PERFORMANCE ANALYSIS IN SOCCER: APPLICATIONS OF PLAYER TRACKING TECHNOLOGY

Submitted by ADAM HEWITT

Bachelor of Applied Science (Human Movement) (Honours)

A thesis submitted in total fulfilment of the requirements for the award of

DOCTOR OF PHILOSOPHY

Supervisor: Dr. Kate Pumpa

Co-Supervisor: Prof. Kevin Thompson

Co-Supervisor: Prof. Keith Lyons

University of Canberra Research Institute for Sport and Exercise

Faculty of Health

University of Canberra, Australia

2016

Abstract

The aim of this thesis was threefold, firstly, to compare current player tracking technology in a single game of soccer. Secondly, to investigate the running requirements of elite women's soccer, in particular the use and application of athlete tracking devices. Finally, how can game style be quantified and defined.

Study One compared four different match analysis systems commonly used in both research and applied settings: video-based time-motion analysis, a semi-automated multiple camera based system, and two commercially available Global Positioning System (GPS) based player tracking systems at 1 Hertz (Hz) and 5 Hz respectively. A comparison was made between each of the systems when recording the same game. Total distance covered during the match for the four systems ranged from 10 830 ± 770 m (semi-automated multiple camera based system) to 9 510 ± 740m (video-based time-motion analysis). At running speeds categorised as high-intensity running (>15 $km \cdot h^{-1}$), the semi-automated multiple camera based system reported the highest distance of 2 650 ± 530 m with video-based time-motion analysis reporting the least amount of distance covered with 1 610 ± 370 m. At speeds considered to be sprinting (>20 $km \cdot h^{-1}$), the video-based time-motion analysis reported the highest value (420 ± 170 m) and 1 Hz GPS units the lowest value (230 ± 160 m). These results demonstrate there are differences in the determination of the absolute distances, and that comparison of results between match analysis systems should be made with caution. Currently, there is no criterion measure for these match analysis methods and as such it was not possible to determine if one system was more accurate than another.

Study Two provided an opportunity to apply player-tracking technology (GPS) to measure activity profiles and determine the physical demands of Australian international level women soccer players. In four international women's soccer games, data was collected on a total of 15 Australian women soccer players using a 5 Hz GPS based athlete tracking device. Results indicated that Australian women soccer players covered 9 140 ± 1 030 m during 90 min of play. The total distance covered by Australian women was less than the 10 300 m reportedly covered by

female soccer players in the Danish First Division. However, there was no apparent difference in the estimated $\dot{V}O_{2max}$, as measured by multi-stage shuttle tests, between these studies. This study suggests that contextual information, including the "game style" of both the team and opposition may influence physical performance in games.

Study Three examined the effect the level of the opposition had on the physical output of Australian women soccer players. In total, 58 game files from 5 Hz athlete-tracking devices from 13 international matches were collected. These files were analysed to examine relationships between physical demands, represented by total distance covered, high intensity running (HIR) and distances covered sprinting, and the level of the opposition, as represented by the Fédération Internationale de Football Association (FIFA) ranking at the time of the match. Higher-ranking opponents elicited less high-speed running and greater low-speed activity compared to playing teams of similar or lower ranking. The results are important to coaches and practitioners in the preparation of players for international competition, and showed that the differing physical demands required were dependent on the level of the opponents. The results also highlighted the need for continued research in the area of integrating contextual information in team sports and demonstrated that soccer can be described as having dynamic and interactive systems. The influence of playing strategy, tactics and subsequently the overall game style was highlighted as playing a significant part in the physical demands of the players.

Study Four explored the concept of game style in field sports such as soccer. The aim of this study was to provide an applied framework with suggested metrics for use by coaches, media, practitioners and sports scientists. Based on the findings of *Studies 1-3* and a systematic review of the relevant literature, a theoretical framework was developed to better understand how a team's game style could be quantified. Soccer games can be broken into key moments of play, and for each of these moments we categorised metrics that provide insight to success or otherwise, to help quantify and measure different methods of playing styles. This study highlights that to date, there had been no clear definition of game style in team sports and as such a novel definition of game style is proposed that can be used by coaches, sport scientists, performance analysts, media and general public.

Studies 1-3 outline four common methods of measuring the physical demands in soccer: video based time motion analysis, GPS at 1 Hz and at 5 Hz and semi-automated multiple camera based systems. As there are no semi-automated multiple camera based systems available in Australia, primarily due to cost and logistical reasons, GPS is widely accepted for use in team sports in tracking player movements in training and competition environments. This research identified that, although there are some limitations, GPS player-tracking technology may be a valuable tool in assessing running demands in soccer players and subsequently contribute to our understanding of game style. The results of the research undertaken also reinforce the differences between methods used to analyse player movement patterns in field sports such as soccer and demonstrate that the results from different systems such as GPS based athlete tracking devices and semi-automated multiple camera based systems cannot be used interchangeably. Indeed, the magnitude of measurement differences between methods suggests that significant measurement error is evident. This was apparent even when the same technologies are used which measure at different sampling rates, such as GPS systems using either 1 Hz or 5 Hz frequencies of measurement. It was also recognised that other factors influence how team sport athletes behave within an interactive system. These factors included the strength of the opposition and their style of play. In turn, these can impact the physical demands of players that change from game to game, and even within games depending on these contextual features. Finally, the concept of what is game style and how it might be measured was examined. Game style was defined as *"the characteristic playing pattern demonstrated by a team during games. It will be regularly repeated in specific situational contexts such that measurement of variables reflecting game style will be relatively stable. Variables of importance are player and ball movements, interaction of players, and will generally involve elements of speed, time and space (location)".*

Acknowledgements

There are so many people that have contributed along this journey of my PhD. From where it all began at the AIS and the staff at the Department of Physiology, Professor Allan Hahn for giving me my opportunity and Dr. David Pyne and Dr. David Martin for truly inspirational discussions and work they do. To the late Doug Tumilty, your pioneering work with the AIS Men's and Women's Soccer program paved the way for me to continue the work you started. Your initial guidance and chats were immense. Adrian Santrac, Head coach of the Australian Women's Soccer team (2001-2004) who provided an opportunity to apply my skills to an international team. There were many, many late nights reviewing and analysing video but it made me such a better practitioner. Tom Sermanni, Head coach of the Australian Women's soccer team (2004-2012), your continued support, willingness to help with my ideas and ability to teach me to play cards (albeit badly) provided me with amazing opportunities and friendships from the world of soccer I cherish. Indeed, the entire playing and coaching staff of the "Matlidas" from 2002 on my first international tour to my last in 2012 was amazing.

To my supervisors, firstly the late Prof. Robert T Withers, an amazing person. A chance meeting at the AIS and discussion about our joint love of football led to one of the biggest learning curves of my career. It took a little longer than anticipated but the promise to finish the PhD is complete. I am truly lucky to have had the opportunity to work with someone like you. Prof. Keith Lyons, from the moment I walked in to introduce myself at the newly created AIS Performance Analysis Unit, I knew I wanted to work with you in the area of Performance Analysis. A true visionary, I have valued your thoughts and insights throughout the journey. If not for your unwavering support and always being there, I would not be in a position to complete this PhD without you. Professor Kevin Thompson and Dr. Kate Pumpa, University of Canberra, who supported my candidature and provided invaluable feedback in the preparation of my Thesis.

Thank you to Prof. Kevin Norton for your help and input with two of the publications and Prof. Roger Eston who provided the nudge and prompting required to committing to finally completing the thesis.

To my work colleagues at AIS, Port Adelaide Football Club and Adelaide United Football Club, thank you for providing opportunities to share and apply ideas in such fantastic settings.

To my family thank you for your support over the course of the thesis.

Finally, and most importantly to Megan, you have been there throughout this long process. We have done more over the course of this thesis than most do in a lifetime, got married, lived in 2 states and six houses and of course had three beautiful children. This thesis is as much yours as it is mine. Thank you for being there and putting up with me.

Abbreviations

GENERAL

CI	confidence intervals
CV	coefficient of variation
DOP	dilution of precision
ES	effect size
FI	fatigue index
FIFA	Fédération Internationale de Football Association
g	grams
GPS	global positioning system
HDOP	horizontal dilution of position
Hz	hertz
km	kilometres
$km\cdot h^{-1}$	kilometres per hour
m	metres
$m\cdot s^{-1}$	metres per second
min	minutes
mm	millimetres
SD	standard deviation
SEE	standard error of the estimate
$\dot{V}O_{2max}$	maximum oxygen consumption
y	years

Structure of the Thesis

This thesis is presented as a thesis by publication; hence the results components of the thesis have been written as a compilation of (stand-alone) papers arranged into chapters (Chapters 3-6). All four of the papers have been either published and/or submitted for publication in peer-reviewed journals. Declarations of author contributions accompany each of these papers. The components of the thesis include:

Chapter 1 : A general introduction including the aims and significance of the thesis, the research questions, and the research context.

Chapter 2 : A review of the literature to identify and discuss match and performance analysis methods in soccer, as well as, concepts on principles of play and methodologies used to describe play.

Chapter 3-6: Studies 1-4 in peer-reviewed journal publication format

Chapter 7: Discussion and Conclusions. General discussion, summary and practical applications are presented along with implications for future research.

Publications

The following publications are presented in support of this thesis by publication:

1. **Hewitt, A**, Withers, R, and Lyons, K, 2007, 'Match analyses of Australian international women soccer players using an athlete tracking device', *Science and Football VI: The Proceedings of the Sixth World Congress on Science and Football.* Eds. Reilly & Korkuszuz, Routledge: London, pp. 224-228

2. Randers, MB, Mujika, I, **Hewitt, A**, Santisteban, J, Bischoff, R, Solano, R, Zubillaga, A, Peltola, E, Krustrup, P, and Mohr, M, 2010 'Application of four different football match analysis systems: a comparative study', *Journal of Sport Sciences*, Vol. 28, no. 2, pp. 171-182.

3. **Hewitt, A**, Norton, KI & Lyons, K 2014, 'Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking', *Journal of Sport Sciences*, Vol. 32, no. 20, pp. 1874-1880.

4. **Hewitt, A**, Norton, KI, 2015, 'Game Style: what is it and how can we measure it?' *International Journal of Performance Analysis* (Currently under review).

Conference Presentations Arising During Candidature

1. **Hewitt, A**., Withers, R., and Lyons, K. (2009). *Match analyses of Australian international female soccer players using an athletic tracking device*. Oral Presentation at VI World Congress on Science and Football, Antalya, Turkey.

2. **Hewitt, A**. and Lyons, K. (2011). *Variation in Movement Patterns of an Elite Woman Soccer Player in International Matches*. VII World Congress on Science and Football Retrieved from http://www.shobix.co.jp/jssf/contents/supplement/index_name.html.

3. **Hewitt, A**., Norton, K., and Lyons, K. (2014). *Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking*. 4th World Conference on Science and Soccer, Portland, USA.

4. **Hewitt, A**. and Norton, K. (2015). *Game Style in Soccer: What is it and how can we measure it?* VIII World Congress on Science and Football, Retrieved from http://wcsf2015.ku.dk/hb-programme/program.pdf.

Table of Contents

List of Tables

List of Figures

Chapter 1- Introduction and Overview

Soccer is one of the most popular sports in the world. In 2007, Fédération Internationale de Football Association (FIFA) predicted that 265 million people played soccer worldwide (Kunz, 2007). There are currently 209 nations recognised for men and 177 for women listed in the FIFA World rankings process. Soccer is a multibillion dollar business with Real Madrid the richest club, valued at $3.44 billion (Ozanian, 2014) and the average salary for a player in the English Premier League is approximately $3.7 million per year (Gaines, 2014). The investment in sport science and areas to improve performance lags behind player salaries although there is a growing trend to explore all avenues to enhance player and team performance.

During a soccer game players perform thousands of movements, for example kicking, running, sprinting, accelerating, decelerating, and changing direction, which are replicated during training (Mohr, Krustrup, & Bangsbo, 2003). Each category of movements varies greatly in their physiological demand. In order to create an activity profile of each athlete, it is necessary to quantify these movement demands in both training and competition. Extensive data in men's football across youth to senior and a range of playing standards has been published in the literature (Bangsbo, 1998; Bangsbo, Norregaard, & Thorso, 1991; Di Salvo et al., 2007; Drust, Reilly, & Rienzi, 1998; Reilly, Bangsbo, & Franks, 2000; Reilly & Gilbourne, 2003; Reilly & Thomas, 1976; Withers, Maricic, Wasilewski, & Kelly, 1982). Normative data derived from these studies provide descriptive information regarding the demands on teams and individuals. This information can be used to identify strengths and weaknesses in individuals and groups. To ensure prescribed training demands are suitable for the required demands of competition, profiles can be established to better prepare players for competition.

Participation at a general and elite level has increased appreciably in women's soccer. In 1971 just two International "A" matches were played compared to 512 matches involving 141 nations in 2010, with approximately 29 million women participating in soccer in 2011 (a 32% increase from 2000) (Fahmy, 2011). The increase in participation at all levels necessitates the need to collect and establish normative data for elite women's soccer. It is also necessary in both men's and women's soccer research to add contextual information to match and physical performance analyses. Team sports such as soccer are dynamic in nature where each part interacts and influences another. As such, match and motion analysis has been difficult with research largely focusing on causation rather than acknowledging the parts of the multifactorial nature of soccer (Cushion et al., 2010; Drust, 2010; Drust, Atkinson, & Reilly, 2007; Gréhaigne, Godbout, & Bouthier, 1997; Mackenzie & Cushion, 2013; Sarmento et al., 2014).

Researchers are increasingly able to describe and quantify discrete events in team games, such as passes, tackles, goal attempts etc., using various technologies. Events in a game such as the number of passes or the success of goal attempts from different zones of the field have been reported in the literature (Bloomfield, Polman, & O' Donoghue, 2004; Bradley, Lago-Penas, Rey, & Gomez Diaz, 2013; Dellal, Chamari, Wong, et al., 2011; Gréhaigne, Godbout, et al., 1997; Gréhaigne, Marchal, & Duprat, 2002; Johnson & Murphy, 2010; Lago-Penas, Lago-Ballesteros, Dellal, & Gomez, 2010; Lames & McGarry, 2007; Olsen, 1988). Typically, the literature reports one or a few of these events at a time with a view to reporting how they relate to success or otherwise. A potential problem with the application of these measurements to the real world is that measurements values differ depending on the measurement protocol and method used. In addition, there is an overarching principle that influences these events during the game, which is the style of play. Coaches, players, the media and the general population discuss game style in a manner that assumes everyone knows and understands. There are no clear definitions for the elements that make up game style. This lack of clear definition is inhibiting sport scientists, coaches, media and spectators understanding about ways to measure and quantify a style of play.

This thesis will compare current match analysis methods such as GPS based athlete tracking devices, a semi-automated multiple-camera based system and video based time-motion analysis, which have been used in soccer to analyse movement patterns. This technology will then be used to establish normative data in elite women's soccer which to date is limited in the literature compared to men's football. Literature pertaining to the movement demands of elite women soccer players is scarce. Often, match analysis in women's soccer is limited to video-based analysis, which is too labour intensive to be a viable solution for long-term training and competition analysis support. In addition, this thesis will investigate how contextual information could influence the physical demands of elite women's soccer. Finally, the concept of game style and metrics to quantify and define game style will be investigated. There is no definition for game or playing style in the literature and a common theme in the review of literature is the influence of contextual information such as playing style or tactics have on the physical demands of players.

1.2 Research Aims and Questions

The aim of this thesis was to investigate methods of performance analysis in soccer and in particular the use and application of athlete tracking devices.

Study 1: Study One compared a video-based time–motion analysis system, a semi-automatic multiple-camera system, and two commercially available GPS systems in their ability to monitor activity patterns and fatigue development in the same football match.

Specifically, the study compared player running characteristics from a soccer match measured by two different GPS systems (1 Hz and 5 Hz), video-based time motion analysis and a semi automatic multiple camera based system. These systems represented the major match analysis systems that were currently in use in research and practical settings at this time. A body of literature was emerging regarding the use of various types of match analysis methods with findings being interchanged between methods.

Research Question 1: Do differences exist between the four major match analysis systems for locomotor activities including total distance covered, high-intensity running (>15 $km \cdot h^{-1}$*), and distance covered sprinting (>20* $km \cdot h^{-1}$*)?*

Research Question 2: Does 5 Hz GPS player-tracking devices provide similar movement pattern information compared to 1 Hz GPS, video-based time motion analysis and semi automatic camera based match analysis technology?

Study 2: The aims of this study were to measure the activity profiles and physical demands of Australian international female soccer players using 5 Hz GPS athlete tracking devices.

Research Question 3: What are the movement demands as defined by total distance covered during a game and distances covered at defined speed bands of Australian women's soccer players in international matches?

Study 3: The aims of the study were twofold: to identify the movement demands and running profiles of elite level women soccer players in international competition using GPS athlete tracking devices, and secondly to examine the effect of the level of opposition, based on FIFA rankings, on the physical demands of the game.

Research Question 5: Does the ranking of the opposition influence the movement profiles of Australian women soccer players?

Research Question 6: Are there differences in the physical demands between positions in Australian women soccer players?

Study 4: The aims of this study were to outline methods that have been previously presented in a way that can help practitioners objectively assess patterns of play, to suggest a framework of meaningful metrics that coaches, analysts, sport scientists and other practitioners can use to assess strategies, and tactics and to characterise game or playing styles and propose a definition of game style.

Research Question 7: What are the elements that make up the concept of game style?

Research Question 8: How can these elements be quantified to describe game style?

