/right imbalances have greater links to the performance aspect of the sport. However in performing a sport specific task caution must be taken as there may be adaptive strategies used by the player to combat imbalances and as such this so maybe need to look at other physical components but the use of the test is quick and could be used to highlight players that require further more time consuming testing, so whilst it may never be seen as a clinical tool it may be used to highlight those at risk.

The percentage difference in bilateral strength asymmetry for injury prevention is inconclusive, in ACL injured patients it has been suggested that a 15% difference is the cut-off point (Fowler and Reilly, 1993). Rahmana *et al.* (2005) suggest that a 10% bilateral difference is a contributing factor to injury. However, as acknowledged by the authors 60% of players in their study had imbalances of greater than 10%. In elite players because of the high velocity work, fatigue component of training, games and the fine motor control of the lower body in football players an injury threshold may need to be lower; this threshold has not been unequivocally established.

Jones and Bamouras (2010) found differences ranging between of 4 to 12% which was similar to Newton *et al.* (2006) who used a number of jumping and hopping tasks as well as squats and isokinetic assessments and found 4 to 16% differences. The present study found comparable data ranges of between 2 and 15% in the isometric testing and in the field test we found differences of up to 15%. What is evident is that the information gathered with the A505 field test provides limb asymmetry information which can be retrospectively used to identify healthy players that may become injured and can also be used in the rehabilitation of injured players for a more effective assessment of return to play and so that it is known when normal function has resumed (Rahnama *et al.*, 2005; Cone 2012).

Whilst a secondary consideration due to the subjects used for this study, was the difference between the different standard of player with the Club level players showing significant differences between the lower limbs in two categories (Concentric Extension measured at 1.08 rad/s and Eccentric Extension measured at 2.16 rad/s) whilst the National level players only registered a significant difference in one category (Eccentric Extension measured at 2.16 rad/s). Iga *et al.* (2009) has shown

that there may be ratio difference due to the playing level of the subject. The results showed that the National players were stronger and faster on both sides of the body and showed lower imbalances, with the concentric extension the same in both legs indication that they are more proficient with the non-dominant leg in kicking. This may provide information for the coach and as it is possible that this information can be linked as a performance indicator or for talent identification.

Conclusion

The ability of players to turn quickly and efficiently in both directions is critical in soccer and with the unique nature of the predominant use in the lower body there is even a greater chance of developing isolateral imbalances than in other field sports. The testing and highlighting of these imbalances is difficult and often overlooked due to the need for specialist equipment. The results suggest that the use of the 505 field test can determine asymmetries during functional dynamic movements in elite youth soccer players.

CHAPTER 8

INTERVENTION STUDY; DOES STRENGTH TRAINING OR PLYOMETRIC TRAINING REDUCE ISOLATERAL DEFICIENCIES?

A number of training stimulus are used in the pursuit of athletic improvement, two of these, plyometric and weight training are commonly used with soccer players. Of interest is the effect that these modes would have on the correction of lower limb bilateral asymmetry data generated from Chapter 7. The aim of this study was to examine, through an intervention training program (strength or plyometric training), an appropriate means of exercise prescription in order to correct said highlighted imbalances highlighted imbalances

8.1 INTRODUCTION

It has been established in previous chapters that bilateral imbalances can be assessed with a field test and from a development perspective it is important that these imbalances are corrected so as to limit the time that is injured and maximise the exposure of the players to the coaching program (Price *et al.*, 2004). Soccer at the elite level requires short bursts of explosive actions during critical moments within the game (Jullien *et al.*, 2008) with the ability of players to turn quickly and efficiently in both directions being critical for success. With the unique nature of the sport and predominant use of the lower body in specific soccer tasks (shooting, acceleration, deceleration, changes of direction, long distance passing) there is a greater chance of developing bilateral imbalances than in other field sports (Maly *et al.*, 2010).

The concept of bilateral deficit was first proposed by Asmussen and Heeboll-Neilsen (1961) in which the bilateral knee extensors force was less than the sum of the unilateral force due to the CNS being unable to activate a large number of bilateral muscle groups. This has implications for the athlete as most lower body movements are uni-lateral in nature and training should closely resemble the mechanics required to perform the sport (McCurdy *et al.*, 2005). The concept of single leg closed kinetic chain free weight training was based on this research and has recently received greater focus due to the ability to load the single limb without overloading the lower back (Boyle, 2011). In addition to strength training, plyometric training has been used to lead to positive adaptations in speed and agility performance (Chelly *et al.*, 2010).

Within the literature there is limited examination of the effect that these two modes of conditioning, strength training (ST) and plyometric training (PT), have on bilateral differences. Perez-Gomez *et al.* (2008) found that 6 weeks of combined weight and plyometric training improved performance in university students. However they used bi-lateral movements and did not test agility and due to the experimental design employed they could not distinguish between the effects of the strength or plyometric training. It is also acknowledged that there was a limitation in the subjects that they used (university students) and postulated that soccer players may respond differently to the training stimulus.

Whilst it is a common belief that players should include weight training (WT) and plyometric training (PT) to improve power (MacDonald *et al.*, 2012) it is unclear which would be most beneficial over a short term training period (6 week) when looking to correct left/right functional asymmetries. Therefore the aim of this study is to examine the effect of isolateral plyometrics and strength training to correct bilateral imbalances in youth academy players.

8.2 METHODS

Participants

A total of 22 outfield youth team (Under 16 and Under 17) players (mean [\pm SD] age, stature, and body mass: $16 \pm .3$ years, 172 ± 2 cm, 65 ± 4 kg, respectively) from a professional soccer clubs academy participated in the study. The players had been involved in a structured academy program for a minimum of 2 years and all players participated on average in \sim 11 hours of training per week over 5 sessions and 1 formal competition game which typically involved two 30 minute weight sessions and 8 hours of soccer training. The soccer training sessions typically consisted of technical and tactical training and normally include a 15-minute warm-up, 20-minute technical training, 20-minute tactical training, 25-minute simulated competition, and a 10-minute cool down. Using the data from the previous chapter in which isolateral differences between each lower limb were detected and calculated, subjects with a greater than 5% difference were selected for this study.

Procedures

The players were ranked as to the isolateral difference ratio in the times obtained in the 505 test scores from Chapter 7. A minimisation of difference protocol was used to organise the training groups (Treasure and MacRae, 1998).

Whilst all the players had been involved with the academy training program which included WT and PT they had not performed any of the single leg exercises that were to be used in this study. There was a two week introduction period in which the players participated in four sessions in which each group was either introduced to the plyometric techniques, or weight training techniques which allowed for the establishment of the five repetition maximum (5RM) weight (McCurdy *et al.*, 2005).