Chapter 2- Review of Literature

2.1 Performance analysis in sport

2.1.1 Match and motion analysis methodologies in soccer

Match analysis of a soccer player has generally been divided into three components: technical (or skill performance), tactical and physical (Carling, Williams, & Reilly, 2005). The technical components primarily consist of the quality of skills executed during a match. The tactical component refers to the overall strategy and style of play executed to defeat the opposition. The physical performance incorporates all of the discrete movements and efforts made by a player during a match. Match analysis refers to the objective recording and analysis of discrete events during training or competition. It may focus on the activity of one player or may include the integration of actions and movements of many players around the ball. Match analysis may range in sophistication from the activity of an individual, to a synthesis of the interplay between individuals in a team (Carling et al., 2005).

Motion analysis is focused on raw features of an individual's activity and movement during a match (Carling et al., 2005). Often this information is reported as the total distance covered, the amount of time spent completing a specific activity or the number of efforts performed in varying movement categories based on speed, for example sprinting, jogging, walking and standing (Carling, Bloomfield, Nelsen, & Reilly, 2008; Cummins, Orr, O'Connor, & West, 2013; Dwyer & Gabbett, 2012a; Sarmento et al., 2014). This information can be used to develop an activity profile of a player, outlining the average running demands for each player in each position in terms of the amount of distance covered walking, jogging, running and sprinting in a game or training session. The information collected can be utilised by coaches, sport scientists and other practitioners to monitor changes in physical performance over time, to quantify the training load imposed on a player, and design match-like drills that better replicate the game demands. Furthermore, this information allows the activity profile of a player to be compared to a similar population, such as a teammate or opposition player.

Motion analysis dates back to the 1970's with researchers such as Reilly & Thomas (1976) first documenting the movements of individual players with pen and paper on a schematic diagram of the playing area. Current analysis technologies now include semi-automatic multiple camera based systems such a ProZone® and Amisco Pro® and athlete tracking systems utilising Global Positioning System (GPS), accelerometers, gyroscopes and magnetometers (CatapultSports, GPSports & STATSports for example). This evolution of match and motion analysis has seen data initially collected from pen and paper based systems progress to fully automated computer based systems capable of recording movements at 100 times per second to quantify player movements in training and competition environments. These notable advancements in technology have increased the efficacy, accuracy and reliability of data collected relating to the measurement of human locomotion. However the use of these differing methodologies such as semi-automatic multiple camera based systems and GPS based athlete tracking devices for match analysis within the literature makes comparisons difficult to interpret with no established criterion method to assess validity and reliability in competition environments (Coutts & Duffield, 2010; Cummins et al., 2013; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010).

The rapid advancement in technology coupled with the quest to gain a competitive and commercial advantage has led to match analysis technology often being released and implemented by professional sporting teams with little scientific evidence of the systems validity and reliability from the manufacturer (Edgecomb & Norton, 2006). Given that these systems are used across a variety of sports then sport-specific ecological validity of the analysis system is required.

2.1.2 Validity and reliability of match and motion analysis systems in soccer

Validity refers to the ability of a measurement tool to reflect what it is designed to measure (Atkinson & Nevill, 1998), whilst criterion- related validity has been described as the capacity of a test to demonstrate agreement with an external measure or gold standard protocol (Robertson, Burnett & Cochrane, 2014). Therefore, the validation of a match analysis system should assess the ability of the system to measure either distance or speed compared to a criterion measure. It was this lack of a criterion or "gold-standard" measurement tool that has resulted in a lack of system validation in the early match analysis literature (Reilly & Thomas, 1976). Recent studies have attempted to utilise a number of criterion measures when assessing newer technologies, resulting in an increase in a number of validation studies (Di Salvo, Collins, McNeill, & Cardinale, 2006; Jennings et al., 2010; MacLeod, Morris, Nevill, & Sunderland, 2009; Varley, Fairweather, & Aughey, 2012). Studies conducted by Di Salvo et al. (2006), Jennings et al. (2010) and MacLeod et al. (2009) incorporated electronic light-gates and calibrated measuring wheels as criterion measures to assess motion analysis systems for distances covered and time over a given distance (10, 20, 30 m for example). Each of these studies utilised a range of distances and prescribed running velocities.

The test- retest reliability of a measurement tool is described by the ability of the tool to consistently provide the same measure (Baumgartner, 1989; Robertson, Burnett & Cochrane, 2014). Therefore, a measurement tool can be reliable without being valid, however, for it to be considered valid, it must be reliable (Baumgartner, 1989). A researcher or practitioner may use match analysis results to monitor the changes in the physical performance of an individual or compare activity profiles between populations, therefore it is vital that the match analysis system is valid and reliable so true changes can be identified (Drust et al., 2007).

2.1.3 Notational analysis

Notational analysis was the earliest method of team sport match analysis, requiring an observer to subjectively quantify the activities undertaken by an individual or the whole team during a match (Reilly & Thomas, 1976). Notational analysis was conducted by observers positioned on the sideline of the playing arena recording outcomes with a pen and paper whilst watching a match (Reilly & Thomas, 1976).

The information collected through notational analysis was primarily associated with tactical and technical information, such as passing or goal scoring patterns (Garganta et al., 1997), or to assess player movement patterns (Reilly & Thomas, 1976; Withers et al., 1982). One such method required an observer to record player movement during a match by recording subjective estimates of the distance travelled at pre-selected activity categories (e.g. standing, walking, jogging or sprinting). A symbol was assigned to each activity and was recorded in one-minute blocks, with each recording translating to 4.6 m (or 5 yards) of travel. This information was then transposed post match with the frequency, total distance and distance covered per minute calculated for each activity (Reilly & Thomas, 1976).

The validity of notational analysis focused on the inter- reliability of the observers. (Reilly & Thomas, 1976) reported an inter-operator reliability of r= 0.61 and r= 0.98 for distance covered per minute and frequency of sprints performed respectively. The strong correlation for sprint frequency indicated notational analysis may be useful for collecting data on the frequency of discrete activities such as tackles, headers, passes and sprints (Reilly & Thomas, 1976; Withers et al., 1982). However, this type of match analysis is limited in its ability to provide information regarding velocity and distance.

2.1.4 Video-based time-motion analysis

Video-based time-motion analysis requires individual players to be filmed and has commonly been used in soccer (Bangsbo et al., 1991; Drust et al., 1998; Withers et al., 1982). Footage is analysed post-match allowing the observer to pause, review and slow down the footage. In team sports such as soccer the camera is usually positioned at the halfway point of the pitch in an elevated position of 3-20+ m and approximately 5-30+ m from the sideline (Bangsbo et al., 1991; Dobson & Keogh, 2007). There are typically two types of camera methods used to film the players for analysis. The first uses a single camera per player for a period of time, typically a half or the whole game (Mohr et al., 2003; Reilly & Thomas, 1976; Withers et al., 1982), allowing the observer to zoom in on a player, while keeping a small area in view. Reference points on the pitch, such as line markings, may then be used to determine movement speeds and distances. There are a number of disadvantages using video-base time-motion analysis to estimate the movement demands of team sports. A separate camera (and operator) is needed for each player tracked, often resulting in a small sample size. By only tracking a single player, or a small number of players per game, there may be incomplete information being reported for the movement profiles (Bradley et al., 2011; Di Salvo et al., 2007; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007). As such, further contextual information including the individual and team's technical and tactical demands and the involvement of the player in the game may not be reported (Bradley et al., 2011; Di Salvo et al., 2007; Rampinini et al., 2007).The second type of camera recording method requires two cameras and operators, each focusing on one half of the playing field with a small overlap in the centre (Spencer et al., 2004). Having two cameras recording in this manner means that all players can be filmed at once, however, the smaller view of each player may make it more difficult for movements to be analysed accurately.

There have been several techniques used to calculate the speed, distance and duration of movements when using video-based time-motion analysis. One such technique required each observed player to be filmed post-match over a known distance for each movement including; jogging, striding, sprinting, moving sideways, walking backwards, and jogging backwards (Reilly & Thomas, 1976; Withers et al., 1982). From this observation an average stride length was determined and assigned to each movement. Post-match analysis of the match footage included coding movements based on the observer's subjective estimation of the player's stride length. The time and distance covered for each movement could then be determined (Reilly & Thomas, 1976; Withers et al., 1982). A second method required the observer to categorise movements based upon running speed calculated from the time a player took to pass reference points on the field. The frequency, distance covered and duration in each category were then determined (Bangsbo et al., 1991; Mohr et al., 2003). These methods of determining distances covered in different speed categories only provide an estimation. By assigning a mean speed for each category the actual distances covered may be over or under estimated. For example, as the observer is reviewing the video footage they are required to determine which category the player is moving at and record the time in each category. The time in each category is multiplied by the average speed assigned in the case of Bangsbo et al. (1991) and Mohr et al. (2003) who have assigned 15 $km \cdot h^{-1}$ for moderate- high speed running. If the player was only travelling at 13 km·h^{-1} or at 17 km·h^{-1} the estimation of distances covered will be misrepresented.

Video-based time-motion analysis requires an observer to review and code individual player movements, and as such research has focused on inter- and intra-observer reliability (Krustrup & Bangsbo, 2001; Withers et al., 1982). Withers et al. (1982) reported excellent inter-observer reliability (r= 0.998) for the total distance covered during a match, however, the determination of distances covered at higher speeds, such as striding and sprinting, produced lower correlation coefficients (r= 0.745 and 0.815 respectively). It was reported that reduced reliability might contribute to observer disagreements on the classification of discrete movements, such as observer discrepancies in determining whether a player is striding or sprinting. Combining the striding and sprinting categories into a single category improved the correlation coefficient to 0.95 (Withers et al., 1982). It would appear that an individual observer's ability to differentiate between high-speed movements is a major limitation for video-based time-motion analysis.

The intra-observer reliability of video-based time-motion analysis has been previously reported (Bangsbo, 1998; Krustrup & Bangsbo, 2001; Reilly & Thomas, 1976; Withers et al., 1982), for example Krustrup and Bangsbo (2001) analysed five matches on two separate occasions separated by six months. The measure of total distance covered has been reported to have a coefficient of variation (CV) of 1% whilst variations in walking, low-speed, high-speed and backwards running resulted in CVs of 2, 5, 3 and 3% respectively (Krustrup & Bangsbo, 2001). These results indicate that the reliability of this technique is less compromised when one observer is used, as multiple observers may differ in the interpretation of movement classifications.

Intra and inter-observer reliability for video-based time-motion analysis has been described in the literature however studies reporting the accuracy of this match analysis technique for measuring distance and speed are questionable. The difficulty in comparing this method of match analysis against a criterion means that a true assessment of the accuracy and validity of the observer's subjective classification is not possible. As a result, the interpretation of player speed and distance data using this method of match analysis should be performed with caution. Given the issues surrounding limited sample sizes, and the data collection and analysis process being laborious and time consuming, video-based time-motion analysis has largely become superseded by other match analysis techniques.

2.1.5 Semi-automated tracking systems

During the late 1990's and early 2000's the development of semi-automated tracking systems allowed sport scientists and practitioners to track multiple players simultaneously, allowing a substantial increase in the sample size and the amount of data able to be collected and analysed in each game. The two most popular commercially available semi-automated tracking systems currently used in professional soccer are Prozone® and Amisco Pro® (Carling et al., 2008). Both of these systems (which have since merged to form one company) utilise technology to allow the simultaneous tracking of all players, officials and the ball through multiple cameras placed at fixed locations around the pitch (Castellano, Alvarez-Pastor, & Bradley, 2014; Rampinini et al., 2007). The cameras are located in a way to allow the entire playing surface to be recorded ensuring every player can be seen for the total match duration (Carling et al., 2008; Castellano et al., 2014). The vision from each camera is simultaneously relayed to dedicated servers and converted to high quality video files using proprietary software (Di Salvo et al., 2006). Sampling at 10 Hertz (Hz) the player trajectory is determined as x and y coordinates, measured in meters from the centre circle on the pitch. Pythagoras' theorem is then used to calculate the distance covered every sample and average speed over 0.5 s intervals (Di Salvo et al., 2006).

Validation of the Prozone® system has been assessed on several occasions (Castellano et al., 2014; Di Salvo et al., 2006; Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009). Player movement data, including average speed and distance was compared between the Prozone® system and the time it took for players to pass through a set of timing gates. There was a range of movements performed including 60 m paced runs, 15 m maximal sprints and 20 m sprints with a 90-degree turn. All movements displayed a high correlation coefficient of > 0.95 and a low typical error (CV< 1.3%) (Di Salvo et al., 2006). Overall the movement data showed a CV of 0.4% and it was concluded that Prozone® is a highly accurate system for assessing player movements. However in the aforementioned studies, only mean speed was assessed. A recent review by Castellano et al. (2014) highlighted a lack of validation and reliability studies for the Amisco system. Semi-automated tracking systems still require manual adjustment from a trained observer to ensure players are correctly identified and tracked, in particular when players are occluded from the camera view, for example during player congestion at corners and free kicks, and/ or during adverse environmental conditions such as heavy rain, and bright light (Carling et al., 2008; Castellano et al., 2014).

The adoption of semi-automated tracking systems by large numbers of clubs in major European men's competitions has seen literature produced with sample sizes of over 500 players and 7000 individual match files (Bradley et al., 2011; Bradley, Carling, et al., 2013; Bradley, Lago-Penas, et al., 2013; Bradley et al., 2009; Di Salvo et al., 2006; Di Salvo et al., 2009; Gregson, Drust, Atkinson, & Di Salvo, 2010), however only Bradley et al. (2014) have applied this technology in women's soccer. This technology has allowed for a greater depth of analysis of player movements in men's soccer including evolutionary changes, seasonal variation, match-to-match and player-to-player variability and comparisons between positions, teammates and opposition (Bradley et al., 2011; Bradley, Carling, et al., 2013; Carling, 2011; Gregson et al., 2010; Rampinini et al., 2007; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009).

Semi-automated video tracking is a popular technique for assessing player movements. However there are still limitations. An observer is still required, and data analysis is a time consuming process often requiring a 24-48 hour turnaround (Carling et al., 2008). The delay in obtaining results limits the practical application of this technology in providing coaches and practitioners with information for post-match recovery and training sessions. In addition, the nature and location of the array of cameras required to obtain the data means these systems are not portable, limiting analysis to games played at suitably equipped stadia (Castellano et al., 2014).

Often clubs train at separate grounds to where they play and they are unable to use the semi-automatic video tracking systems to track training sessions. Consequently these teams rely on other methods of analysis in training compared to games. Finally, the installation and use of these systems are expensive and often incur a service charge for the analysis of match data. Therefore, the systems are predominantly used by clubs in the top professional soccer leagues and are not accessible to moderate or amateur level teams. Currently there are no clubs in any football code with stadia fitted semi-automatic video based tracking systems in Australia.

2.2 Global positioning systems

2.2.1 Background

The first Global Positioning System (GPS) system was originally developed in 1973 for the United States military and operated with the use of 24 satellites orbiting the Earth (Lachow, 1995; Townshend, Worringham, & Stewart, 2008). Each of the dedicated GPS satellites contained an atomic clock that transmitted low-power radio signals containing information pertaining to the exact time to a ground-based GPS receiver (Larsson, 2003). Once the ground-based receiver receives the signal, the length of time taken for the signal to travel from the satellite to the receiver is calculated by comparing the time of signal transmission to the time of arrival. The distance of the satellite from the GPS receiver can then be calculated by multiplying the signal travel time by the speed of light (Larsson, 2003). To acquire the accurate position of the GPS receiver, a minimum of four satellites need to be in communication with the receiver. The position can then be trigonometrically determined (Larsson, 2003). In 1983, GPS technology was released for civilian use, however the US Department of Defense applied an intentional "error" measurement to the civilian satellite transmission known as Selective Availability, to limit hostile forces using the system (Schutz & Chambaz, 1997). In order to reduce the errors associated with Selective Availability differential GPS was developed. This required a stationary receiver at a known and calculated position allowing the GPS signal given by the satellite to be compared to a known point, thus establishing the corrective error of the signal (Townshend et al., 2008). The use of differential GPS in applications such as athlete tracking was initially limited as the units were very expensive, bulky and weighed approximately 4 kg each. In May 2000, Selective Availability was switched off thus increasing the accuracy of non-differential GPS, which subsequently became cheaper, lighter and smaller. Development of this technology has led to new opportunities in the analysis of player performance in the sporting world (Townshend et al., 2008).

2.2.2 Applications of GPS as a player-tracking tool

In 2003, the first commercially available GPS unit designed for tracking team sport athletes was developed by GPSports (Edgecomb & Norton, 2006). Since then the adoption of GPS units in team sports has increased substantially and is now commonly used in sports such as soccer, Australian Rules, rugby league and hockey (Gabbett, 2010; Gabbett, Jenkins, & Abernethy, 2012; Wisbey, Montgomery, Pyne, & Rattray, 2010). The three main manufacturers of athlete tracking devices designed for team sport use are GPSports, CatapultSports and StatSports. Advancements in technology meant that the electronic components have reduced in size dramatically, thus enabling the size of a typical GPS unit to be smaller than a mobile phone. For example, the current CatapultSports Optimeye S5 is approximately 19 x 50 x 88 mm and weighs less than 65 g. Players wear a custom made vest that houses the unit on the upper back region between the shoulder blades. Players also have custom pockets fitted to player attire for use during competition in sports such as Australian Rules (Wisbey et al., 2010).

Although relatively expensive, the use of GPS units may be seen as a more viable alternative to technologies such as semi-automated tracking systems with no ongoing services fees. GPS units are portable which allows them to be used during training sessions as well as home and away matches without the need for detailed installation of cameras. GPS units can also be used both domestically and internationally. For these reasons, GPS technology has been adopted in countries and sports where alternatives such as semi-automated tracking systems are not available.

2.2.3 Validity and reliability of GPS

Differences in equipment (i.e. GPS unit model and sampling rates), the criterion methods used and ecological validity, make the comparison between measurement systems reported for accuracy and reliability difficult. Edgecomb and Norton (2006) attempted to validate GPS by comparing distances reported by a 1 Hz GPS unit to a known distance as determined by a calibrated trundle wheel. Although GPS distance was strongly correlated to the criterion measure (r= 0.998), there was a reported average error of approximately 5%. A technical error of measurement of 5.5% was reported for the 1 Hz GPS unit. This research provided a platform for establishing the use of GPS in applied team sport settings as it demonstrated that although there were some limitations, data collected for distance covered could be reported with some level of accuracy. However, a significant limitation was that information on the effect of different running speeds on the measure of distance was not taken into consideration.

As well as reporting distances covered, literature of match analysis in soccer utilising GPS technology also examines the speed of the players. The speed of displacement is determined by measuring the rate of change in the satellites' frequency attributable to movement of the receiver, otherwise known as the Doppler shift (Townshend et al., 2008; Witte & Wilson, 2004). A common method of assessing the accuracy of GPS to measure speed has used timing gates set up at predetermined distances to enable participants wearing GPS devices to move through. Speed is then calculated by dividing the distance between gates by the time taken for the participant to move through them. This method only determines average speed over the distance between gates rather than the continuous nature that the GPS devices calculate speed via Doppler shift.

Only one study has compared GPS devices to the novel criterion method of laser measurement (Varley et al., 2012). Laser measurement devices sample at over 50 Hz and are able to determine almost instantaneous speed data. Three participants completed 80 running trials, whilst simultaneously assessing GPS validity against the laser measurement device. Participants completed straight-line running consisting of a constant velocity phase (categorised as 1-3 $m \cdot s^{-1}$, 3-5 $m \cdot s^{-1}$, and 5-8 $m \cdot s^{-1}$) followed by a maximal acceleration and deceleration phase to a complete stop. Varley et al. (2012) concluded that both 5 Hz and 10 Hz GPS units could be used by researchers to detect changes in match running during team sports as the signal is greater than the inherent noise. Although this study utilised a criterion measure to validate the GPS devices, only straight line running was examined, which is not typical of team sport athletes, who are constantly changing direction.

Recent research estimating the accuracy and reliability of 5 Hz GPS units (Coutts & Duffield, 2010; Duffield, Reid, Baker, & Spratford, 2010; MacLeod et al., 2009) and current 10 Hz GPS (Castellano, Casamichana, Calleja-González, San Román, & Ostojic, 2011) demonstrates that devices measuring at higher sampling rates provide greater accuracy in the estimation of distance covered in team-sport related movements. Research comparing 1 Hz devices to 5 Hz devices reported Standard Estimate Error (SEE) for distance covered of approximately 32% compared to 9% respectively (Coutts & Duffield, 2010; Duffield et al., 2010; Jennings et al., 2010). Comparing 5 Hz to 10 Hz units showed that 5 Hz units had a considerably higher SEE (Castellano et al., 2011). The lack of a standardised criterion methodology in measuring accuracy and reliability of GPS units in team-sport movements means there are often discrepancies in the methods used to compare units between researchers. However, an increase in sampling rate appears to improve the accuracy of the estimation of distances covered.

Inter-unit variability of GPS units of the same make and model was reported in a study by Jennings et al. (2010). Elite Australian Rules players (n=20) wore 2 GPS units of the same manufacturer and model. Each player completed a series of straight line running, change of direction courses and a team sport running simulation circuit at four speeds to elicit walking, jogging, striding and sprinting. The results indicated variations between units for the straight line running (9.9 ± 4.8% to 11.9 ± 19.5%) and for the change of direction course (9.5 ± 7.2% to 10.7 ± 7.9%) (Jennings et al., 2010). The team sport running simulation circuit elicited similar results for total distance covered (10.3 ± 6.3%) and distance covered at high intensity running (10.3 ± 15.6%). Jennings et al. (2010) recommend that players wear the same GPS unit for each field based session (training or competition) and that the level of inter-unit variability should be taken into consideration if comparing results between players wearing different GPS units.

The multifactorial nature of movements in high intensity intermittent team sport sports such as soccer makes the validation of athlete tracking devices difficult (Bangsbo, 1998; Di Salvo et al., 2010; Di Salvo et al., 2009; Drust et al., 1998; Mohr, Krustrup, & Bangsbo, 2005; Reilly, 1997). The literature thus far has reported a range of methods to assess the validity of these devices incorporating straight-line running, change of direction or agility courses, acceleration and deceleration phases (Di Salvo et al., 2006; Duffield et al., 2010; Edgecomb & Norton, 2006; Jennings et al., 2010; Varley et al., 2012). These methods have focused on testing and reporting isolated components of team sport movements (such as the ability of the athlete tracking devices to measure a series of 20 m efforts) over known distances (as measured by calibrated measuring devices), with electronic timing devices (such as light-gates) or laser measurement devices (Di Salvo et al., 2006; Duffield et al., 2010; Edgecomb & Norton, 2006; Jennings et al., 2010; Varley et al., 2012). In contrast, the literature pertaining to the match and motion analysis of team sports report parameters such as total distance covered in a 90 min period, or 15 min period, peak 5 min period, distance covered in a velocity band (i.e. 0-6 $km \cdot h^{-1}$, 6-12 $km \cdot h^{-1}$, 12-15 $km \cdot h^{-1}$, 15-19 $km \cdot h^{-1}$ and 20+ $km \cdot h^{-1}$) or the number of efforts in over various thresholds rather than the isolated movements outlined in validity and reliability literature (Bangsbo, 1998; Cummins et al., 2013; Gregson et al., 2010; Mackenzie & Cushion, 2013; Mohr et al., 2005). Therefore, it is suggested that the validity and reliability of GPS devices needs to be relative to the application it is being used for.

An important component in the accuracy of GPS is the number and location of the satellites. As previously identified, a theoretical minimum of four satellites is required to obtain a three dimensional position fix. Not only is the number of satellites of importance but the geometrical arrangement of the satellites, relative to each other and the receiver. This is a quantified measure known as the dilution of precision (DOP) (Witte & Wilson, 2004). The greatest predicted accuracy of triangulation will occur when one satellite is directly overhead and the remainder are equally spread around the horizon and will produce a DOP of 1. On the other hand, higher DOP values will be seen if the satellites are tightly clustered overhead and a maximal value of 50 would occur meaning the position fix is unreliable (Witte & Wilson, 2004). This requirement means that there can be a significant impact in the analysis of team sports if "line of sight" is obscured, such as soccer, when playing in stadia with reduced roof openings that inhibit the view of the horizon for the GPS receivers.

2.3 Physical demands in soccer

2.3.1 Movements demands in soccer

The movement demands of men's soccer players have been well researched (Bangsbo, 1998; Bangsbo et al., 1991; Di Salvo et al., 2007; Drust et al., 1998; Reilly et al., 2000; Reilly & Gilbourne, 2003; Reilly & Thomas, 1976; Withers et al., 1982). As previously mentioned, there have been a variety of match analysis methods used to determine these movement demands (Bangsbo, 1998; Reilly et al., 2000; Reilly & Gilbourne, 2003; Reilly & Thomas, 1976; Withers et al., 1982). In general, the total distance covered by a male professional soccer player is approximately 11 000 m with ranges between 9 000 – 12 000 m (Bangsbo et al., 1991; Bradley et al., 2009; Carling, 2010; Di Salvo et al., 2007; Withers et al., 1982). Typically 75 to 85% of total distance is covered at speeds classified as low speed leading some researchers to conclude that movement demands in soccer are predominately aerobic in nature (Bangsbo et al., 1991; Bradley et al., 2009; Carling, 2010; Di Salvo et al., 2007; Mohr et al., 2003; Withers et al., 1982). However the remaining movements may consist of over 500 high-intensity efforts including high-speed running, jumping, changes-of-direction, sprinting, accelerations and decelerations which require a significant anaerobic energy contribution (Bangsbo et al., 1991; Bradley et al., 2009; Withers et al., 1982). High intensity, physically demanding tasks are considered to be critical in the outcome of the success or otherwise of the performance of the individual and that of the team (Reilly et al., 2000). As such, large portions of the literature have concentrated on quantifying these movements in competition (Bradley, Carling, et al., 2013; Bradley, Lago-Penas, et al., 2013; Bradley et al., 2009; Di Salvo et al., 2007; Di

Salvo et al., 2009) and training environments (Buchheit, Mendez-Villanueva, Delhomel, Brughelli, & Ahmaidi, 2010; Helgerud, Engen, Wisloff, & Hoff, 2001).

2.4 Gender differences in physical performance and soccer

Although female participation in soccer dates back to the commencement of the modern game in around 1863 with the formation of the English Football Association, female soccer games only gained popularity during World War I when games were organised to raise funds for charity, with some games attracting over 50 000 spectators (Williamson, 1991). However, in 1921, the English Football Association decided to ban female soccer games suggesting that it was unsuitable for females to be playing soccer (Williamson, 1991). The ban on female soccer was not lifted until 1971. Today, female soccer is one of the fastest growing sports, with a report commissioned by FIFA in 2006 to assess the global participation in both men's and women's soccer demonstrating 26 million female soccer players worldwide (FIFA, 2007).

Research quantifying the physical demands of male soccer players has used a variety of match analysis techniques in a range of competitions (Bangsbo et al., 1991; Bradley et al., 2009; Di Salvo et al., 2007; Gregson et al., 2010; Reilly & Thomas, 1976; Withers et al., 1982). Considerably less information exists regarding these demands of elite female soccer players. The first reports of physical demands of female soccer players indicated that players covered average total distances of 8 500 ± 2 200 m (Davis & Brewer, 1993). More recent studies have observed that female soccer players consistently cover a total distance of 9 000 to 12 000 m in a game (Andersson, Karlsen, Blomhoff, Raastad, & Kadi, 2010; Andersson, Randers, Heiner-Moller, Krustrup, & Mohr, 2010; Bradley, Dellal, Mohr, Castellano, & Wilkie, 2014; Gabbett & Mulvey, 2008; Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Mohr, Krustrup, Andersson, Kirkendal, & Bangsbo, 2008b). It appears that the relative physiological loads obtained during matches are similar across gender, and so it has been suggested that the aerobic system is heavily taxed throughout female soccer games, particularly during periods of high intensity work of a game (Bradley et al., 2014). However, male players have been shown to possess a higher physical capacity than females across a range of aerobic and anaerobic fitness tests. A comparison of 54 male and 59 female players tracked during Union of European Football Associates (UEFA) Champion League matches using a semi-automated multiple camera based system (Amisco® Pro, Nice, France) demonstrated large differences for a number of match performance variables both physical and technical (Bradley et al., 2014). Male players were able to cover more distance in total and covered more distance at higher speeds (>15 $km \cdot h^{-1}$). At higher speed thresholds, the differences were more pronounced in the second half of the game. Technically, female players lost the ball more often and had lower pass completion rates than male players (Bradley et al., 2014).

2.5 Tactical and technical performance in soccer

Although successful performance in soccer match play requires superior levels of physical fitness to sustain a high work rate during matches, it is perhaps the synthesis of the physical, technical and tactical skill level that usually separates successful soccer players and team performance at the elite levels of competition.

Studies comparing tactical characteristics of successful versus unsuccessful soccer teams during matches have shown various traits for success (Garganta et al., 1997; Hughes, Robertson, & Nicholson, 1988; Luhtanen, Korhonen, & Ilka, 1997; Olsen, 1988; Tenga, Holme, Ronglan, & Bahr, 2010; Tenga & Sigmundstad, 2011). It was shown that successful teams at the 1986 FIFA Men's World Cup had more kicks and shots at goal inside the penalty area, less fouls, more use and possession of the ball in the midfield area of the pitch and more touches per possession (Hughes et al., 1988). Olsen (1988) investigated 52 matches of the 1986 World Cup and found successful teams to have less dribbling into a scoring position on the field, more single touches of the ball before shooting at goal, a high incidence of goals with less than two preceding passes. During the 1990 World Cup, Luhtanen (1997) investigated the tactical characteristics of successful teams. This study showed successful teams had more offensive actions, more offensive attacks where the ball was not lost, greater number of passes to the centre of the field, more scoring attempts, shots on goal and greater numbers of goals. Garganta et al. (1997) found successful teams changed the rhythm of the game from fast to slow ball movements, varied their attacking methods and had different direct and indirect styles of play. More recently, a study based on 177 matches from the 2002, 2006 and 2010 FIFA World Cups revealed that the variables which related to attacking play and best differentiated between winning, drawing and losing teams were total shots, shots on target and ball possession. Defensive "success" was characterised by teams with less total shots received and shots on target received (Castellano, Casamichana, & Lago, 2012; Lago-Penas et al., 2010).

These investigations on the technical and tactical aspects of soccer match play demonstrate that teams apply different tactics, team formations and ball movements to win matches (Castellano et al., 2012; Garganta et al., 1997; Lago-Penas et al., 2010; Luhtanen et al., 1997; Tenga et al., 2010; Tenga & Sigmundstad, 2011). These tactics are likely to impact the movement patterns and the physiological demands of match play. The tactical style of play and skill level of players, therefore, should also be considered when analysing the performance of soccer players during a match.

2.6 Factors affecting on-field physical performance of elite soccer

2.6.1 Match Conditions

Each soccer match is played against a unique opposition, often with subtle and sometimes notably different tactical styles of play. Furthermore, matches are played in different environmental conditions against opponents of varying skill level. Each of these factors may impact the movements made by players on the field. This section, therefore, discusses the different match conditions that should be considered when analysing performance.

2.6.2 Playing Position

A number of studies have reported on the fitness capacities of players of various playing positions and formations (Bangsbo et al., 1991; Bradley et al., 2011; Carling, 2011; Di Salvo et al., 2007; Reilly & Thomas, 1976). In a large-scale study into the motion characteristics of top class soccer players, Di Salvo et al. (2007) analysed 300 male players from the top Spanish League using a computerised match analysis system. The results indicated midfield players covered a greater total distance than defenders and forwards (Di Salvo et al., 2007).

Using a multiple-camera computerised tracking system, Carling et al. (2011) analysed 45 matches from the highest men's competition in France over three season to investigate the effect a team's playing formation has on the physical demands of players. Using one team as a reference team playing a 4-3-3 or 4-5-1 system of play, opposition formations of 4-4-2, 4-3-3 or 4-5-1, and 4-3-2-1 were compared to assess the impact on physical indicators such as total distance covered, high intensity running (14.4-19.7 $km \cdot h^{-1}$), very high intensity running (>19.8 $km \cdot h^{-1}$), and technical indicators such as the number of passes and the number of touches per possession. Overall, it was suggested that the opposition's team formation had little impact on the reference team's physical performance (Carling et al., 2011). However, there were differences in the skill-demands according to the opponent's formation that may have applications in the technical and tactical preparation of teams.

Bradley et al. (2011) examined the effect of 3 playing formations 4-4-2, 4-3-3 and 4-5-1 on high-intensity running and technical performance. Twenty English Premier League games were analysed using a multiple-camera computerised tracking system. Overall ball possession and high-intensity running did not differ between 4-4-2, 4-3-3 and 4-5-1 formations. However when looking at different playing positions in the formations, it was shown that attackers in a 4-3-3 performed more high-intensity running than attackers in 4-4-2 and 4-5-1 formation (Bradley et al., 2011).

In summary, the literature demonstrates that playing position and formation is an important factor to consider when analysing the physical performance of a soccer player. However, only Carling et al. (2011) and Bradley et al. (2011) utilised additional contextual information such as the playing formation of both teams to examine its affects on the physical requirements of different playing positions.

2.6.3 Competition level

When analysing the on-field performance of soccer players during match play, the standard of competition may be of influence. Numerous studies have shown a difference in the physical capacities and characteristics of players in various leagues around the world (Bloomfield et al., 2004; Dunbar & Treasure, 2004; Rienzi, Drust, Reilly, Carter, & Martin, 2000). When comparing between different divisions of specific leagues, there also appears to be a difference in physical capacity. For example, first team players performed better than reserve team players across three English Premier League clubs in a battery of physical performance tests including lactate threshold testing as a measure of aerobic fitness, 20 m sprint test (speed), vertical jump (leg power), Illinois agility test (agility) and repeat speed consisting of 8x40 m efforts (anaerobic) (Dunbar & Treasure, 2004; Power, Dunbar, & Treasure, 2005). Similar differences in the physical characteristics between age groups were reported in a study of 146 Portuguese soccer players using a 7x34 m repeated sprint test which was able to determine differences between groups of players across various age and ability levels ranging from First Division down to under 12 players (Sampaio & Maçās, 2004).

Research has highlighted teams competing in the European leagues covering more total distance in games compared to teams from Japan and South American Leagues (Kan et al., 2004; Bangsbo et al., 1991; Rienzi et al., 2000). Japanese players playing in lower ranked leagues have been recorded as running less than 7 000 m in a game (Kan et al., 2004) compared to their European counterparts who run 8 000-10 000 m (Bangsbo et al., 1991; Rienzi et al., 2000). Kan et al. (2004) also found the average speed of Japanese players to be faster for teams in an international match versus a domestic Japanese League match. A study by Rienzi et al. (2000) found differences in work rates on the field between leagues with South American players covering 1 500 m less distance than English Premier League players. The discrepancies in the total distance covered in games between leagues maybe due to the physical fitness of players in the top European leagues being superior or differences in the style of play that may limit the amount of running in games, or most likely to be a combination of both of these factors.