The training program contained two sessions a week for six weeks with the exercises changing every two weeks (Table 8.1). The session format followed the same plan each time with all the players performing a general warm up followed by a dynamic stretch and completing glute activation exercises with minibands before splitting into the WT or PT groups. A qualified strength and conditioning coach and three coaches supervised each of the sessions.

Table 8.1: Plyometric and weight training exercises used over the training period

	Week 1 and 2	Week 3 and 4	Week 5 and 6
Plyometrics	1 leg hop onto box	1 leg hop over hurdle	Tripe hop
	Lateral bound	Lateral/medial hop	Lat/medial line drill
Weights	Step-up	RFESS	Pistol Squat
	Lateral Squat	Walking zig-zag lunge	Lateral step ups

In both groups two exercises were included with 3 sets of 5 repetitions performed on each leg. The PT group was instructed to minimize ground contact and to maximize jumping height (in hurdle, cone and depth jumps) or distance (in forward hops). The ST group was instructed use as much weight as possible whilst maintaining the five repetitions and exercise technique. The plyometric training volume and intensity was based on the recommendations of Chu (1998) and the weight training volume was matched accordingly.

At the conclusion of the six week training period all the players were retested on the A505 test.

Statistical Analysis

The effects of the training types were analysed for both dominant and non-dominant legs using Analysis of Covariance where the dependent variable was post time data, the fixed factor was the training type and covariance was the pre-training times. Effect sizes were determined using partial eta squared (η^2). Within training group effects of training were determined using paired t-tests. Statistical significance was fixed at $P < 0.05$ and all statistical analysis were conducted using SPSS (IBM, version 20).

8.3 RESULTS

Of the 22 subjects that started the study all completed the twelve sessions over the six week training period and fulfilled the pre and post training A505 testing requirements. There was no overall difference between the training groups in either the dominant ($f = 0.026$, $p = 0.619$, $CI = -0.043, 0.026$ s, $\eta p^2 = 0.013$) or the non-dominant leg ($f = 1.946$, $p = 0.179$, $CI = -0.064, 0.013$ s, $\eta p^2 = 0.093$).

The dominant leg in both the weight training condition (mean diff = 0.003, $t = 0.24$, $p = 0.82$, $CI = -0.02, 0.02$, $d = 0.63$) and in the plyometric condition (mean diff = 0.006, $t = 0.55$, $p = 0.59$, $CI = -0.03, 0.02$, $d = 0.15$) was not significantly different over the time period with the non-dominant leg in the weight training condition (mean diff = 0.09, $t = 7.13$, $p < 0.005$, $CI = 0.06, 0.12$, $d = 1.87$) and in the plyometric condition (mean diff = 0.07, $t = 5.2$, $p < 0.005$, $CI = 0.04, 0.09$, $d = 1.39$) showing significant improvement (Table 8.2) when compared to the baseline data this corresponded to a decrease in the dominant/non-dominant ratio of 3.13% in the weight training group and a decrease of 2.54% in the plyometric group.

Further statistical analysis confirmed that there was no significant difference between the two training protocols ($P=0.830$)

Table 8.2: Comparison of dominant and non-dominant legs pre and post weight or plyometric training(Mean \pm SD). # indicates significantly different to dominant side; * indicates significant difference from pre training values.

	Weight training			Plyometric Training		
	Dominant (sec)	Non Dominant (sec)	Difference (%)	Dominant (sec)	Non Dominant (sec)	Difference (%)
Pre training	2.39 (\pm 0.06)	2.64 (\pm 0.07)#	9.49	2.40 (\pm 0.12)	2.64 (\pm 0.13)#	8.89
Post training	2.38 (\pm 0.08)	2.55 (\pm 0.1)#*	6.36	2.41 (\pm 0.13)	2.57 (\pm 0.17)#*	6.35

8.4 DISCUSSION

The aim of the present chapter was to examine the effect of isolateral plyometrics and strength training to correct bilateral imbalances in youth academy players. The key findings of this study are that 6 weeks of ST or PT significantly improved the bilateral difference ratio in youth soccer players but that there was no difference between the two training modes. The results show that whilst the non-dominant leg improved by 3.13% in the weight training protocol and by 2.54% in the plyometric protocol the dominant leg in both protocols did not improve.

A number of weight-training and plyometric training studies within the literature have examined performance improvement however this is the first study to compare these training modes to a field test examining isolateral differences. Makaruk *et al.* (2011) in examining unilateral and bilateral plyometric training suggests that six weeks unilateral plyometric exercises can improve performance by 11% which was more than four times the improvement seen in this study however the training volume was more than three times that used in this study suggesting that the authors could have used a greater load. However Makaruk *et al.* (2011) used recreationally trained women and assessed performance using the vertical jump test so comparisons are difficult. The volume of the exercise prescription in this study was determined using Chu's (1998) intensity classification and was consciously low due to the players involvement in competitive soccer games and training. As a comparison this study used 30 foot touches per session where Kotzamanidis (2006) used 60 foot touches per session increasing to 100 when examining plyometric training with youth soccer players over a 10-week period.

Chelly *et al.* (2010) using soccer players found that an eight week in-season plyometric training improved leg power, but as with other studies the assessment focused on a number of plyometric tests and speed over 40m and as presented in previous chapters these assessments not representative of the sport. Thomas *et al.* (2009) suggest that improvement of 9% in soccer players agility over 6 weeks by using plyometric training is due to the greater emphasis on deceleration and subsequent acceleration. Our results concur with the literature in that short term PT is effective in improving soccer specific agility however due to the unique nature of our testing it is difficult draw greater comparisons with these plyometric training studies.

A number of studies have shown significant improvement in power using short term PT programs without the corresponding increase in agility (Miller *et al.*, 2006 and Vaczi *et al.*, 2013). However as discussed in previous chapters the use of the T agility and Illinois agility tests is not representative of soccer specific movements. In contrast to our results, Jullien *et al.* (2008) found that strength training in the form of three sets of three repetitions of squats did not improve performance however their methodology required the strength training group to also to perform the agility circuit. In addition the use of the bilateral squat exercise may have influenced the results given the unilateral nature of the sport and the three week training period could be considered to short a time frame to witness performance improvements. In addition the programming of these exercise five times a week may have led to the players overtraining (Jullien *et al.*, 2008). In contrast Billows (2003) has shown that sprinting speed is improved in adolescent soccer players when a six week weight training programme is followed. However the link between sports performance and resistance exercise has not been fully established, since few investigators have used robust scientific procedures to address this question (Stratton *et al.*, 2004) and there is limited information on this type of training due to the safety and ethical issues involved with children in the lifting of free weights (Diallo *et al.*, 2001; Stratton *et al.*, 2004).