A more recent study compared the match performance and physical capacity of players in the top three competitive standards of English soccer (Bradley, Carling, et al., 2013; Carling, 2011). Match performance data including total distance covered, high-intensity running distances and the amount of distance covered sprinting, from players in the FA Premier League, Championship, and League 1 using a multiple-camera system were analysed. In addition, a subsection of players of the three leagues performed the Yo-Yo intermittent endurance test level 2 (Yo-Yo IE2) to determine physical capacity. The results indicated that players in League 1 and the Championship performed more high-intensity running than those in the Premier League. Technical indicators such as pass completion, frequency of forward and total passes, balls received and average touches per possession were higher in the Premier League compared to lower standards. There were no differences in the results of Yo-Yo IE2 across the three leagues. The data demonstrated that high-intensity running distance was greater in players at lower compared to higher competitive standards despite a similar physical capacity in a subsample of players in each standard (Bradley, Carling, et al., 2013; Carling, 2011).

There are some discrepancies in the literature relating to the physical capacities of players in different professional soccer leagues, and its affect on players' ability to physically perform during a match. Studies by Dunbar and Treasure (2004), Power et al. (2005) and Sampaio & Maçãs (2004) indicated that players from higher levels of competition performed better in a series of tests designed to assess speed, power, aerobic endurance and repeated speed. However no game based performance indicators such as the number of sprints, distance covered at high intensity or total distance covered was reported. Bradley et al. (2013) and Carling (2011) showed that there was no difference in Yo-Yo IE2 results in players sampled from the three highest levels of competition in England. However there were differences in the match related performance indicators with players in the lower two levels of competition completing more high intensity running than those players from the highest level. This would suggest that factors other than physical capacity (as measured by Yo-Yo IE2) determine the amount of high intensity running in a game, factors such as strategy, tactics and style of play may be of equal importance.

2.6.4 Environmental conditions

Matches and training for soccer are often performed in unfavourable environmental conditions. High altitude, heat, humidity and cold have been identified as factors that may affect soccer performance (Carling, Dupont, & Le Gall, 2011; Dvorak & Racinais, 2010). Previous investigations into on-field performance have shown that the physical performance of players are affected by environmental conditions (Ekblom, 1986).

The final soccer match of the 2008 Olympic Games in Beijing was played at 12:00pm local time. Thirty minutes prior to the game commencing the wet-bulb-globe temperature (WBGT) was 34.3 °C, indicating a high health risk at rest, without taking into account the effect on elite soccer performance (Dvorak & Racinais, 2010). High ambient temperatures resulted in a 54% decrease in high intensity running in the final 15-min period compared to the first in a friendly game played by Spanish professional soccer players in hot conditions (31 °C) (Mohr et al., 2010). Similarly, in two games played by Turkish semi-professional players in moderate heat (34 °C) or high heat (36 °C), high intensity running performance in the second half of the high heat game was shown to be substantially compromised with a mean decrease of 19% compared to the moderate heat conditions (Ozgunen et al., 2010). Although the average ambient temperatures in the moderate heat and high heat conditions only differ by 2 °C there was a 23% difference in relative humidity between the 2 games. Ozgunen et al. (2010) calculated the Heat Index (HI) score, an index combining both air temperature and relative humidity to determine the human-perceived equivalent temperature, to be significantly different ($P<0.001$) at 35±1 and 49±1 °C between moderate and high heat conditions respectively. Factors such as thermal stress and dehydration were linked to the decrease in running performance over the course of the games played in hot conditions (Ozgunen et al., 2010).

A number of competitions are played during periods of colder ambient temperatures that may affect the on-field physical performance of soccer players (Carling et al., 2011). However, the physical activity profiles of professional soccer players in four temperature ranges (≤5 °C, 6-10 °C, 11-20 °C and ≥21 °C), Carling, Dupont and Le

Gall (2011) suggested that there was no decrease in physical performance in cold conditions.

In addition to temperature and humidity, the physical performance of soccer players is also likely to be affected by playing at moderate to high levels of altitude (Aughey et al., 2013; Garvican et al., 2014; Gore, McSharry, Hewitt, & Saunders, 2008). A review of approximately 100 years of matches from World Cup Qualifying matches held in the South American region illustrate that football competition at moderate/high altitude (>2 000 m) favors the home team (Gore et al., 2008). A comparison of sea-level and high altitude performance (La Paz: 3 600 m) of elite youth soccer players showed that high altitude reduced the total distance covered compared to sea-level performance (Aughey et al., 2013). The study included sea-level based players and players normally residing at altitude however the reduced running performance when playing at high altitude was similar for both groups (Aughey et al., 2013). Even moderate altitude (1 600 m) was shown to negatively influence the total distance covered by 28 youth soccer players compared to sea level performance (Garvican et al., 2014).

In summary, environmental conditions such as heat and humidity and altitude may influence the physical performance of soccer with colder temperatures having less effect. However, research has focused on the physical performance rather than effect of these conditions on the technical or tactical performance of soccer matches. Factors such as rain, wind and pitch conditions (firm, soft, artificial) may also influence performance factors in soccer, however there is a lack of research into these environmental conditions on soccer performance.

2.6.5 Match strategy and tactics

In any invasion based team sport there appears to be a natural sequence of events where players are either defenders or attackers in connection with configurations of play (Gréhaigne, Richard, & Griffin, 2005). As shown in Figure 1, Gréhaigne et al. (2005) differentiate between the concepts of “attack” and “offense”, and identifies that there is a defensive aspect to attack. When a team is in “attack”, the offensive aspect is scoring or attempting to score, whilst maintaining possession or conserving the ball is suggested to be the defensive aspect of an attacking play. Attempting to recover possession or putting pressure on the opposition to regain possession is seen as the offensive side of the defence. Finally, defending the goal relates to the defensive actions of the defence (Gréhaigne et al., 2005). Rather than a basic model of attacking or defending, (Gréhaigne et al., 2005) outline a more complex model with the use of offensive and defensive characteristics.

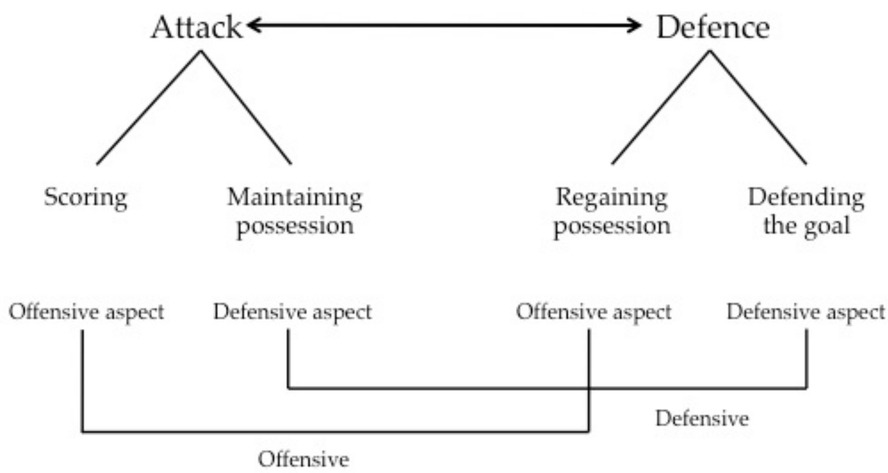


Figure 2-1 Offensive and defensive characteristics of attacking and defending play. Gréhaigne et al. (2005)

Invasion based team sport, such as soccer, display teams closely coordinated within a given set of rules, focused on winning the match (Gréhaigne et al., 2005). Furthermore, as outlined in Figure 2-1, each team must coordinate offensive and defensive aspects of attacking and defending with the primary aim of scoring and preventing scores respectively (Gréhaigne et al., 2005).

To plan and coordinate individual players within a team, coaches use strategy and tactics. These terms are sometimes used interchangeably, however, it is necessary to delineate and understand the differences between these terms. Bouthier, Gréhaigne, and Godbout (1999) outline the components of strategy referring to plans, principles of play or guidelines established before a match. Conversely, tactics involve events executed during the game in order to adapt to the immediate requirements of the opposition. Furthermore, Gréhaigne et al. (2005) outlines the two key components of strategy to be elements predetermined in advance for the team to organise itself (e.g. background play, team composition) and secondly, positional instruction assigned to an individual during training prior to the match. Whereas, tactics relate to the individual response taken in reaction to an opponent in a game and the adjustment of the team to the conditions of play.

Hughes (1973) stated that there is no system of play that will overcome inaccurate passing or poor shooting and that a team's loss is usually not because of a formation or system (i.e. 4-3-3) although spectators and media sometimes indicate otherwise. Bangsbo and Peitersen (2000) describe styles of play as "the characteristic way in which a team uses a system of play. Selecting a style of play should take into account the playing qualities a team possesses."

Currently playing style is primarily based on coaching philosophies (Hughes, 1973). Bangsbo and Peitersen (2000) outline four playing styles that describe the attacking aspect of the game:

1) Systematic build up of play or possession based play: characterised by many passes between players in the defensive third and the middle third of the playing field, trying to maintain possession for long periods of play, moving players into the attacking third of the field to establish longer periods of play per possession.
2) Direct Play: a team consciously plays the ball quickly forward into the attacking third and tries to create goal-scoring opportunities. A primary aim of direct play is that the opposition's defense is often somewhat disorganised at the moment the ball is regained.
3) Counterattacking Play: fast, direct counterattack with few players, initiated as soon as possession is regained, followed by a quick forward pass. In the instant of passing, one or two players should rush forward to support the player who receives the ball in plenty of space.
4) Total Soccer: a term first used to refer to the Dutch team's style of play in the 1974 World Cup, a style of play where the players switch positions during the build-up play in an attempt to confuse defenders.

Bangsbo and Peitersen (2000) outline three defensive styles:

1) Collective Defensive Style or Block Defending: characterised by consistent zonal marking in the defensive half of the pitch.
2) Low-Pressure: a team on losing possession, consciously retreats into its own half of the playing field
3) Pressure Play: an offensive style of defense where the team tries to win possession as quickly as possible and close to the opposition's goal as possible.

The description of what the style of play is by Bangsbo and Peitersen fails to include any methods as to how it would be possible to quantify the characteristics of playing style and continues by stating that the style of play of a team should be influenced by the playing qualities without outlining what these qualities might be and which qualities are better suited to different playing styles.

Often soccer teams are not only remembered for the championships or trophies won, but also for the way they played. The "total football" played by the Netherlands, Barcelona and Spain's "tika-taka" possession based football or the defensive mindset of Italy are a few examples of styles of play that are as much a part of those teams' signature style as the success of the teams. However, the analysis and quantification of the impact of strategy, tactics and playing style in soccer is scarce in the scientific literature. The majority of research has focused on descriptive studies of physical characteristics of sub-populations of players or discrete events looking for cause and effect results. When analysing the physical performance of soccer players, the tactics of the game needs to be taken into account.

The locomotion characteristics of players have been extensively described, however these studies have not documented the style of play. The influence of different styles of play on the location and movement demands for each playing position is poorly understood. Different styles of play employed by professional soccer teams include playing with an emphasis on retaining possession, slowing down the speed of the game, delaying attacking moves until opportunities to attack are presented or playing with an emphasis on speed of movement. Although little research has been undertaken on the effects of different styles of play on movement demands this may provide some explanation as to why there can be large variations in distances travelled by elite division one players (6 600 – 12 000 m) during matches played in different international leagues (Withers et al., 1982; Rienzi et al., 2000; Kan et al., 2004).

The introduction of player and ball tracking technology in sport via platforms such as ProZone, Amisco or even GPS based technology has been identified as fast becoming the norm in professional sport (Bialkowski, Lucey, Carr, Yue, Sridharan & Matthews, 2014). Sporting organisations receive large volumes of spatiotemporal data from external data providers such as Opta®, STATS® or Champion Data®, but sometime lack the computational skills or resource to adequately analyse such large data sets (Lucey, Oliver, Carr. Roth & Matthews, 2014). Traditional sport analytics approaches use event-based statistics to drive analysis and decision-making despite the increase in ball and player tracking data becoming available. The emerging field of sports spatiotemporal analytics uses spatiotemporal data such as ball and player tracking data to drive automatic team behavior/strategy analysis (Lucey et al., 2014).

2.7 Summary

Soccer is a multifaceted game comprised of three major aspects: physical, technical and tactical. There have been various systems introduced to quantify the physical demands of soccer during competitive matches. The advancement of technology has made new methods more accessible allowing for a greater volume of data to be collected in less time. This review highlights the need to compare differences between these systems to ensure practitioners are aware of potential differences between motion analysis systems.

The comparative lack of information regarding the physical demands of elite level women's soccer compared to the men's game has been identified. Greater understanding of these physical demands will aid coaches and sport scientists in devising training preparation, training specificity, player training load management and periodisation.

Finally, a team’s style of play is likely to affect the work rate of players during a match. The tactical emphasis of the game should be considered when evaluating the physical performance of a player. However, the style of play or game style is poorly defined in the literature and the terminology of strategy, tactics and game style are incorrectly interchanged.

Chapter 3- Application of four different football match analysis systems: a comparative study

3.1 Publication Overview

The following represents a study completed in 2009 and was the culmination of a collaborative research project involving researchers from Australia, Spain, Denmark and Qatar. My role in the project was as a primary researcher and project coordinator. The research was borne out of discussions held initially at the World Congress of Science and Football (2007) in Antalya, Turkey. With extensive research presented across a number of different match analysis systems I had discussions with Inigo Mujika about the need to have all of the different match analysis systems operating on the same game to be able to compare. However, as there were no semi-automated multiple camera based systems (ProZone or Amisco) operating in Australia it made it logistically impossible to conduct the project in Australia. After further discussions we were able to access the Amisco match analysis system through the La Liga team Athletic Bilbao who also allowed us to use their reserves and senior youth team players in a friendly match for our project. We invited Peter Krustrup and Magni Mohr to be part of the research project due to their vast experience in video based time motion match analysis in peer reviewed literature. The aim of the project was to have independent "experts" in match analysis systems collect data in the same game on the same players. The data would then be pooled for comparisons of the different match analysis systems. The four systems identified were: semi-automated multiple camera based analysis (Amisco), 1 Hz GPS (Spi 10, GPSports), 5 Hz GPS (minimax, Catapult Sports) and video based time motion analysis.

As well as leading the project concept and design I played a significant part of the data collection and analysis and provided drafts of major sections for the final manuscript.

3.2 Author Declaration for Thesis Chapter 3

Publication title: Application of four different football match analysis systems: a comparative study

Publication details: Published in *Journal of Sport Sciences*, Vol. 28, no. 2, pp. 171-182.

Declaration for Thesis Chapter Three

Declaration by candidate

In the case of Chapter Three, the nature and extent of my contribution to the work was the following:

Nature of contribution
I was responsible for the project design and concept. I had a significant contribution to the data collection and analysis as well as the preparation of the manuscript. Overall I estimate the extent of my contribution of this manuscript to be 20% and equivalent to the lead author.

The following co-authors contributed to the work.

Name	**Nature of contribution**	**Extent of contribution (%)**	**Contributor is also a student at UC Y/N**
Morten Randers	Data Collection & analysis, manuscript preparation	20	N
Inigo Mujika	Project design and concept, data collection and analysis	15	N
Juanma Santisteben	Data collection	5	N
Rasmus Bischoff	Data collection and analysis	5	N
Roberto Solano	Data collection and analysis	5	N
Asier Zubillaga	Data collection and analysis	5	N
Esa Peltola	Data collection	5	N
Peter Krustrup	Data collection and analysis, manuscript review	5	N
Magni Mohr	Data collection and analysis, manuscript review	15	N

Candidate's Signature		**Date** 4/9/15

Declaration by co-authors

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	University of Copenhagen and University of South Australia, School Health Sciences: Date stored from August 2009

	Name & Signature	**Date**
Signature 1	**Morten Randers:**	4/9/15
Signature 2	**Inigo Mujika:**	18/8/15
Signature 3	**Juanma Santisteben:**	20/8/15
Signature 4	**Rasmus Bischoff:**	3/9/15
Signature 5	**Roberto Solano:**	3/9/15
Signature 6	**Asier Zubillaga:**	31/8/15
Signature 7	**Esa Peltola:**	1/9/15
Signature 8	**Peter Krustrup:**	25/8/15
Signature 9	**Magni Mohr:**	21/8/15

3.3 Application of four different football match analysis systems: A comparative study

*Morten Randers[1], Iñigo Mujika[2], **Adam Hewitt**[3], Juanma Santisteban[4], Rasmus Bischoff[1], Roberto Solano[5], Asier Zubillaga[6], Esa Peltola[5], Peter Krustrup[1], & Magni Mohr[1]*

[1]Department of Exercise and Sport Sciences, University of Copenhagen, Copenhagen, Denmark, [2]USP Araba Sport Clinic, Vitoria-Gasteiz, Basque Country, Spain, [3]Australian Institute of Sport, Canberra, ACT, Australia, [4]Medical Services, Athletic Club Bilbao, Bilbao, Spain, [5]Aspire Academy for Sports Excellence, Doha, Qatar, and [6]Faculty of Physical Activity and Sport Sciences, University of the Basque Country, Bilbao, Spain

(Accepted 20 October 2009)

Abstract

Using a video-based time–motion analysis system, a semi-automatic multiple-camera system, and two commercially available GPS systems (GPS-1; 5 Hz and GPS-2; 1 Hz), we compared activity pattern and fatigue development in the same football match. Twenty football players competing in the Spanish second and third division participated in the study. Total distance covered during the match for the four systems was as follows: 10.83±0.77 km (semi-automatic multiple-camera system, n=20), 9.51±0.74 km (video-based time–motion analysis system, n =17), 10.72±0.70 km (GPS-1, n =18), and 9.52±0.89 km (GPS-2, n =13). Distance covered by high-intensity running for the four systems was as follows: 2.65±0.53 km (semi-automatic multiple-camera system), 1.61±0.37 km (video-based time-motion analysing system), 2.03±0.60 km (GPS-1), and 1.66±0.44 km (GPS-2). Distance covered by sprinting for the four systems was as follows: 0.38±0.18 km (semi-automatic multiple-camera system), 0.42±0.17 km (video-based time–motion analysing system), 0.37±0.19 km (GPS-1), and 0.23±0.16 km (GPS-2). All four systems demonstrated greater ($P \leq 0.05$) total distance covered and high-intensity running in the first 15-min period and less ($P \leq 0.05$) total distance covered and high-intensity running during the last 15-min period than all other 15-min intervals, with a reduction ($P \leq 0.05$) in high-intensity running from the first to the last 15-min period of 46±19%, 37±26%, 50±26%, and 45±27% for the semi-automatic multiple-camera system, video-based time–motion analysis system, GPS-1, and GPS-2, respectively. Our results show that the four systems were able to detect similar performance decrements during a football game and can be used to study game-induced fatigue. Rather large between-system differences were present in the determination of the absolute distances covered, meaning that any comparisons of results between different match analysis systems should be done with caution.

Keywords: GPS, multiple-camera system, time–motion analysis, high-intensity running, fatigue, soccer

Introduction

In association football (i.e. soccer), where prolonged intermittent exercise is performed in combination with brief periods of maximal and near maximal effort exercise, players have highly complex movement patterns that are unpredictable and dictated by numerous variables (Di Salvo et al., 2007; Krustrup et al., 2005; Mohr et al., 2008b; Mohr et al., 2003; Rampinini et al., 2007; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009; Rienzi et al., 2000). Due to the multifactorial requirements for success in football, many attempts have been made to elucidate the physiological demands of football match play based upon estimates of distance covered and fluctuations in running intensity throughout a game (Bangsbo et al., 1991; Mohr et al., 2008b; Mohr et al., 2003). Video-based time-motion analysis has been applied widely (Bangsbo, 1998; Reilly & Thomas, 1976; Withers et al., 1982) and such analyses have provided evidence that the distance covered at high intensity depends on playing position, standard of competition, physical capacity of the player, and physical performance of the opponent (Krustrup et al., 2005; Mohr et al., 2003; Rampinini et al., 2007). Furthermore, time-motion analyses have shown that the performance of players deteriorates after the most intense periods of the game, at the beginning of the second half and towards the end of a game (for a review, see Mohr et al. (2005). Fatigue develops during a football match both transiently following short-term high-intensity sequences and towards the end of a game (Bangsbo, Iaia, & Krustrup, 2007; Bangsbo & Mohr, 2005; Mohr et al., 2008b; Mohr et al., 2003); however, it is unclear whether the same fatigue patterns will be detected with different match analysis systems.

Advances in technology have allowed new methods of assessing movement patterns in football, including the multiple-camera method (Di Salvo et al., 2007; Rampinini et al., 2007; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009) and global positioning systems (Coutts & Duffield, 2008; Edgecomb & Norton, 2006; Kirkendall, Leonard, & Garrett, 2004). In comparison to time-consuming video-based time-motion analysis, these new match analysis systems have greater objectivity and some of them a higher time- resolution, which allows a more comprehensive study of locomotion patterns in football. However, no studies have tested this assertion by combining simultaneously video-based time-motion analysis, semi-automatic multiple-camera systems, and GPS monitoring in the same football match. Due to the unpredictable and indiscrete nature of movement patterns in football, to date there is no ''gold standard'' method for determining movement patterns and workload in the sport. However, information about possible differences between the aforementioned systems is highly warranted. Edgecomb and Norton (2006) compared a GPS system with a manual computer-based tracking system to estimate distances covered on an Australian Rules Football field and showed that the GPS system overestimated true values by ≈4.8% compared with a calibrated trundle wheel. This evaluation of distances covered was not, however, performed during a training session or competitive game and movement at different speeds was not compared.

In the present study, we compared a video-based time-motion analysis system, a semi-automatic multiple-camera system, and two commercially available GPS systems in their ability to monitor activity patterns and fatigue development in the same football match.

Methods

Participants

Twenty highly trained outfield football players from the development programme of a professional club and currently competing in the Spanish second and third divisions took part in the study. Players' age, body mass, and stature (mean ± s) were 19.3 ± 1.2 years, 73.6 ± 5.3 kg, and 1.79 ± 0.06 m, respectively. The players were regular starters in their respective teams and were representative of all outfield-playing positions. The players had a Yo-Yo IR1 performance of 2950 ± 425 m, a vertical countermovement jump height of 44 ± 4 cm, and an average 30-m sprint speed of 7.19 ± 0.02 $m \cdot s^{-1}$. All players were informed of the risks and discomfort associated with the experiment before providing their written consent to participate. The study followed the Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by the Ethics Committee of the University of the Basque Country (UPV-EHU).

Experimental design

A test-game (two halves of 47.5 min separated by 15 min of normal half-time) between the two teams was arranged by the researchers. The game was played 7 days after the last game of the competitive season. The game took place at San Mame´s Stadium (Bilbao, Basque Country) at noon at an average temperature of 30 °C, which was determined from continuous readings provided by a station of the Basque Service of Meteorology (Euskalmet) situated ≈1 km from the stadium. The pre-game and half time procedures, as well as the coaching during the game, were similar to a competitive game. The players' activity profiles were assessed during the entire game by a video-based time-motion analysis system (VTM: Bangsbo et al., 1991; Mohr et al., 2003), the Amisco® multiple-camera semi-automatic passive tracking system (MCS: Di Salvo et al., 2007), and two commercially available global positioning systems (GPS-1: Edgecomb & Norton, 2006; GPS-2: Coutts & Duffield, 2008). The data analysis and treatment for the four systems were performed by researchers in four different countries, and the different investigators were blinded to all other results. The researchers evaluated the ability of each system to track player movement and to detect changes during the game. Furthermore, the four systems were compared in terms of their capability to measure distances covered at different speed.

Time-motion analysis

Each player was video-recorded individually close up throughout the entire match. The 20 digital video cameras (GR-D23E, JVC, Japan) were positioned at the side of the pitch, at the level of the midfield line, at a height of about 25 m and at a distance of 30-40 m from the touchline. The videotapes were later replayed on a monitor for computerised coding of activity patterns. The following locomotor categories were adopted: standing (0 km·h^{-1}), walking (6 km·h^{-1}), jogging (8 km·h^{-1}), low-speed running (12 km·h^{-1}), moderate-speed running (15 km·h^{-1}), high-speed running (18 km·h^{-1}), sprinting (30 km·h^{-1}), and backward running (10 km·h^{-1}). The locomotor categories were chosen in accordance with Bangsbo et al. (1991). Thus, the time for the player to pass pre- markers in the grass, the centre circle, and other known distances was used to calculate the speed for each activity of locomotion. All time-motion analyses were performed by the same experienced observer, who has analysed more than 400 matches. The reproducibility of the results obtained by time-motion analysis has been determined, and no systematic differences were observed in test–retest analysis of the same match. The intra-individual variations in walking, low-intensity running, high-intensity running, and backward running were 2, 5, 3, and 3%, respectively (Krustrup & Bangsbo, 2001). The inter-individual variation in results obtained by two independent experienced observers was never more than 4% in any of the locomotor activities (Bangsbo et al., 1991). The above activities were later divided into four locomotor categories: (1) standing; (2) walking; (3) low-intensity running, encompassing jogging, low-speed running, and backward running; and (4) high-intensity running, consisting of moderate-speed running, high-speed running, and sprinting. The frequency and duration of each activity were recorded and data are presented for 5-, 15-, 45-, and 90-min periods. The distance covered for each activity within each interval was determined as the product of the total time and mean speed for that activity. The total distance covered during a match was calculated as the sum of the distances covered during each type of activity. To be able to compare time-motion analysis with the other three systems, the above-mentioned categories included specific speed intervals: standing (0-2 $km \cdot h^{-1}$), walking (2-7 $km \cdot h^{-1}$), jogging (7-9 $km \cdot h^{-1}$), low-speed running (9-13 $km \cdot h^{-1}$), moderate-speed running (13-16 $km \cdot h^{-1}$), high-speed running (16-22 $km \cdot h^{-1}$), and sprinting (> 22 $km \cdot h^{-1}$).

Amisco™ multiple-camera system

The Amisco™ system is a multiple-camera match analysis system (Amisco Pro™, version 1.0.2, Nice, France). The movements of all 20 outfield players were observed during the entire game by eight stable, synchronised cameras positioned at the top of the San Mame´s Stadium (Bilbao, Basque Country) at a sampling frequency of 25 measures a second. Signals and angles obtained by the encoders were sequentially converted into digital data and recorded on six computers for post- match analyses. From the stored data, the distance covered, time spent in the different movement categories, and the frequency of occurrence for each activity were determined by Athletic Mode Amisco Pro™, Nice, France (Di Salvo et al., 2007). Match analyses were used to distinguish between the same intensity categories as described in the time–motion analysis section.

Global positioning system

The GPS technology was originally designed for military use, but recently it has been applied to the analysis of performance in football. Edgecomb and Norton (2006) compared a GPS system with a manual computer-based tracking system to estimate distances covered on an Australian Football field and showed relatively minor variations. The system uses signals from at least three Earth-orbiting satellites to determine the position and calculate movement speeds and distances. Two different commercially available GPS units (MinimaxX v2.0, Catapult, Scoresby, Australia, and GPSports SPI Elite, Canberra, Australia) were placed on the player's upper back, one inside a neoprene pouch attached to a harness around the player's shoulders, the other inside another pouch sewn into a sleeveless under- shirt. The receivers were placed as recommended by the manufacturers and were not occluded. Based on signals from at least three satellites, the receiver is able to calculate and record data on position, time, and speed with a time-resolution of 5 and 1 Hz for the two systems (GPS-1 and GPS-2, respectively). Both systems used the GPS Doppler data. The data from each receiver were treated in the same manner and data were extracted using proprietary software (MinimaxX analyse software v2.5, GPSports team AMS v1.2.1.12). Match analyses were also carried out considering the above-mentioned intensity categories.

Statistical analysis

Differences between the distances covered in the first and second halves were determined using Student's paired t-test. To keep a high number of participants, the four systems were compared in pairs using Student's paired t-test. Differences in activities between 15-min periods in the match were determined using a one-way repeated-measure analysis of variance (ANOVA). In the case of a significant difference between time periods, a Tukey's post hoc test was used to identify the points of difference. To compare the systems, correlation coefficients were determined and tested for significance using Pearson's regression test. Furthermore, the coefficient of variation (CV) was used as a measure of intra-individual variation within different locomotor categories between the match analysis systems and was calculated as the standard deviation of the difference between the four systems divided by the mean and multiplied by 100 (Atkinson & Nevill, 1998). Data are presented as means ± standard deviation (s). Statistical significance was set as $P \leq 0.05$. Bonferroni correction was used for the multiple paired t-test resulting in $P \leq 0.008$ when the four systems were compared and $P \leq 0.012$ when three systems were compared. Due to technical problems some players' data were lost, which means that the number of participants differs depending on which systems are being compared. Three video recording (VTM) were lost due to technical problems. Data from two GPS-1 receivers were lost because the transmitters stopped recording during the game, whereas five GPS-2 receivers stopped recording during the game and data from two receivers were affected by noise.

Results

Activity pattern

Total distance covered ranged from 9.51±0.74 km measured with the video-based time-motion analysis system to 10.83±0.77 km measured with the semi-automatic multiple-camera system (Table 3.1). Distance covered in high-intensity running and sprinting ranged from 1.61±0.38 km (time-motion analysis) to 2.65±0.53 km (multiple-camera system) and from 0.23±0.16 km (GPS-2) to 0.42±0.17 km (time–motion analysis), respectively (Table 3.1). Distance covered at low-intensity running ranged from 2.93±0.62 km (GPS-2) to 3.60±0.54 km (multiple-camera system), whereas walking ranged between 4.40±0.37 km (GPS-2) and 5.13±0.85 km (GPS-1). The multiple-camera system, GPS-1, and GPS-2 determined a distance covered at 0-2 $km \cdot h^{-1}$ that refers to the category standing (0.08±0.02, 0.48±0.03, and 0.31±0.09 km, respectively), whereas time-motion analysis considers movement at this speed as standing and considers the distance to be 0. Total running distance, which corresponds to the total distance covered excluding distance covered by walking and the distance covered in the category ''standing'', ranged from 6.23±0.99 km (multiple-camera system) to 4.77±0.96 km (GPS-2) (Table 3.1).

Peak distance covered in a 5-min interval was 0.71±0.04, 0.64±0.04, 0.73±0.06, and 0.61 +0.06 km for the multiple-camera system, time-motion analysis, GPS-1, and GPS-2, respectively. The peak distance covered in high-intensity running was 0.25±0.04, 0.18±0.04, 0.22±0.05, and 0.18±0.05 km for these four systems, respectively (Figure 3.1), whereas the peak sprint distance reached 0.06±0.02, 0.06±0.02, 0.07±0.02, and 0.05±0.02 km, respectively.

Table 3-1 Total distance covered, high-intensity running, distance covered by sprinting, low-intensity running, and total running distance throughout the entire game measured with the semi-automatic multiple-camera system (MCS), the video-based time-motion analysis system (VTM), GPS-1 and GPS-2 (mean±s).

		n	Total distance covered (km)	High-intensity running (km)	Sprinting (km)	Low-intensity running (km)	Total running distance (km)
MCS		20	10.83 ± 0.77	2.65 ± 0.53	0.38 ± 0.18	3.60 ± 0.54	6.23 ± 0.99
VTM		17	9.51 ± 0.74	1.61 ± 0.37	0.42 ± 0.17	3.41 ± 0.53	5.02 ± 0.58
GPS-1		18	10.72 ± 0.70	2.03 ± 0.60	0.37 ± 0.19	3.08 ± 0.54	5.10 ± 1.08
GPS-2		13	9.52 ± 0.89	1.66 ± 0.44	0.23 ± 0.16	2.93 ± 0.62	4.77 ± 0.96
MCS *vs* GPS-1	MCS	18	10.85 ± 0.81	*2.66 ± 0.56	0.37 ± 0.18	*3.62 ± 0.57	*6.25 ± 1.04
	GPS-1	18	10.72 ± 0.70	2.03 ± 0.60	0.37 ± 0.19	3.08 ± 0.54	5.10 ± 1.08
VTM *vs* GPS-2	VTM	10	9.51 ± 0.83	1.58 ± 0.37	*0.42 ± 0.18	*3.37 ± 0.59	**4.95 ± 0.71
	GPS-2	10	9.50 ± 0.86	1.66 ± 0.41	0.26 ± 0.16	2.83 ± 0.49	4.69 ± 0.79
VTM *vs* GPS-1	VTM	15	*9.52 ± 0.78	**1.58 ± 0.34	0.39 ± 0.17	*3.49 ± 0.50	5.07 ± 0.60
	GPS-1	15	10.73 ± 0.67	1.94 ± 0.56	0.35 ± 0.19	2.99 ± 0.47	4.92 ± 0.95
MCS *vs* GPS-2	MCS	12	*10.84 ± 0.96	*2.61 ± 0.66	*0.36 ± 0.22	*3.68 ± 0.68	*6.26 ± 1.24
	GPS-2	12	9.56 ± 0.92	1.65 ± 0.46	0.23 ± 0.16	2.95 ± 0.64	4.80 ± 0.99
MCS *vs* VTM	MCS	17	*10.75 ± 0.72	*2.62 ± 0.49	0.40 ± 0.18	3.50 ± 0.43	*6.08 ± 0.85
	VTM	17	9.51 ± 0.74	1.61 ± 0.38	0.42 ± 0.17	3.41 ± 0.53	5.02 ± 0.58
GPS-1 *vs* GPS-2	GPS-1	11	*10.76 ± 0.80	2.00 ± 0.76	**0.36 ± 0.23	3.04 ± 0.65	5.04 ± 1.34
	GPS-2	11	9.64 ± 0.93	1.67 ± 0.48	0.22 ± 0.16	2.98 ± 0.66	4.88 ± 1.00

*Significant difference between two systems (P<0.001); **No significant difference between two systems (0.008< P < 0.05)

Comparing the systems

The multiple-camera system measured a longer total distance covered during the whole match compared with time–motion analysis (12%, n =17, P≤0.001) and GPS-2 (12%, n=12, P≤0.001), whereas no difference was observed between the multiple-camera system and GPS-1 (n=18, P≤0.4). In addition, GPS-1 registered a longer total distance than time– motion analysis (13%, n=15, P≤0.001) and GPS-2 (10%, n=11, P≤0.001), but there was no difference between time–motion analysis and GPS-2 (Table 3.1).