Present findings indicate that both exercise types, WT and PT, are effective in producing performance adaptations however the type and magnitude of these changes require consideration of the principal of specificity in the design of strength training programs. Observed improvements are most likely due to neuromuscular adaptations due to the short term of the training period (Hakkinen *et al.*, 1996). McCurdy *et al.* (2005) in untrained participants found that unilateral weight training improved bilateral strength and vice versa however more research is needed on trained subjects. A limitation suggested by DiStefano *et al.* (2013) is that weight training only targets muscle in one plane and would therefore not have an effect on the multi directional agility test that was used in this study. However by incorporating lateral movements within the WT methodology this phenomena was not observed as the results between the two methodologies was similar.

It has been suggested that the plyometric protocol may have improved landing mechanics and whilst force production is an important aspect of performance there are a number of other areas that aid in the improvement of the performance of the athlete (DiStefano *et al.*, 2013). Movement quality and stability were not examined but are important to consider especially in injury prevention and require a closer examination with laboratory based equipment. Whilst not tested in this study previous research also demonstrated increased proprioception after plyometric training (Myer *et al.*, 2006)

with Vaczi *et al.* (2013) using single leg jumps in lateral directions to increase joint stability and proprioception, which are considered important factors in agility tasks. As such, improvements in agility could be attributed to neural adaptation and inter-muscular coordination.

Future studies should attempt to extend on the work presented here and examine combined sessions of plyometric and weight training (complex training) to determine if similar or greater results can be achieved than if each training mode is applied individually. Complex training may be the optimal training due to enhanced neuromuscular activity (MacDonald *et al.*, 2012) and this type of training has also been used to positively affect agility performance (Thomas *et al.*, 2009).

8.5 CONCLUSION

In conclusion this study has examined the effect that isolateral plyometric and weight training over six weeks has on bilateral imbalances of the dominant and non-dominant lower limbs when performing the 505 test. Whilst the non-dominant leg improved in its performance in the 505 field test there was no improvement in the dominant leg. However this partial improvement decreased the bilateral 505 ratio and it can be postulated, as suggested in the previous chapter, that this would reduce the likelihood of injury in the players.

CHAPTER 9

SYNTHESIS OF FINDINGS

9 Synthesis of findings

This Chapter presents an initial overview of the findings in relation to the original aims and objectives of the thesis set out in Chapter 1. A general discussion is then presented where specific attention is given to how the data and studies have advanced the understanding of elite youth football player's development by examining the performance/movement profiles and characteristics in games and comparing to Adult first team players. Within this discussion the limitations of the chosen experimental designs are examined and recommendations for future research are also provided.

9.1 Achievement of Aims and Objectives

Aim 1

The aim of this study was to compare data collected using a 5Hz GPS system (MinimaxX, Catapult) and the PZ match analysis system and to establish satellite and HDOP threshold limits within the GPS software to allow direct comparison between the two data sets with a focus on high intensity running (>4m/s).

This objective was addressed by the completion of Study 1 (Chapter 4). In order for this thesis to provide a strong methodological basis in which to provide valid and reliable data for the subsequent studies from Academy Scholarship games it was important for the GPS capture conditions to be investigated and compared with the 'gold standard' method of match capture software (ProZone™). By examining the number of satellites and the HDOP it was established that for the accurate assessment of high velocity running (>4m/s) a HDOP of less than 1.8 was required and that this provided valid data that allowed for a direct comparison with PZ data. This study implemented and improved on the methodology of Harley *et al.* (2011) and provided a sound methodological platform for which to use GPS in studying the activity profile of games players.

Aim 2

The aims of this study were to quantify match play intensity according to outfield playing position in elite youth soccer at a scholarship (U18) level in total distance and high intensity running when compared to First team players.

This objective was addressed by the completion of Study 2 (Chapter 5) by examining the work profiles of Elite Academy players over eleven competitive games using the GPS capture conditions highlighted in the previous study. The data showed that whilst the total distance covered during a match was

similar, the high intensity running (>4 m/s) performed was less than that in the elite adult game. The high demand soccer specific movement profiles were similar in both the adult and youth game (less than 10m and with one change of direction) and provided the framework from which to develop a soccer specific fitness test. The collected data provided a unique analysis of the work rates and positional demands of the game at the elite scholarship level and provide information for which benchmarks can be set for the developing youth soccer player.

Aim 3

The aim of this study was to adapt the Draper and Lancaster (ADL) test to soccer specific distances and (1) determine the test-retest reliability of the test, and (2) investigate the ability of the test to discriminate between different levels of players by comparing the results between club and national level soccer players.

This objective was addressed by the completion of Study 3 (Chapter 6) in which the ADL test was found to be reliable in test retest situations, it was also established as a valid predictor of level of sport participation as it discriminated between players of lesser ability (club) and higher ability (national). It can be used in a football setting to assess the main fitness components (explosive speed, leading speed and agility) which have been highlighted as important and predictive of physiological differences between academy and elite players in the previous study.

Aim 4

The aim of this study was to assess if the A505 test could determine bilateral muscle imbalances between the dominant and non-dominant lower limbs in elite youth soccer players when compared with isokinetic data.

Building on the work of the previous study this objective was addressed by the completion of Study 4 (Chapter 7). In comparing the times from the A505 field test on the dominant and non-dominant lower limbs with isokinetic data it was established that the A505 test could highlight those individuals with isolateral lower limb imbalances. The testing and highlighting of these imbalances is difficult and often overlooked due to the need for specialist equipment however the results suggest that the use of the A505 field test can determine asymmetries during functional dynamic movements in elite youth soccer players.

Aim 5

The aim of this study was to examine the effect of isolateral plyometrics (PT) and strength training (ST) to correct bilateral imbalances in youth academy players.

By using the ADL agility test developed in study 4 to test for isolateral differences this objective was addressed by the completion of Study 5 (Chapter 8) which showed that both training modalities improved the ratio between the lower limbs in soccer players over a six week period. The inclusion of either form of training would therefore be warranted when the reduction in bilateral deficit is required and it is postulated that this would reduce the likelihood of non-contact injury in the players.