The GPS-1 system measured more walking than the multiple-camera system (5.13±0.85 vs. 4.51±0.31 km, n=18, P≤0.01) and time-motion analysis (5.28±0.86 vs. 4.45±0.47 km, n=15, P≤0.01) but not GPS-2 (5.19±0.91 vs.4.44±0.40 km, n=12, P≤0.019). No differences between the three other systems were observed. The multi-camera system recorded a longer (P≤0.001) total running distance compared with time-motion analysis (17%, n=17), GPS-1 (18%, n=18), and GPS-2 (23%, n=12), whereas there were no differences between the latter three systems (Table 3.1). The multi-camera system did not differ from time-motion analysis in the distance covered at low- intensity running over 90 min, but it recorded more (P≤0.001) low-intensity running than GPS-1 (15%, n=18) and GPS-2 (20%, n=13). Both GPS-1 and GPS-2 showed less (P≤0.001) low- intensity running than time–motion analysis (14%, n≤15 and 16%, n=11, respectively), but there was no difference between GPS-1 and GPS-2 (Table 3.1).

The multi-camera system measured more (P≤0.001) high-intensity running than the other three systems (time–motion analysis: 39%, n=17; GPS-1: 24%, n=18; GPS-2: 37%, n=13). Moreover, the distance covered in high-intensity running as measured by GPS-1 tended to be longer (P≤0.025) than with time-motion analysis (23%, n=15) and GPS-2 (17%, n=12, P≤0.067), whereas no difference was observed between time-motion analysis and GPS-2. The GPS-2 system tracked less (P≤0.001) distance while sprinting than the multiple-camera system (38%, n=12) and time-motion analysis (36%, n=10), and there was a tendency for this compared with GPS-1 (39%, n=11, P≤0.048). No differences were observed between GPS-1, time–motion analysis, and the multiple-camera system (Table 3.1).

Total distance covered, distance covered at low intensity, and distance covered in high-intensity running for the whole match measured with the multiple-camera system correlated with time-motion analysis, GPS-1 and GPS-2; GPS-2 correlated with time-motion analysis and GPS-1; whereas no correlation was found between time-motion analysis and GPS-1. Distance covered when walking measured with the four systems did not correlate with each other (Table 3.2). The distance covered when sprinting over the entire match measured with time-motion analysis correlated with the multiple-camera system, GPS-1 and GPS-2. Furthermore, the multiple-camera system and GPS-2 correlated, whereas GPS-1 did not correlate with either the multiple-camera system or GPS-2 (Table 3.2).

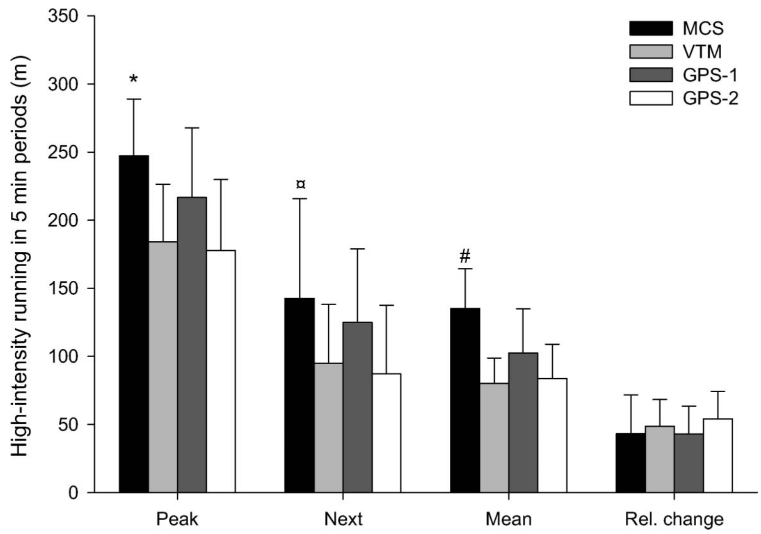


Figure 3-1 Peak high-intensity running in a 5-min period, the following 5 min, average values of the remaining 5-min periods, and the relative change from peak to the next 5-min period measured with the semi-automatic multiple-camera system (MCS, n =20), the video-based time– motion analysis system (VTM, n=17), GPS-1 (n=18), and GPS-2 (n=13). Data are means± standard deviations. *Significantly different from VTM and GPS-2 (P≤0.001). ¤Significantly different from VTM and GPS-2 (P≤0.008). #Significantly different from all other systems (P≤0.001).

Table 3-2 Correlations and coefficients of variations (CV) between the different match analysis systems for total distance covered, total running distance, walking, low-intensity running, high intensity running, and sprinting.

Total distance covered during 90 min				
	MCS	VTM	GPS-1	GPS-2
MCS		r=0.82 P<0.001 CV=4%	r=0.62 P<0.01 CV=4%	r=0.90 P<0.001 CV=4%
VTM			r=0.51 P=0.054 CV=7%	r=0.81 P<0.01 CV=3%
GPS-1				r=0.62 P<0.05 CV=7%

Total running distance during 90 min				
	MCS	VTM	GPS-1	GPS-2
MCS		r=0.86 P<0.001 CV=8%	r=0.62 P<0.01 CV=12%	r=0.93 P<0.001 CV=8%
VTM			r=0.35 P=0.20 CV=12%	r=0.91 P<0.001 CV=4%
GPS-1				r=0.76 P<0.01 CV=11%

Distance covered with walking during 90 min				
	MCS	VTM	GPS-1	GPS-2
MCS		r=0.24 P=0.35 CV=6%	r=0.38 P=0.12 CV=13%	r=0.53 P=0.06 CV=5%
VTM			r=0.39 P=0.15 CV=12%	r=0.52 P=0.10 CV=5%
GPS-1				r=0.01 P=0.96 CV=16%

Low-intensity running during 90 min				
	MCS	VTM	GPS-1	GPS-2
MCS		r=0.70 P<0.01 CV=7%	r=0.70 P<0.01 CV=10%	r=0.93 P<0.001 CV=8%
VTM			r=0.49 P=0.07 CV=9%	r=0.90 P<0.001 CV=8%
GPS-1				r=0.81 P<0.01 CV=9%

High-intensity running during 90 min				
	MCS	VTM	GPS-1	GPS-2
MCS		r=0.68 P<0.01 CV=18%	r=0.54 P<0.05 CV=20%	r=0.93 P<0.001 CV=13%
VTM			r=0.32 P=0.25 CV=25%	r=0.84 P<0.01 CV=8%
GPS-1				r=0.67 P<0.05 CV=24%

Sprinting distance during 90 min				
	MCS	VTM	GPS-1	GPS-2
MCS		r=0.85 P<0.001 CV=13%	r=0.42 P=0.08 CV=39%	r=0.93 P<0.001 CV=23%
VTM			r=0.59 P<0.05 CV=23%	r=0.88 P<0.001 CV=26%
GPS-1				r=0.43 P=0.18 CV=69%

Note: MCS vs. GPS-1, n=18; VTM vs. GPS-2, n=10; VTM vs. GPS-1, n=15; MCS vs. GPS-2, n=12; MCS vs. VTM, n=17; GPS-1 vs. GPS-2, n=11.
MCS= semi-automatic multiple-camera system; VTM=video-based time-motion analysis system

Sprint velocity and frequency

Peak sprint velocity was higher as measured with GPS-1 (range 31.0-48.5 km·h^{-1}) than with the multiple-camera system (range 27.2–35.6 km·h^{-1}) (35.4±4.3 vs. 32.2±2.0 km·h^{-1}, n=16, P≤0.017) and GPS-2 (range 22.4–32.6 km·h^{-1}) (34.3±2.8 vs. 28.9±2.8 km·h^{-1}, n=12, P≤0.01). Furthermore, the multiple-camera system showed a higher peak velocity than GPS-2 (32.5±2.1 vs. 29.1±2.8 km·h^{-1}, n=13, P≤0.001; Figure 2). Peak running velocity measured with the multiple-camera system correlated with GPS-2 (r=0.87, n=13, P≤0.001), whereas neither GPS-1 and the multiple-camera system nor GPS-1 and GPS-2 were correlated (P≤0.05). The number of sprints recorded was 19.9±8.7, 28.2±10.2, 26.7±9.4, and 14.7±8.8 for the multiple-camera system, time-motion analysis, GPS-1, and GPS-2, respectively. Time-motion analysis recorded more sprints than the multiple-camera system (29.1±10.4 vs. 19.9±8.9, n =16, P≤0.001) and GPS-2 (28.4±10.8 vs. 14.2±8.9, n=12, P≤0.001), while GPS-1 detected more (P≤0.001) sprints than the multiple-camera system (27.9±9.1 vs. 19.5±8.8) and GPS-2 (28.2±9.6 vs. 15.1±8.9). No difference was observed between time–motion analysis and GPS-1 or between GPS-2 and the multiple-camera system.

Fatigue indicators

Total distance covered and distance covered in high-intensity running in the second half assessed with the multiple-camera system, time-motion analysis, GPS-1, and GPS-2 were lower (P≤0.001) than in the first half for all systems (7.4±8.8%, 10.4±7.5%, 7.2±7.5%, 10.1±6.7% and 20.0±19.1%, 27.2±19.6%, 20.2±20.8%, 21.9±18.3%, respectively; Figure 3). Time-motion analysis and GPS-1 detected significantly (P≤0.001) less distance covered with sprinting during the second half compared with the first (27.3±28.5% and 38.6±26.1%, respectively; Figure 3), whereas distance while sprinting in the second half tended to be lower for GPS-2 (P≤0.089) with no difference between the two halves for the multiple-camera system (Figure 3).

In the first 15 min of the game, the total distance measured was 1.95±0.15, 1.76±0.18, 2.06±0.17, and 1.69±0.15 km for the multiple-camera system, time-motion analysis, GPS-1, and GPS-2, respectively, all of which were higher ($P \leq 0.001$) than for all other 15-min intervals. Furthermore, the total distance covered during the last 15 min (1.46±0.18, 1.24±0.17, 1.46±0.11, and 1.26±0.17 km for the multiple-camera system, time–motion analysis, GPS-1, and GPS-2, respectively) was lower ($P \leq 0.01$) than for all other 15-min intervals.

The distance covered in high-intensity running in the first 15 min was 0.58±0.13, 0.37±0.13, 0.47±0.13, and 0.38±0.12 km for the multiple- camera system, time-motion analysis, GPS-1, and GPS-2, respectively, all of which were higher than in all other 15-min intervals ($P \leq 0.001$). Furthermore, a shorter distance was recorded while in high-intensity running during the last 15 min than in all other 15-min intervals (0.26±0.10, 0.12±0.07, 0.22±0.14, and 0.16±0.09 km for the multiple-camera system, time–motion analysis, GPS-1, and GPS-2, respectively; $P \leq 0.01$). The game-fatigue index (i.e. the difference in high-intensity running during the first and the last 15 min of the game) was 45.7±19.1%, 37.4±26.4%, 49.9±25.7%, and 44.7±27.2% for the multiple-camera system, time–motion analysis, GPS-1, and GPS-2, respectively, which were not significantly different from each other ($P \leq 0.45$).

In the first 15-min period, the distance covered while sprinting was 0.08±0.04, 0.09±0.05, 0.08±0.05, and 0.06±0.04 km measured for the multiple-camera system, time–motion analysis, GPS-1, and GPS-2, respectively. This was more than during the last 15 min of the match (0.03±0.04, 0.03±0.03, 0.04±0.05, and 0.02±0.02 km, respectively; $P \leq 0.01$).

To compare the ability of the four systems to detect changes in workload during the game, the total distance covered in the first 15-min period was used as the reference. The total distances covered in the remaining 15-min periods, all of which were lower than during the first 15-min period, were expressed relative to the reference interval. No difference was found between the four systems for 15–30, 45–60, 60–75 or 75–90 min, whereas GPS-1 detected less ($P \leq 0.01$) distance covered than the multiple-camera system, time-motion analysis, and GPS-2 in the 30–45 min period (77.4±6.8% vs. 87.7±4.8%, 86.0±6.5%, and 89.1±4.9%, respectively; Figure 4a). When the first 15-min period was used as reference and high-intensity running in the remaining 15-min periods was calculated as a percentage of the first 15-min interval, no differences were observed between the multiple-camera system, time–motion analysis, and GPS-1 in any of the 15-min periods (Figure 4b).

The peak distance covered with high-intensity running in a 5-min period was 247±42, 184±42, 217±51, and 178±52 m for the multiple-camera system, time-motion analysis, GPS-1, and GPS-2, respectively (Figure 3.1). In the next 5-min period, the amount of high-intensity running was determined to be 142±73, 95±43, 125±54, and 87±51 m for the multiple-camera system, time–motion analysis, GPS-1, and GPS-2, respectively, which correspond to 57±29%, 51±20%, 57±20%, and 42±20% of the peak distance, respectively. These values were not different from the average distances covered in high-intensity running during all other 5-min periods (136±29, 81±19, 103±32, and 84±35 m, respectively). Although the multiple-camera system measured a greater peak distance covered at high intensity than time–motion analysis and GPS-2 ($P \le 0.001$) but not GPS-1 ($P=0.027$), the relative difference between the peak and the next 5-min period did not differ.

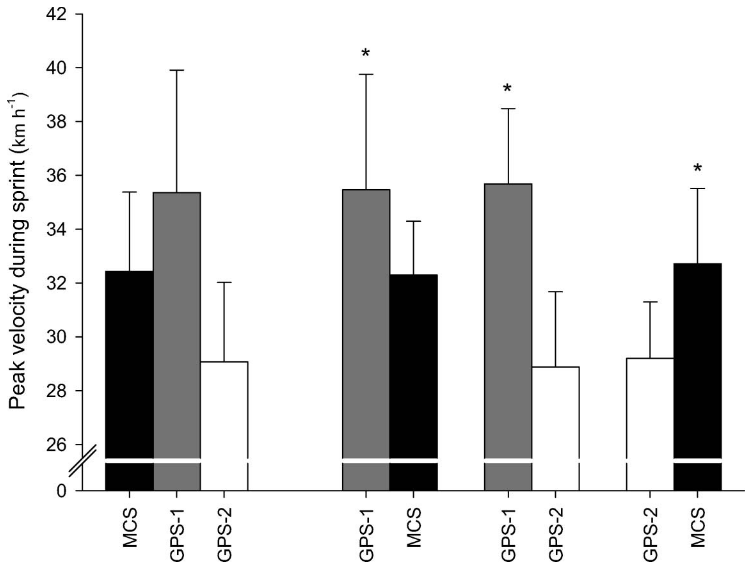


Figure 3-2 Peak velocity measured with the semi-automatic multiple-camera system (MCS, n=18), GPS-1 (n=16), and GPS-2 (n=13). MCS vs. GPS-1 (n=16), MCS vs. GPS-2 (n=13), and GPS-1 vs. GPS-2 (n=12). Data are means±standard deviations. *Significant difference between the two systems: $P \leq 0.001$

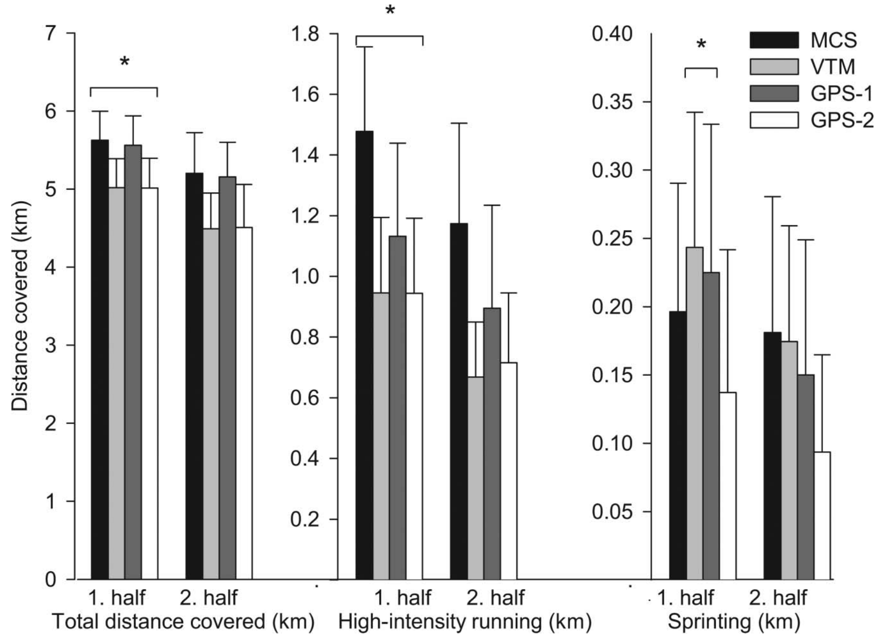


Figure 3-3 Total distance covered, high-intensity running, and sprinting during the first and second half measured with the semi-automatic multiple-camera system (MCS, n=20), the video-based time–motion analysis system (VTM, n=17), GPS-1 (n=18), and GPS-2 (n=13). Data are presented as means±standard deviations. *Significant difference between the first and second half: P≤0.001.