9.2 General Discussion of Findings

The investment in the development of elite youth footballers has been substantial in England but despite the increased focus in recent times there still remains questions in the development model, with a particular gap in the literature at the Under 18 scholarship level (Mills *et al.*, 2012). This is of particular importance as it is the bridge between the academy and first team football (Williams and Reilly, 2000) and from a development aspect what is required is an increase in a players performance but a reduction in injury incidence, and these two training goals are often at conflict with one another (Mayhew *et al.*, 2004; Vaeyens *et al.*, 2013). The overall aim of this thesis was to quantify the workload and establish the demands of the game at the elite scholarship level and provide information for which bench marks can be set for the developing youth soccer players when compared to First team data.

In order to quantify and compare academy players with their first team equivalents the movement profiles and workload in games needed to be assessed. This has traditionally been achieved with simplistic or labour intensive methods (Hughes, 2008) however with the development of GPS units a large amount of physical performance data can be generated within a short time frame (Jennings *et al.*, 2010i) and this has seen the match and training data increase markedly in the last 5 years which has been reflected in the number of studies published reporting the movement profiles in a number of sports (Table 2.2). It has also seen a number of authors examine the reliability and validity of GPS units (Petersen *et al.*, (2009); Jennings *et al.*, 2010ii) and whilst total distance has been shown to be accurate the precision of the recording of high speed sports specific movements has been called into question (Duffield *et al.*, 2010). However the reporting format that is currently used within the literature sees the number of satellites and HDOP reported as the average across the collection period and across all the subjects which may hide periods of less than optimal collection of data which would

have an influence on the quality of the overall information collected. This thesis has used a novel approach (Chapter 4) in the discrimination of the captured data into grouping it into quality categories and therefore providing feedback on each data collection point (table 4.1).

Whilst there have been a number of authors who have examined the reliability and validity of using GPS in a sporting context (Table 2.1) there has been only one study (Harley *et al.*, 2011) that has compared GPS and ProZone™, the most widely used analysis software in soccer, and hence this area required a greater examination due to both technologies extensive use in football. From the data obtained it was established that the traditional way of reporting the capture conditions (mean number of satellites and HDOP) could provide data that, whilst appearing valid, may in fact be 'washed out' due to the averaging of the capture conditions across the capture period and what was seen was that within a capture period the satellite and HDOP conditions could change markedly. This phenomena was amplified when used within a stadium due to the high stands effectively reducing the vision of the sky and therefore reducing the number of visible satellites. By examining and analysing the number of satellites and the HDOP across a number of capture values we established minimum standards when using and comparing this technology. We also suggest a novel reporting procedure that gave a clearer understanding and representation of the data collected (Table 4.1). This examination can be extended by allocating points or a weighing factor to each capture criteria and hence a index value could be allocated which would allow for a quicker and easier format to interpret the data.

However a limitation of study one was that the data used in this thesis to establish the capture conditions for use with GPS was based on one game. Whilst the data was split to produce a larger range of reference points, it would have been beneficial to have captured more games which would have produced a greater number of conditions in which to examine the differences between PZ and GPS. However this is difficult due to PZ only being available at First team grounds, and the limitation of players wearing monitoring equipment during competitive matches and the availability of the pitch due to first team games. Such information would not only allow for the analysis of the capture conditions but also the examination of the GPS units in measuring impacts through the use of the data generated by the accelerometers.

Whilst the technology continues to improve with regard to sampling frequency of the units, which has seen 10Hz models become available, the collection of the movement data is still reliant on the quality of the collection conditions that have been examined and discussed in this thesis and as such still

needs to be examined when looking at the data collected, also as more satellite systems come online such as Galileo (European), GLONASS (Russian), and Beidou (Chinese). The data collected in this thesis was only obtained from one manufacturer of GPS units and the data will be specific to their capture and processing algorithms, additional systems are available which operate in a similar fashion to ProZone™ and what would be of interest is the differences in these systems and there analysis of the captured data under the same capture conditions.

A further validation method for the GPS system would be to compare velocity profiles under optimal capture conditions established in this thesis with timing gates to establish if this is the new gold standard. In addition the raw GPS data may be converted to PZ positional data and processed through the PZ software and this would provide the most accurate comparison of the two systems to date and would examine the accuracy and effect that the GPS smoothing algorithms has on the GPS data.

The criteria for GPS capture conditions established in study 1 (Chapter 4) provide the sport scientist with minimum requirements when examining collected match or training data. There is a tendency within the elite sporting environment to use data with little or no consideration of the reliability of the measurement tool, often relying on the manufacturer's instructions rather than scientific rigor. This can have major implications for the development and monitoring of training programs with elite athletes and as such this information is essential in the assessment of both players, matches and the training programs that they are involved with.

Perhaps the most significant contribution of this thesis to the literature was the quantification of the match performance of elite youth team soccer players (Chapter 5) which indicated that the total distance covered in matches was similar to their adult equivalents but highlighted the discrepancy in high speed running. Anecdotally this has been observed but until now it has not been documented and should have an influence on the preparation of youth team players in both the area of long term athlete development and in talent identification. It is surprising that this area has not be examined in the past or in more detail but the teams often operate outside the normal academy structure and the players are seen as a protected commodity

Di salvo *et al.* (2008) has reported the match profiles of elite adult players and with the data presented in this thesis a direct comparison of elite youth players has been achieved. What has been highlighted is a discrepancy in the performance pathway and indicates a substantial floor in the player's development and by highlighting this performance area a greater focus on time and resources can be

given. Of interest is the development of this physical attribute over time and if it is a maturation or a conditioning issue.

Within the coaching philosophy, future studies should look at the work rates and movement profiles of players when playing in different positions and team formations as this would provide a greater understanding of both the player's capability and the positional demands in soccer. This can be seen where recently there has been a focus on the different playing formations used in competitive games with teams adjusting their style according to the opposition, most notably from a traditional 4-4-2 formation to a 4-2-3-1 playing style (Harrison, 2010). By collecting positional data when using these team formations a greater understanding will be established that would be of benefit to the soccer and conditioning coach alike.

The presented GPS data have several practical applications in terms of training program design. Soccer Academies in England are often highlighted when the national team fails to progress in international tournaments and as such the general perception is to train for longer to get more 'contact time'. The results of this thesis show that the ability of the players to cover and participate in volume work during competitive matches is comparable to that of elite first team players but that the requirements of the high speed work is lacking. Therefore a greater focus on high intensity actions is required which requires players not to be in a fatigued state and hence the focus should be on the manipulation of the work/rest ratios in training to achieve this. This implies that the long term athlete development models that clubs currently use need to be re-examined in order to give a greater chance of their youth players progressing to the first team.

Having established the movement profiles of elite players a further aim of this thesis was to develop a soccer specific field test which focused on the high intensity requirements of the game (Chapter 6). This thesis has developed a novel field testing procedure (ADL) which can differentiate between players of different abilities by using the game specific physical requirements that have been highlighted as important in the elite adult game. This physical discrepancy can now be assessed with the development and assessment of the A505 test and the development of norms across all age groups and playing abilities can be developed. Of interest is using this test as a repeated sprint test to determine a fatigue index which may provide the sport scientist and coach with a greater understanding of the issues surrounding the development process.

In addition to highlighting the game specific movement limitations the importance of research conducted on elite level players is obvious however due to the restriction and availability of first team players there was no data to reference when examining the ADL test scores. Of interest would have been testing scores of elite first team players which would have provided elite player norms as it is widely believed that developing the ability to express force quickly (high RFD) and rapidly is crucial in the training and development of elite athletes. However a relatively small body of experimental literature exists investigating the testing and training of these qualities in elite populations over an extended period. In addition the ability to track players through a long term athlete program would also generate a number of performance markers, with the successful First team players establishing benchmarks for future youth players to mimic.

From a scouting and talent identification approach the match performance movement variables established in this thesis can highlighting of those individuals that otherwise may not be recognised at an elite level due to their technical ability. In addition the ADL test that was developed in this thesis may provide further evidence of outstanding individuals performance in speed and agility tasks that are specific to soccer.

The frequency of lower limb injury has been highlighted as high in soccer and iso-lateral imbalances have been suggested as one mechanism for this high incidence rate (Cone, 2012). The ADL is of interest to the strength and conditioning coach and the sports scientist in the area of injury prevention as a further application of the data as the A505 is it is an easily implemented test that can be incorporated into the training day to highlight lower limb bilateral differences (Hawkins *et al.*, 2001). This has major implications in the area of injury prevention due to its ability to highlight players with potential for injury due to iso-lateral lower limb discrepancies (Chapter 7).

Within the literature and this thesis it has been established that in an elite youth soccer population there are players with bilateral differences, which is also replicated in an elite adult population. What is unclear and of interest is the onset of this condition and its development. It is assumed that it is due to the overuse of the dominant leg for kicking however this contention has not been examined over an extended period and it is unknown if it can be highlighted at an early age and subsequently corrected.

To advance and extend this novel approach to injury prevention both strength and plyometric training were examined to determine the most effective method to correct these muscle imbalances. Surprisingly both methods produced similar results indicating that, especially in the novice trainer, either form of bilateral training will improve the bilateral ratio. However the timeframe used for the intervention study (Chapter 8) was conducted over a short training period (6 weeks), with a small sample size and in a population undertaking a number of training components. A larger training group with a longer training duration is needed to add to the understanding of training adaptations following plyometric and weight training.

To establish the optimum training (intervention) prescription in order to correct said imbalances further studies are warranted which examine the time frame and the exercises used and whilst this thesis established that plyometric and strength training improved performance over a six week period. What is of interest is the long term effects of this type of training and there interaction on an elite youth soccer population. A number of variables could then be examined such as non-contact injury rates which would major implications for the soccer development program.

A major issue with the subjects included in this thesis was that they were all members of an Academy at a professional club and as such there were a limited number that could be included within the studies in this thesis. A possible improvement to the methodologies used would be to examine those from different clubs but this is unlikely as the author was employed by the professional club from which the players in the presented studies were also members of.

The studies in this thesis have investigated questions concerned with the development and testing and in elite youth soccer players. The studies have provided results that have tangible applications for practitioners working with similar populations to the participants in these studies. However, there are a number of areas where future research would provide greater understanding and further advance strength and conditioning practice. It has furthered the knowledge in this area with novel studies that have advanced our understanding and extended current thinking and practices used within the area of player development in soccer in England

CHAPTER 10

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CHAPTER 11

APPENDIX

Provision of Performance Insights

Client: Sky News

Contact: Amy Lewis

Project: Premier League Physical Trends Research: 2006-2013

Total Distance covered by teams has increased marginally since 2006: 108km per team per game in 2006/07 compared to 110.2km in 2012/13 (2.1% rise). Whilst total distance has been an adopted measure with media and broadcasters there is no research to support any correlation between total distance and game success. What are more important are the thresholds and work-rates by which teams and players operate.

In contrast to the minimal change in total distance there has been a significant change over time in the ways in which players cover this distance.

- Teams now cover an average of 12.1km per game at **High Intensity Speeds** or faster. In 2006/07 this figure stood at just 9.4km.
- **High Intensity Speed** is defined as being anything faster than 5.5m/s (75% of top speed for the average player).
 - **High Intensity Distance** as a proportion of total distance covered per team per game has risen from 8.7% to 11% over the same time period.
 - This season, for the first time, the average player will cover marathon distance (42km) at **High Intensity Speed** (>5.5m/s) over the course of a season. Consistently running at this pace would give them a **marathon time of 2:07.52**, enough to have beaten Uganda's Stephen Kiprotich to the 2012 Olympic men's title by 9 seconds.
- A strong indicator of physical fitness is **Recovery Time** (defined as the time between individual high intensity activity) has fallen by 39% over the last six years.
 - Players used to take an average of 54 seconds between high intensity activities; they now take just 33 seconds.
- The **Total Number of Sprints** per team per game has increased 82% in the last six seasons, an 11% average increase per season.
 - The **Total Sprint Distance** per team has also increased by 50.9% confirming that whilst players are sprinting more, they are also sprinting further.
- The data also shows a negative trend in seasons following international summer tournaments where we consistently see a fall in high intensity distance covered towards the end of the season. This is generally accepted to be a sign of player fatigue.

Advanced Analysis

The next level of analysis would be to look at changes by position to quantify where the greatest changes in physical performance outputs have occurred.