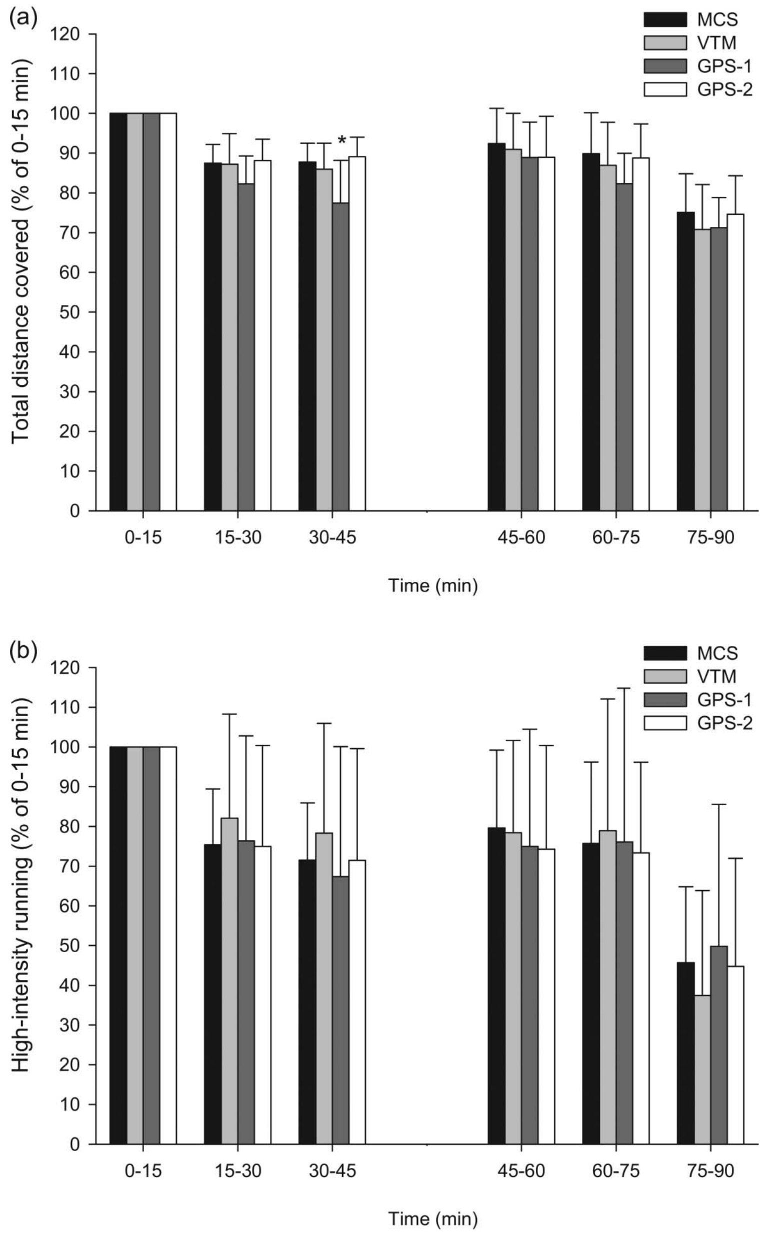


Figure 3-4 (a) Total distance covered and (b) high-intensity running in 15-min periods measured with the semi-automatic multiple-camera system (MCS, n=20), the video-based time–motion analysis system (VTM, n=17), GPS-1 (n=18), and GPS-2 (n=13). Period 0–15 min is set to 100 and the rest of the 15-min periods are presented as a percentage of the 0–15 min periods. Data are means±standard deviations. *Significant different from the other three systems: P≤0.001.

Discussion

For the first time, the present study compared four match analysis method during the same football match. This comparison was warranted, since video-based time–motion analysis systems, semi-automatic multiple-camera systems, and different GPS systems have been applied in the literature and in many top football clubs. No ''gold standard'' method exists, but a comparison of the most frequently used tracking methods makes it possible to compare findings from different studies. The major findings of the present study were that the four systems detected similar decreases in running distances during the game, whereas rather large between-system differences were observed in the absolute distances covered within each locomotor category. Thus, each of the respective systems appears to be able to examine movement patterns during football games, whereas absolute values reported for running distances seem to be highly dependent on the system and these differences should be taken into account when comparing results collected with different systems.

Several studies using different locomotion tracking systems have reported values of 9-12km for total distance covered during football games (Bangsbo, 1994; Bangsbo et al., 1991; Di Salvo et al., 2007; Mohr et al., 2003; Rampinini et al., 2007a, 2007b, 2008; Reilly & Thomas, 1976; Rienzi et al., 2000). It is unclear, however, how exact these distances are. In the present study, the semi-automatic multiple-camera system and GPS-1 (5 Hz) measured a total distance covered around 1 km longer than the video-based time-motion analysis system and GPS-2 (1 Hz). The major contributor to the total distance covered was walking, which makes up one-third to one-half of the total distance covered in a game, and since distance covered by walking by the different systems was highly variable, this explains part of the observed differences in absolute distances covered between the systems. The GPS-1 system measured walking distance to be 0.6-0.7 km longer than the other three systems, which explains most of the difference in total distance between the GPS-1 and video-based time-motion analysis system and GPS-2. Distance covered in the walking category is not that important a variable for evaluation of the physical loading of a football game. Therefore, total running distance was also compared within the systems. The semi-automatic multiple-camera system assessed a total running distance ≈1 km longer than the other systems. When the four systems were compared within the low-intensity running category, the semi-automatic multiple-camera system and video-based time-motion analysis system measured ≈0.5km low-intensity running than the two GPS systems. Moreover, the amount of low-intensity running was correlated between all systems except between the video-based time-motion analysing system and GPS-1, suggesting that the difference between these two systems lies within this category. No difference was observed between the semi-automatic multiple-camera system and video-based time-motion analysis system, demonstrating that the main difference in total running distance between those two systems is to be found within the intense running categories. The video-based time-motion analysis system has a category for backward and sideways running that is not a separate category in the other three systems. This category is encompassed in low-intensity running and almost all backward and sideways running is performed within this speed category (7-13 $km \cdot h^{-1}$). However, it is possible that some backward and sideways running is performed at higher speed, but this is considered to be a minor part.

High-intensity running in a football game is likely to be the most important measurement for physical match performance (Bangsbo, 1994; Bangsbo, Mohr, & Krustrup, 2006; Drust, Atkinson, & Reilly, 2007; Krustrup et al., 2003; Mohr et al., 2005; Rampinini et al., 2007b, 2008). High-intensity running during a game correlates with intense intermittent test performance (Krustrup et al., 2003, 2005, 2006; Rampinini et al., 2007a). Moreover, the amount of high-intensity running in a game is sensitive to seasonal variations (Mohr et al., 2003; Rampinini et al., 2007b) and training interventions (Helgerud, Engen, Wisløff, & Hoff, 2001; Impellizzeri et al., 2006; Krustrup & Bangsbo, 2001). Mohr and colleagues (2003, 2008) showed that both male and female elite players cover a markedly greater distance in high-intensity running than players of a lower standard of play. However, Rampinini et al. (2008) have recently shown that high-intensity running with the ball and technical skills may be more important for success.

In the present study, the distance covered in high-intensity running measured by the semi-automatic multiple-camera system measured was 0.6-1.0km longer than for the three other systems. The distance covered in high-intensity running measured with the semi-automatic multiple-camera system was 2.65km, which is 9% and 39%, more than reported for video-based time-motion analysis for Italian top-class and Danish intermediate professional football players, respectively (Mohr et al., 2003).

The distance in high intensity running recorded with the video-based time-motion analysis system and GPS-2 in the present friendly game was 1.61 and 1.66 km, which is lower than previously reported, whereas the distance recorded by GPS-1 (2.03km) was within the range often reported for professional football players during competitive games (Di Salvo et al., 2007; Mohr et al., 2003). The peak distance covered with high-intensity running in a 5-min period ranged from 184 to 247 m. This is similar to or longer than reported for high-class football players measured with a video-based time-motion analysis system (Mohr et al., 2003). The difference in high-intensity running between the video-based time-motion analysis system, the semi-automatic multiple-camera system, and GPS-1 was not due to differences in sprinting distance, since no differences were observed between the three systems. On the other hand, the GPS-2 system detected a sprint distance that was 0.15-0.20 km less than the other systems, which partly explains the differences in high-intensity running between GPS-2 and GPS-1. The GPS-2 system has a time-resolution of 1Hz, which could explain the difference in sprint distance between this system and GPS-1 and the semi-automatic multiple-camera system, since the average 30-m sprint speed was 7.19 ± 0.04 $m \cdot s^{-1}$. Although most sprints are performed directly forwards, there is sometimes a change of direction (Bloomfield, Polman, & O'Donoghue, 2007), which could cause problems for GPS-2 measuring distances covered at high speed. The GPS-2 system measured a lower maximal sprinting speed than GPS-1 and the semi-automatic multiple-camera system, which could also indicate that 1 Hz is an insufficient time-resolution when measuring high-speed activities. In line with this, GPS-2 measured only about 50–75% of the number of sprints detected by the other three systems.

A common finding in studies of activity patterns in football is large individual variation between players, which among other things is associated with playing position (Bangsbo et al., 1991; Di Salvo et al., 2007; Krustrup et al., 2005; Mohr et al., 2003; 2008; Reilly & Thomas, 1976), physical capacity (Bangsbo et al., 1991; Krustrup et al., 2005, Mohr et al., 2003; Rampinini et al., 2008), and the opponent (Rampinini et al., 2007b). Despite the differences in absolute distances between the systems in the present study, moderate to strong correlations were observed between nearly all systems, indicating that the systems are capable of measuring individual movement patterns. Match analysis has been used to examine fluctuations in exercise intensity and indications of fatigue in several studies (Andersson et al., 2008; Bangsbo, 1994; Bangsbo & Mohr, 2005; Bangsbo et al., 1991; Di Salvo et al., 2007; Ekblom, 1986; Krustrup et al., 2005; Mohr et al., 2003, 2008; Rampinini et al., 2007a, 2007b, 2008; Reilly & Thomas, 1976; Saltin, 1973; Van Gool, Van Gerven, & Boutmans, 1988). These studies report differences between the two halves of a game with the work rate decreasing in the second half. In support of these studies, all four systems demonstrated that both total distance covered and high-intensity running declined in the second half compared with the first. On the other hand, only two systems recorded a significantly lower sprinting distance in the second half compared with the first. Fatigue has been suggested to develop during the final 15 min of an elite football game (Bangsbo et al., 2006; Mohr et al., 2005), since the distance covered in total by high-intensity running and sprinting has been shown to decline substantially in this period (Bangsbo & Mohr, 2005; Krustrup et al., 2005; Mohr et al., 2003, 2008), which is reflected in a deterioration in physical performance (Krustrup et al., 2006; Mohr, Krustrup, Nybo, Nielsen, & Bangsbo, 2004). In the present study, all four systems showed that total distance covered, total running distance, and distance covered in high-intensity running were lower during the last 15 min of the game than in any other 15-min period. Usually the first 15 min of a game sees the highest work rates (Mohr et al., 2003, 2005, 2008). In support of this, total distance covered by running and by high-intensity running was higher during the first 15 min than in any other 15-min interval during the game, indicating that all systems can detect fluctuations in intensity during a football game. A game-fatigue index was calculated based on the relative difference in high-intensity running between the first and last 15-min period. The game-fatigue index was not different (37–50%; $P \leq 0.6$) between the four tracking systems, indicating that all systems can be used to examine performance decrements during a football game.

Using match analysis, Mohr et al. (2003, 2008) showed that fatigue develops temporarily during a game, which is further supported by Krustrup et al. (2006). Thus, in the studies of Mohr and colleagues it was evident that the amount of high-intensity running covered in the 5-min period after the peak 5-min intervals was lower than the game average. In the present study, the peak period was located in the same period with all systems. In addition, the decline in match performance from the peak 5-min period to the following 5 min was the same in all systems (41–49%). Thus, it appears that peak intensity periods and temporary fatigue can be assessed by all four systems used in the present study.

In conclusion, all four systems were able to detect performance decrements during a football game and can be applied to study development of fatigue in elite football. Our results also revealed rather large between-system differences in the determination of the absolute distances covered, implying that any comparison of results using different match analysis systems should be done with caution.

Acknowledgements

The authors would like to thank the players and the coaching staff of Athletic Club Bilbao for their participation, effort, and support. Acknowledgement is also due to the Faculty of Physical Activity and Sport Sciences, University of the Basque Country (UPV-EHU), for providing technical support for video recordings for time–motion analysis.

References

Andersson, H., Ekblom, B., & Krustrup P. (2008). Elite football on artificial turf versus natural grass: Movement pattern, technical standards, and player impressions. *Journal of Sports Sciences*, 26, 113–122.

Atkinson, G., & Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine*, 26, 217–238.

Bangsbo, J. (1994). The physiology of soccer- with special reference to intense intermittent exercise. *Acta Physiologica Scandinavica*, 151, 1–193.

Bangsbo, J., Iaia, F. M., & Krustrup, P. (2007). Metabolic response and fatigue in soccer. *International Journal of Sports Physiology and Performance*, 2, 111–127.

Bangsbo, J., & Mohr, M. (2005). Variation in running speed and recovery time after a sprint during top-class soccer matches. *Medicine and Science in Sports and Exercise*, 37, 87.

Bangsbo, J., Mohr, M., & Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Sciences*, 24, 665–674.

Bangsbo, J., Nørregaard, L., & Thorsøe, F. (1991). Activity profile of competition soccer. *Canadian Journal of Sports Science*, 16,110–116.

Bloomfield, J., Polman, R., & O'Donoghue, P. (2007). Physical demands of different positions in FA Premier League soccer. *Journal of Sports Science and Medicine*, 6, 63–70.

Coutts, A. J., & Duffield, R. (2008). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport*. DOI: 10.1016/ j.jsams.2008.

Di Salvo, V., Baron, R., Tschan, H., Calderon Montero, F. J., Bach, N., & Pigozzi, F. (2007). Performance characteristics according to playing position in elite soccer. *International Journal of Sports Medicine*, 28, 222–227.

Drust, B., Atkinson, G., & Reilly, T. (2007). Future perspectives in the evaluation of the physiological demands of soccer. *Sports Medicine*, 37, 783–805.

Edgecomb, S. J., & Norton, K. I. (2006). Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian football. *Journal of Science and Medicine Sport*, 9, 25–32.

Ekblom, B. (1986). Applied physiology of soccer. *Sports Medicine*, 3, 50–60.

Helgerud, J., Engen, L. C., Wisløff, U., & Hoff, J. (2001). Aerobic endurance training improves soccer performance. *Medicine and Science in Sports and Exercise*, 33, 1925–1931.

Impellizzeri, F. M., Marcora, S. M., Castagna, C., & Reilly, T., Sassi, A. Iaia, F. M., & Rampinini, E. (2006). Physiological and performance effects of generic versus specific aerobic training in soccer players. *International Journal of Sports Medicine*, 27(6), 483–492.

Kirkendall, D. T., Leonard, K., & Garrett, W. E., Jr. (2004). On the relationship between fitness and running volume and intensity in female soccer players. *Journal of Sports Sciences*, 22, 549–550.

Krustrup, P., & Bangsbo, J. (2001). Physiological demands of top- class soccer refereeing in relation to physical capacity: Effect of intense intermittent exercise training. *Journal of Sports Sciences*, 19, 881–891.

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steenberg, A., et al. (2003). The Yo-Yo intermittent recovery test: Physiological response, reliability and validity. *Medicine and Science in Sports and Exercise,* 35, 695–705.

Krustrup, P., Mohr, M., Ellingsgaard, H., & Bangsbo, J. (2005). Physical demands during an elite female soccer game: Importance of training status. *Medicine and Science in Sports and Exercise*, 37, 1242–1248.

Krustrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjær, M., & Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: Implications for sprint performance. *Medicine and Science in Sports and Exercise,* 38, 1165–1174.

Mohr, M., Krustrup, P., Andersson, H., Kirkendall, D., & Bangsbo, J. (2008). Match activities in elite women soccer players at different performance levels. *Journal of Strength and Conditioning Research*, 22, 341–349.

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sports Sciences*, 21, 439–449.

Mohr, M., Krustrup, P., & Bangsbo, J. (2005). Fatigue in soccer: A brief review. *Journal of Sports Sciences*, 23,593–599.

Mohr, M., Krustrup, P., Nybo, L., Nielsen, J. J., & Bangsbo, J. (2004). Muscle temperature and sprint performance during soccer matches – beneficial effects of re-warm up at half-time. *Scandinavian Journal of Medicine and Science in Sports*, 15, 136–143.
Rampinini, E., Bishop, D., Marcora, S. M., Ferrari Bravo, D., Sassi, R., & Impellizzeri, F. M. (2007a). Validation of simple field tests as indicators of match-related performance in top- level professional soccer players. *International Journal of Sports Medicine*, 28, 228–235.
Rampinini, E., Coutts, A. J., Castagna, C., Sassi, R., & Impellizzeri, F. M. (2007b). Variation in top level soccer match performance. *International Journal of Sports Medicine*, 28,1018–1024.
Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisløff, U. (2008). Technical performance during soccer matches of the Italian Serie A league: Effect of fatigue and competitive level. *Journal of Science and Medicine in Sport*. DOI: 10.1016/j.jsams.2007.1010.1002
Reilly, T., & Thomas, V. (1976). A motion analysis of work-rate in different positional roles in professional football match-play. *Journal of Human Movement Studies*, 2, 87–97.
Rienzi, E., Drust, B., Reilly, T., Carter, J. E. L., & Martin, A. (2000). Investigation of anthropometric and work-rate profiles of elite South American international soccer players. *Journal of Sports Medicine and Physical Fitness*, 40, 162–169.
Saltin, B. (1973). Metabolic fundamentals in exercise. *Medicine and Science in Sports and Exercise*, 5, 137–146.
Van Gool, D., Van Gerven, D., & Boutmans, J. (1988). The physiological load imposed on soccer players during real match- play. In T. Reilly, A. Lees, K. Davids, & W. J. Murphy (Eds.), *Science and football* (pp. 51–59). London: E & FN Spon.