Appendix B: Individual HDOP and Satellite capture data

Player 1														
HDOP	15-25 mins		25-35 mins		35 mins-end		50-60 mins		60-70 mins		70-80 mins		80mins-end	
	number	%	number	%	number	%	number	%	number	%	number	%	number	%
<1	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1.1-5	0	0.0%	0	0.0%	0	0.0%	1118	37.4%	1600	53.4%	1658	55.3%	1432	33.6%
1.5-2	0	0.0%	0	0.0%	0	0.0%	549	18.4%	819	27.3%	407	13.6%	1495	35.1%
2-2.5	0	0.0%	0	0.0%	0	0.0%	87	2.9%	398	13.3%	404	13.5%	265	6.2%
>2.5	2997	100.0%	2998	100.0%	3482	100.0%	1237	41.4%	179	6.0%	529	17.6%	1067	25.1%
Ave	3.55		4.26		5.33		2.27		1.71		1.84		2.06	
SAT	number	%	number	%	number	%	number	%	number	%	number	%	number	%
0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
3	72	2.4%	157	5.2%	338	9.7%	1	0.0%	0	0.0%	0	0.0%	3	0.1%
4	1354	45.2%	1369	45.7%	2081	59.8%	154	5.1%	72	2.4%	28	0.9%	117	2.7%
5	1571	52.4%	1472	49.1%	1063	30.5%	571	19.1%	836	27.9%	772	25.8%	1946	45.7%
6	0	0.0%	0	0.0%	0	0.0%	1963	65.6%	2032	67.8%	2144	71.5%	2144	50.3%
7	0	0.0%	0	0.0%	0	0.0%	302	10.1%	56	1.9%	54	1.8%	49	1.2%
8	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
9	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Ave	4.50		4.44		4.21		5.81		5.69		5.74		5.50	
Player 2														
HDOP	15-25 mins		25-35 mins		35 mins-end		50-60 mins		60-70 mins		70-80 mins		80mins-end	
	number	%	number	%	number	%	number	%	number	%	number	%	number	%
<1	0	0.0%	0	0.0%	0	0.0%	91	3.5%	0	0.0%	0	0.0%	0	0.0%
1.1-5	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	563	18.8%	1504	35.3%
1.5-2	0	0.0%	0	0.0%	0	0.0%	1774	68.9%	2572	85.9%	1631	54.4%	1149	27.0%
2-2.5	0	0.0%	0	0.0%	0	0.0%	36	1.4%	334	11.2%	332	11.1%	421	9.9%
>2.5	2993	100.0%	2993	100.0%	3484	100.0%	672	26.1%	88	2.9%	471	15.7%	1186	27.8%
Ave	3.82		4.33		5.57		2.02		1.79		1.89		2.07	
SAT	number	%	number	%	number	%	number	%	number	%	number	%	number	%
0	0	0.0%	0	0.0%	0	0.0%	91	3.5%	0	0.0%	0	0.0%	0	0.0%
1	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
3	360	12.0%	528	17.6%	1773	50.9%	0	0.0%	15	0.5%	1	0.0%	2	0.0%
4	2633	88.0%	2465	82.4%	1711	49.1%	582	22.6%	233	7.8%	119	4.0%	121	2.8%
5	0	0.0%	0	0.0%	0	0.0%	1900	73.8%	2746	91.7%	2078	69.3%	1707	40.1%
6	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	799	26.7%	2430	57.0%
7	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
8	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
9	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Ave	3.88		3.82		3.49		4.60		4.91		5.23		5.54	
Player 3														
HDOP	15-25 mins		25-35 mins		35 mins-end		50-60 mins		60-70 mins		70-80 mins		80mins-end	
	number	%	number	%	number	%	number	%	number	%	number	%	number	%
<1	0	0.0%	0	0.0%	0	0.0%	0	0.0%	34	1.2%	0	0.0%	0	0.0%
1.1-5	0	0.0%	0	0.0%	0	0.0%	979	32.8%	854	29.6%	1378	46.0%	1435	33.7%
1.5-2	0	0.0%	0	0.0%	0	0.0%	1328	44.5%	976	33.8%	1053	35.2%	1639	38.5%
2-2.5	725	24.2%	100	3.3%	4	0.1%	121	4.1%	909	31.5%	358	12.0%	522	12.3%
>2.5	2269	75.8%	2894	96.7%	3482	99.9%	555	18.6%	113	3.9%	206	6.9%	665	15.6%
Ave	2.85		3.09		3.33		1.92		1.84		1.73		1.91	
SAT	number	%	number	%	number	%	number	%	number	%	number	%	number	%
0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2	0	0.0%	0	0.0%	0	0.0%	0	0.0%	34	1.2%	0	0.0%	0	0.0%
3	2	0.1%	3	0.1%	8	0.2%	7	0.2%	85	2.9%	0	0.0%	59	1.4%
4	266	8.9%	217	7.2%	622	17.8%	72	2.4%	445	15.4%	34	1.1%	340	8.0%
5	1402	46.8%	2215	74.0%	2785	79.9%	1023	34.3%	1056	36.6%	784	26.2%	1218	28.6%
6	1324	44.2%	559	18.7%	71	2.0%	1807	60.6%	1218	42.2%	2174	72.6%	2534	59.5%
7	0	0.0%	0	0.0%	0	0.0%	74	2.5%	48	1.7%	3	0.1%	110	2.6%
8	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
9	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Ave	5.35		5.11		4.84		5.63		5.21		5.72		5.54	
Player 4														
HDOP	15-25 mins		25-35 mins		35 mins-end		50-60 mins		60-70 mins		70-80 mins		80mins-end	
	number	%	number	%	number	%	number	%	number	%	number	%	number	%
<1	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1.1-5	0	0.0%	54	1.8%	0	0.0%	506	17.0%	1104	36.9%	1023	34.1%	1450	34.1%
1.5-2	0	0.0%	295	9.8%	985	28.3%	1315	44.1%	1035	34.6%	901	30.0%	1193	28.0%
2-2.5	228	7.6%	482	16.1%	341	9.8%	59	2.0%	556	18.6%	652	21.7%	203	4.8%
>2.5	2766	92.4%	2165	72.3%	2155	61.9%	1103	37.0%	300	10.0%	427	14.2%	1411	33.1%
Ave	3.38		3.11		2.81		2.25		1.85		1.91		2.06	
SAT	number	%	number	%	number	%	number	%	number	%	number	%	number	%
0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
3	84	2.8%	13	0.4%	5	0.1%	0	0.0%	8	0.3%	0	0.0%	0	0.0%
4	1051	35.1%	333	11.1%	358	10.3%	47	1.6%	152	5.1%	66	2.2%	55	1.3%
5	1482	49.5%	1484	49.5%	2284	65.6%	1549	51.9%	1016	33.9%	1344	44.8%	1864	43.8%
6	377	12.6%	1033	34.5%	800	23.0%	1330	44.6%	1772	59.2%	1560	51.9%	2338	54.9%
7	0	0.0%	133	4.4%	34	1.0%	57	1.9%	47	1.6%	33	1.1%	0	0.0%
8	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
9	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Ave	4.72		5.31		5.14		5.47		5.57		5.52		5.54	

Player5		15-25 mins		25-35 mins		35 mins-end		50-60 mins		60-70 mins		70-80 mins		80mins-end	
HDOP		number	%	number	%	number	%	number	%	number	%	number	%	number	%
<1		2	0.1%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1.1.5		0	0.0%	0	0.0%	0	0.0%	308	10.3%	1489	49.8%	1221	40.7%	1717	40.3%
1.5-2		0	0.0%	0	0.0%	0	0.0%	173	5.8%	727	24.3%	420	14.0%	498	11.7%
2-2.5		0	0.0%	0	0.0%	0	0.0%	358	12.0%	409	13.7%	337	11.2%	349	8.2%
>2.5		2994	99.9%	2997	100.0%	2999	100.0%	2150	71.9%	367	12.3%	1023	34.1%	1692	39.8%
Ave		3.50		4.39		4.26		3.04		1.78		2.10		2.17	
SAT		number	%	number	%	number	%	number	%	number	%	number	%	number	%
0		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2		2	0.1%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
3		99	3.3%	560	18.7%	302	10.1%	0	0.0%	0	0.0%	8	0.3%	1	0.0%
4		1396	46.6%	1819	60.7%	1498	49.9%	38	1.3%	46	1.5%	191	6.4%	93	2.2%
5		1499	50.0%	618	20.6%	1176	39.2%	998	33.4%	821	27.4%	1131	37.7%	1101	25.9%
6		0	0.0%	0	0.0%	23	0.8%	1788	59.8%	2051	68.5%	1655	55.1%	2222	52.2%
7		0	0.0%	0	0.0%	0	0.0%	165	5.5%	74	2.5%	16	0.5%	839	19.7%
8		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
9		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Ave		4.47		4.02		4.31		5.70		5.72		5.49		5.89	

Player 6		15-25 mins		25-35 mins		35 mins-end		50-60 mins		60-70 mins		70-80 mins		80mins-end	
HDOP		number	%	number	%	number	%	number	%	number	%	number	%	number	%
<1		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1.1.5		0	0.0%	0	0.0%	0	0.0%	942	31.5%	1388	46.3%	1368	45.7%	890	20.9%
1.5-2		0	0.0%	0	0.0%	0	0.0%	503	16.8%	690	23.0%	579	19.3%	314	7.4%
2-2.5		0	0.0%	0	0.0%	4	0.1%	60	2.0%	612	20.4%	473	15.8%	1773	41.6%
>2.5		2989	100.0%	2999	100.0%	3474	99.9%	1486	49.7%	306	10.2%	574	19.2%	1288	30.2%
Ave		3.48		4.29		3.92		2.47		1.84		1.90		2.37	
SAT		number	%	number	%	number	%	number	%	number	%	number	%	number	%
0		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
3		47	1.6%	80	2.7%	146	4.2%	0	0.0%	11	0.4%	5	0.2%	2	0.0%
4		1217	40.7%	1496	49.9%	867	24.9%	69	2.3%	100	3.3%	65	2.2%	74	1.7%
5		1725	57.7%	1423	47.4%	2181	62.7%	815	27.2%	780	26.0%	879	29.4%	666	15.6%
6		0	0.0%	0	0.0%	284	8.2%	1929	64.5%	2058	68.7%	1910	63.8%	2476	58.1%
7		0	0.0%	0	0.0%	0	0.0%	178	6.0%	47	1.6%	135	4.5%	1047	24.5%
8		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
9		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Ave		4.56		4.45		4.75		5.74		5.68		5.70		6.05	

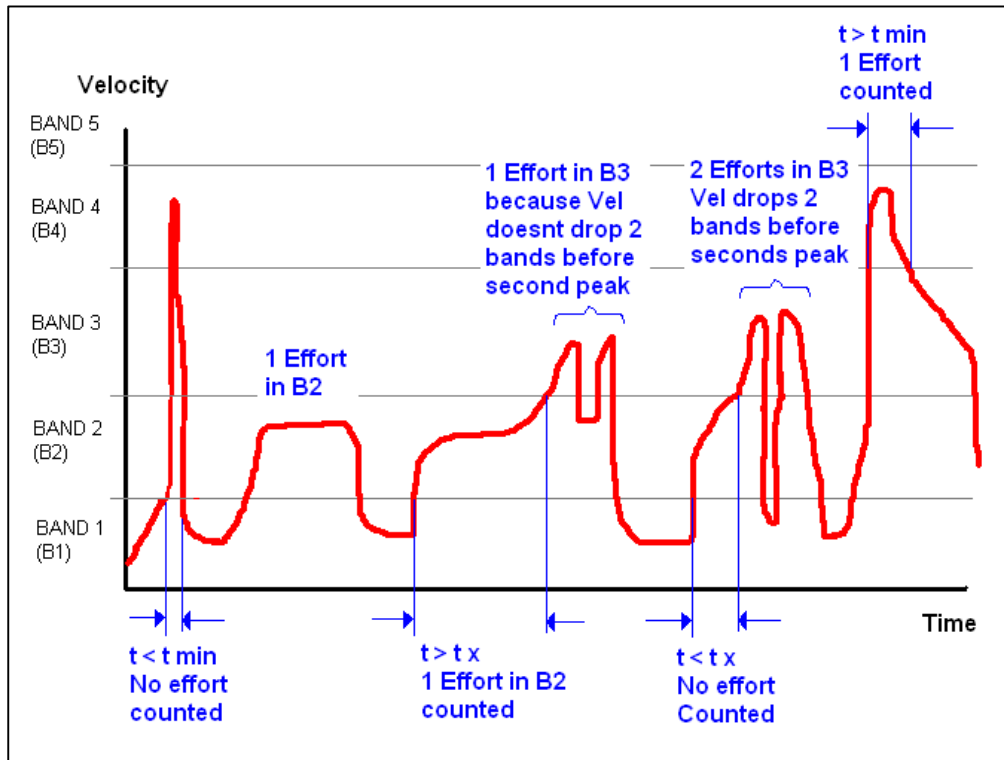
Player 7		15-25 mins		25-35 mins		35 mins-end		50-60 mins		60-70 mins		70-80 mins		80mins-end	
HDOP		number	%	number	%	number	%	number	%	number	%	number	%	number	%
<1		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1.1.5		0	0.0%	0	0.0%	0	0.0%	1068	35.7%	920	30.8%	1435	47.8%	1680	39.5%
1.5-2		0	0.0%	0	0.0%	0	0.0%	1225	41.0%	1458	48.7%	1026	34.2%	1607	37.8%
2-2.5		1012	33.8%	91	3.0%	0	0.0%	253	8.5%	514	17.2%	342	11.4%	192	4.5%
>2.5		1984	66.2%	2911	97.0%	3478	100.0%	442	14.8%	99	3.3%	196	6.5%	777	18.3%
Ave		2.76		3.12		3.34		1.87		1.74		1.71		1.90	
SAT		number	%	number	%	number	%	number	%	number	%	number	%	number	%
0		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
3		1	0.0%	2	0.1%	4	0.1%	0	0.0%	3	0.1%	0	0.0%	1	0.0%
4		86	2.9%	237	7.9%	325	9.3%	82	2.7%	159	5.3%	35	1.2%	54	1.3%
5		1334	44.5%	1741	58.0%	2317	66.6%	931	31.2%	1316	44.0%	881	29.4%	1398	32.8%
6		1575	52.6%	1022	34.0%	831	23.9%	1779	59.5%	1503	50.3%	2073	69.1%	2803	65.9%
7		0	0.0%	0	0.0%	1	0.0%	196	6.6%	10	0.3%	10	0.3%	0	0.0%
8		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
9		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Ave		5.50		5.26		5.14		5.70		5.45		5.69		5.65	

Player8		15-25 mins		25-35 mins		35 mins-end		50-60 mins		60-70 mins		70-80 mins		80mins-end	
HDOP		number	%	number	%	number	%	number	%	number	%	number	%	number	%
<1		0	0.0%	0	0.0%	0	0.0%	20	0.7%	0	0.0%	18	0.6%	0	0.0%
1.1.5		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1.5-2		0	0.0%	0	0.0%	0	0.0%	0	0.0%	1576	52.7%	2629	87.6%	3001	70.5%
2-2.5		0	0.0%	0	0.0%	5	0.1%	0	0.0%	389	13.0%	278	9.3%	413	9.7%
>2.5		2990	100.0%	2998	100.0%	3472	99.9%	2896	99.3%	1023	34.2%	76	2.5%	840	19.7%
Ave		4.22		4.35		3.93		3.32		2.52		1.77		2.02	
SAT		number	%	number	%	number	%	number	%	number	%	number	%	number	%
0		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2		0	0.0%	0	0.0%	0	0.0%	19	0.7%	0	0.0%	13	0.4%	0	0.0%
3		208	7.0%	49	1.6%	28	0.8%	61	2.1%	55	1.8%	88	2.9%	44	1.0%
4		1093	36.6%	1338	44.6%	885	25.5%	2204	75.6%	1139	38.1%	274	9.1%	1040	24.4%
5		1689	56.5%	1611	53.7%	2236	64.3%	632	21.7%	1640	54.9%	2562	85.4%	3170	74.5%
6		0	0.0%	0	0.0%	328	9.4%	0	0.0%	154	5.2%	64	2.1%	0	0.0%
7		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
8		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
9		0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Ave		4.50		4.52		4.82		4.18		4.63		4.86		4.73	

Player9														
HDOP	15-25 mins		25-35 mins		35 mins-end		50-60 mins		60-70 mins		70-80 mins		80mins-end	
	number	%	number	%	number	%	number	%	number	%	number	%	number	%
<1	0	0.0%	0	0.0%	0	0.0%	58	2.1%	0	0.0%	0	0.0%	0	0.0%
1.1.5	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	31	0.7%
1.5-2	0	0.0%	0	0.0%	0	0.0%	1692	61.4%	2760	92.3%	2517	83.9%	3504	82.3%
2-2.5	0	0.0%	2	0.1%	1	0.0%	60	2.2%	188	6.3%	314	10.5%	295	6.9%
>2.5	2994	100.0%	2994	99.9%	3479	100.0%	945	34.3%	43	1.4%	170	5.7%	428	10.1%
Ave	3.40		3.83		3.42		2.17		1.75		1.83		1.89	
SAT	number		number		number		number		number		number		number	
	number	%	number	%	number	%	number	%	number	%	number	%	number	%
0	0	0.0%	0	0.0%	0	0.0%	59	2.1%	0	0.0%	0	0.0%	0	0.0%
1	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
3	40	1.3%	67	2.2%	14	0.4%	0	0.0%	1	0.0%	1	0.0%	2	0.0%
4	859	28.7%	1139	38.0%	676	19.4%	169	6.1%	100	3.3%	194	6.5%	180	4.2%
5	2095	70.0%	1525	50.9%	2351	67.6%	1896	68.8%	2833	94.7%	2052	68.4%	2278	53.5%
6	0	0.0%	265	8.8%	439	12.6%	631	22.9%	57	1.9%	751	25.0%	1798	42.2%
7	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	3	0.1%	0	0.0%
8	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
9	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Ave	4.69		4.66		4.92		5.06		4.98		5.19		5.38	

Player 10														
HDOP	15-25 mins		25-35 mins		35 mins-end		50-60 mins		60-70 mins		70-80 mins		80mins-end	
	number	%	number	%	number	%	number	%	number	%	number	%	number	%
<1	6	0.2%	0	0.0%	0	0.0%								
1.1.5	0	0.0%	0	0.0%	0	0.0%								
1.5-2	24	0.8%	286	9.5%	1100	37.1%								
2-2.5	65	2.2%	567	18.9%	696	23.5%								
>2.5	2898	96.8%	2144	71.5%	1169	39.4%								
Ave	3.54		3.94		2.55									
SAT	number		number		number		number		number		number		number	
	number	%	number	%	number	%	number	%	number	%	number	%	number	%
0	0	0.0%	0	0.0%	0	0.0%								
1	0	0.0%	0	0.0%	0	0.0%								
2	6	0.2%	0	0.0%	0	0.0%								
3	483	16.1%	30	1.0%	7	0.2%								
4	1470	49.1%	582	19.4%	335	11.3%								
5	859	28.7%	1496	49.9%	1488	50.2%								
6	175	5.8%	889	29.7%	1135	38.3%								
7	0	0.0%	0	0.0%	0	0.0%								
8	0	0.0%	0	0.0%	0	0.0%								
9	0	0.0%	0	0.0%	0	0.0%								
Ave	4.24		5.08		5.27									

Appendix C: Speed capture conditions within GPS software



Appendix D: EFC first team match performance measures (season 07/08 average, finished 5th in table)

	Total Distance (m)	Number of Sprints	High intensity Distance (>5.5 m/s)
Attackers	9724	36	896
Central Midfielders	11246	36	1013
Wide Midfielders	11591	44	1196
Central Defenders	9466	23	632
Wide Defenders	10435	36	960

Appendix E: Young, James and Montgomery (2002) model of agility