Chapter 4- Match analyses of Australian international women soccer players using an athlete tracking device

Hewitt, A, Withers, R, and Lyons, K, 2007, 'Match analyses of Australian international women soccer players using an athlete tracking device', *Science and Football VI: The Proceedings of the Sixth World Congress on Science and Football.* Eds. Reilly & Korkuszuz, Routledge: London, pp. 224-228

4.1 Publication Overview

The findings in Study 1 concluded that although there were differences between the match analysis systems, 5Hz GPS could be considered a valid and reliable tool in identifying movement patterns in a game of soccer.

The movement demands of men's soccer have been published throughout the literature using a range of technologies to estimate distances covered in broadly defined velocity bands. However, women's soccer has not received the same attention in this area. The vast majority of the papers presented describing the physical demands during a game of women's soccer were derived from video-based time motion analysis. With the emergence of 5Hz GPS technology, Study 2 proposed to apply a novel player tracking method to provide coaches and practitioners with descriptive movement analysis patterns that will help in the training and preparation of players.

4.2 Author Declaration for Thesis Chapter 4

Publication title: Match analyses of Australian international women soccer players using an athlete-tracking device

Publication details: Published in *Science and Football VI: The Proceedings of the Sixth World Congress on Science and Football. 2007. Eds. Reilly & Korkuszuz, Routledge: London, pp. 224-228*

Declaration for Thesis Chapter Four

Declaration by candidate

In the case of Chapter Four, the nature and extent of my contribution to the work was the following:

Nature of contribution
I was responsible for the project design and concept as well as the data collection. I had a significant contribution to the data analysis and preparation of the manuscript. I estimate my total contribution to this manuscript to equate to 80%.

The following co-authors contributed to the work.

Name	**Nature of contribution**	**Extent of contribution (%)**	**Contributor is also a student at UC Y/N**
Keith Lyons	Manuscript editing	5	N
Bob Withers	Manuscript editing and data analysis	15	N

Candidate's Signature		**17/8/2015**

Declaration by co-authors

The undersigned hereby certify that:

(7) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.

(8) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;

(9) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;

(10) there are no other authors of the publication according to these criteria;

(11) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and

(12) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	Data is stored electronically at the Australian Institute of Sport: Performance Analysis Unit and at the University of South Australia, School of Health Sciences.

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

	Name & Signature	**Date**
Signature 1	Keith Lyons	15 August 2015
Signature 2	Professor Bob Withers deceased.	

4.3 Match analyses of Australian international female soccer players using an athlete tracking device

Adam Hewitt,[1,2] Robert Withers[1] and Keith Lyons[2]

[1] Flinders University, Australia; [2] Australian Institute of Sport, Australia

Introduction

The physiological characteristics of women soccer players have been reported previously (Jensen and Larsson, 1992; Rhodes and Mosher, 1992; Davis and Brewer, 1993; Tumilty, 1993; Tamer *et al.*, 1997; Todd *et al.*, 2002; Krustrup *et al.*, 2005). These studies show that maximal aerobic power, sprinting ability and intermittent exercise performance of elite players are critical determinants of fitness (Jensen and Larsson, 1992; Rhodes and Mosher, 1992; Davis and Brewer, 1993; Tumilty, 1993; Tamer *et al.*, 1997; Todd *et al.*, 2002; Krustrup *et al.*, 2005). Only Krustrup *et al.* (2005) have reported the activity profile of elite international female soccer players during match play. They studied 14 players from the Danish Division 1 during competitive matches using video based time–motion analysis and they reported the total distance covered during a game to be 10300 m (range: 9700– 11300 m).

Over the past thirty years, video tracking has generally been considered the most accurate and accessible method for estimating movement distances in time- motion studies (Edgecomb and Norton, 2006). However, video systems do not function in real time, may be subject to errors due to gait changes during game movements and are extremely labour-intensive (Edgecomb and Norton, 2006).

Until recently, the testing of sport performance and more specifically team sport performance has been restricted to laboratory-based or simulated field tests. Multiple factors that are hard to control for, plus the need for extremely labour-intensive, expensive equipment and unacceptable error rates have limited the use of sport-specific field-testing (Larsson, 2003). The global positioning system (GPS) is a navigation system which was originally developed for military use but it has recently been applied to aviation, marine and outdoor recreational activities. The GPS system utilises 27 operational satellites that are in orbit around the earth. Each satellite is equipped with an atomic clock. The satellites constantly send information (at the speed of light) about exact time to the GPS receiver. By comparing the time given by a satellite and the time within the GPS receiver, the signal travel time is calculated. The distance to the satellite is then determined by multiplying the signal travel time by the speed of light. Up until 1999 the US Department of Defense included a deliberate error into the GPS system, designed to reduce the risk of hostile forces using the GPS system against the US (Larsson, 2003). The advent of GPS technology miniaturisation has meant that the GPS packaging is now small enough to be worn unobtrusively by players during training and competition.

The athlete tracking devices were developed by the Collaborative Research Centre for Microtechnology which is an Australian government initiative. In addition to the GPS module, the athlete tracking devices are equipped with triaxial accelerometers, triaxial gyroscopes and triaxial magnetometers. The aim of this study was to utilise this emerging technology to measure the activity profiles and physical demands of Australian international female soccer players.

Methods

Subjects

Fifteen Australian national female soccer players participated in the study. Their age, height and mass were: 23.5 ± 2.5 (±SD) years, 1.70 ± 0.05 m and 64.88 ± 4.6 kg, respectively. The average number of international appearances for each player was 46.

The playing positions were: defenders (N = 6, 24.3 ±1.0 years, 1.69 ±0.02 m and 63.2 ±0.8 kg), midfielders (N=5, 23.4 ±3.75 years, 1.70 ±0.03 m and 63.1 ±2.7 kg) and attackers (N = 4, 22.9 ±0.8 years, 1.71 ±0.08 m and 71.1 ±1.7 kg).

The players were competing in the 2006 Asian Football Confederation (AFC) Women's Asian Cup held in Australia which also doubled as the AFC qualification path for the 2007 FIFA Women's World Cup. The four matches analysed involved three nations ranked higher than Australia (15): Japan (13), Korea DPR (7) and China PR (8) and one nation ranked below Australia, Korean Republic (23).

Match analysis

Players were fitted with the athlete tracking device via a Lycra sleeveless garment which was equipped with a pocket to house the device. The athlete tracking device was located above the midpoint of the shoulder blades. Many players are wearing similar garments under playing attire and none of them reported any discomfort. Locomotor activity was categorised as: slow walking (0–5 km·h^{-1}), walking (5–8 km·h^{-1}), low-speed running (8–12 km·h^{-1}), moderate-speed running (12–16 km·h^{-1}), high-speed running (16–20 km·h^{-1}) and sprinting (>20 km·h^{-1}).

Table 4-1 Whole-game locomotor activity profiles of Australian international female soccer players

Speed (km·h^{-1})	*Locomotor Description*	*Distance (m)*		
		Mean	*SD*	*%*
0-5	Slow Walking	2400	120	26
5-8	Walking	2100	110	23
8-12	Low-speed Running	2330	190	26
12-16	Moderate-speed running	1410	160	15
16-20	High-speed running	620	110	7
20+	Sprinting	280	80	3
Total		9140	1030	

Table 4-2 Results of 2006 Women's Asian Cup, playing formations and total average distance covered by Australian players per match

	Opponent	*Final Score*	*Formations*	*Distance (m)*
Round 1	Korea Republic	4-0	4-3-3 *vs* 4-3-3	9060 ± 760
Round 3	DPR Korea	0-0	4-3-3 *vs* 5-3-2	9230 ± 770
Semi-Final	Japan	2-0	4-4-2 *vs* 4-5-1	9670 ± 810
Final	China	2-2*	4-4-2 *vs* 4-4-2	8900 ± 760**

Source: AFC Women's Asian Cup website (http://www.the-afc.com/english/competitions/WomenAsianCup2006/fixtures/default.asp)

*= China won the match 4-2 on penalties after extra time.

**= Total distance covered at the completion of normal time.

Results

Locomotor activity patterns are presented in Table 39.1. The total distance covered during a game was 9 140 m, 2 310 ± 580 m of which comprised moderate speed to sprint running (≥12 km·h^{-1}). Average distances covered were: defenders 9 010 (7 200–9 760) m; midfielders 9 640 (7 620–10 960) m; and attackers 8 510 (8 490–9 440) m.

Discussion

The results of this study showed that Australian international female soccer players covered an average of 9 140 m during a full game. This value is less than the 10 300 m reported by Krustrup *et al.* (2005). Possible reasons for these differences are the: 1) styles of play, 2) methods of analysis, 3) styles of play of the opposition, and 4) physical capacities of the players.

The styles of play of both teams will influence the physical requirements of the game. The impact of changing the style of play, formation of the team or emphasis of the match all affect the amount and type of running required. The style of play and the result of the match have not been reported or acknowledged during previous research on the activity profiles on male and female soccer players. Variation in the distances covered and the running profiles for each game in this study are probably largely influenced by the different playing styles and formations. Even within a playing formation written out on paper, the different instructions to individual players and team rules will influence the amount of running required by the players in those positions. The technical and tactical abilities of the players will also influence the running requirements. For example, a team in control of the ball for long periods of the game and maintaining possession may not need to cover as much ground as the team without the ball. Applications of GPS technology to team sport are relatively new. No research has been conducted which compares the traditional video-based time–motion analysis methods with GPS-based values. However, the relative ease of collecting information on multiple players during a single session will allow more data during matches to be collected.

Krustrup *et al.* (2005) reported a VO_{2max} of 49.4 $ml.kg^{-1}.min^{-1}$ (43.4–56.8) for their Danish Division 1 players who were tested using an incremental treadmill test. Routine fitness testing, using the Multi-stage Shuttle Test (Léger and Lambert, 1982) and conducted at the AIS prior to the Australian women's soccer team competing for the 2006 AFC Women's Asian Cup, resulted in VO_{2max} values of 49.8 ± 3.5 (48.0–59.0) $ml.kg^{-1}.min^{-1}$. Although the Australian female soccer players covered less distance in a match than the Danish Division 1 players, the difference was not due to their lower maximal aerobic power. These findings support those of Krustrup *et al.* (2003) which showed that maximal oxygen consumption was not correlated with the total distance covered by male youth soccer players. Conversely, Helgerud *et al.* (2001) demonstrated a significant increase in the total distance covered, number of sprints and involvements with the ball when players are subjected to additional training which is designed to increase VO_{2max}.

In summary, our findings expand on the limited data in the literature on the running requirements of women's football. We were able to demonstrate that GPS is an emerging technology that can be further utilised in applied research on team sports. The ability to collect data on numerous players in the same game or training session will allow researchers access to unprecedented information.

References

AFC Asian Women's Cup 2006– Schedule/results, Asian Football Confederation, Malaysia, viewed 5 January 2007, <http://www.the-afc.com/english/competitions/WomenAsianCup2006/fixtures/default.asp>.

Davis, J. A. and Brewer, J., 1993, Applied physiology of female soccer players. *Sports Medicine*, 16, 180–9.

Edgecomb, S. J. and Norton, K. I., 2006, Comparison of global positioning and computer- based tracking systems for measuring player movement distance during Australian Football. *Journal of Science and Medicine in Sport,* 9, 25–32.

Helgreud, J., Engen, L, C., Wisloff, U. and Hoff, J., 2001, Aerobic endurance training improves soccer performance. *Medicine and Science in Sports and Exercise,* 33, 1925–31.

Jensen, K. and Larsson, B., 1992, Variations in physical capacity among the Danish national soccer team for women during a period of supplemental training. *Journal of Sports Sciences,* 10, 144–5.

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., Pedeersen, P. and Bangsbo, J., 2003, The Yo-Yo intermittent recovery test: physiological response, reliability, and validity. *Medicine and Science in Sports and Exercise,* 33, 697–705.

Krustrup, P., Mohr, M., Ellingsgaard, H. and Bangsbo, J., ,2005, Physical demands during an elite female soccer game: importance of training status. *Medicine and Science in Sports and Exercise,* 37, 1242–8.

Larsson, P., 2003, Global Positioning System and sport-specific testing. *Sports Medicine,* 33, 1093–101.

Leger, L. A., and Lambert, J., 1982, A maximal multistage 20–m shuttle run test to predict VO2max *European Journal of Applied Physiology and Occupational Physiology* 49, 1–12.

Rhodes, E. C. and Mosher, R. E., 1992, Aerobic and anaerobic characteristics of elite female university players. *Journal of Sports Sciences,* 10, 143–4.

Tamer, K., Gunay, M., Tiryaki, G., Cicioolu, I. and Erol, E., 1997, Physiological characteristics of Turkish female soccer players. In: *Science and Football III, e*dited by Reilly, T., Bangsbo, J. and Hughes, M., (London, E&FN Spon), pp. 37–9.

Todd, M. K., Scott, D. and Chisnall, P. J., 2002, Fitness characteristics of English female soccer players: an analysis by position and playing standard. In: *Science and Football IV, e*dited by Spinks, W. Reilly, T. and Murphy, A. (London: Routledge), pp. 374–81.

Tumility, D., 1993, Physiological characteristics of elite soccer players. *Sports Medicine*, 16, 80–96.

Chapter 5- Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking

5.1 Publication Overview

Study 2 demonstrated that 5 Hz GPS data could provide descriptive data relating to the movement patterns of Australian women soccer players in international competition. This information is invaluable to coaches, sport scientists and other practitioners working in the areas of player preparation to provide match data that was previously unobtainable. The emergence of this technology, and that of semi-automated multiple camera based systems in the men's game, has seen a sudden rise in descriptive research regarding the movement demands in soccer. The literature provides background regarding the general movement patterns over time of different positions, competition standards and age groups. However, most of this research lacks contextual information to start to understand how other factors influence each other. For example, the data presented in Table 4.1 of Study 2 outlines the total distance covered in the game for different matches but also provides the outcome of the game and the formation of both the Australian team and the opposition in each game. Although Study 2 did not provide a statistical analysis regarding this information it is an important step in the evolutionary process to include this contextual information. It is interesting to note that the Australian team changed the formation once they reached the semi-final and final stage of the tournament.

One of the aims of Study 3 was to continue to build on this concept of examining the influence of contextual information, in this case the relative strength of the opposition and if there is any influence on the physical demands during the game.

5.2 Author Declaration for Thesis Chapter 5

Publication title: Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking

Publication details: Published in *Journal of Sport Sciences*, 2014, vol. 32, no. 20, pp. 1874-1880.

Declaration for Thesis Chapter Five

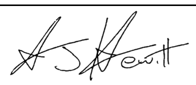
Declaration by candidate

In the case of Chapter Five, the nature and extent of my contribution to the work was the following:

Nature of contribution
I was responsible for the project design and concept as well as the data collection. I had a significant contribution to the data analysis and preparation of the manuscript. Overall I estimate the extent of my contribution of this manuscript to be 75%.

The following co-authors contributed to the work.

Name	**Nature of contribution**	**Extent of contribution (%)**	**Contributor is also a student at UC Y/N**
Kevin Norton	Manuscript editing & data analysis	20	N
Keith Lyons	Manuscript review	5	N

Candidate's Signature		**Date** **16/08/2015**

Declaration by co-authors

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;

(4) there are no other authors of the publication according to these criteria;

(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and

(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	Data is stored at the University of South Australia, School of Health Sciences, City Easy Campus. Data will be held for at least five years from 1 June 2015.

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

	Name & Signature	**Date**
Signature 1	Keith Lyons	15 August 2015
Signature 2	[illegible]	16 August 2015

5.3 Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking

Adam Hewitt, Kevin Norton & Keith Lyons

Abstract

Movement patterns in elite men's soccer have been reported in depth, however less research exists in women's soccer. The aims of the study were to identify the movement profiles of elite women soccer players in international competition, and examine the effect the level of opposition, based on FIFA rankings, had on the physical demands of the game. MinimaxX athlete tracking devices were used by 15 players during 13 international matches against opponent teams of varying ability. Total distance covered averaged 9 292±175 m. There was a decrease in high intensity running (HIR) in the 60-75 min and 75-90 min periods compared to the 0-15 min period of 22.4% and 26.1% respectively ($p=0.022$, $p= 0.004$) although sprint distances remained unchanged across game periods. HIR distances covered were significantly greater for midfielders versus defenders, while defenders had lower sprinting compared to both midfielders and attackers. Stronger opponents elicited less HIR and greater low speed activity (LSA) compared to playing teams of similar or lower ranking. These results are important to coaches to prepare players for international competition and show the differing demands required depending on the ability of the opponents.

Introduction

The physical demands and player movement patterns within soccer games, using a range of player tracking technologies, have been reported in depth for elite male athletes (Bangsbo et al., 1991; Bradley et al., 2009; Di Salvo et al., 2007; Gregson et al., 2010; Orendurff et al., 2010). Considerably less information exists regarding the physical demands and movement patterns of elite female soccer players (Andersson, Karlsen, et al., 2010; Andersson et al., 2008; Davis & Brewer, 1993; Krustrup et al., 2005).

Studies on female soccer players have revealed the majority of match play is spent in low-intensity activities (for example, standing, walking and jogging), with shorter periods of higher-intensity anaerobic work (Andersson, Randers, et al., 2010; Bangsbo, Mohr, & Krustrup, 2006; Di Salvo et al., 2010; Di Salvo et al., 2007; Mohr et al., 2008b; Mohr et al., 2003; Reilly et al., 2000). Overall, elite players have been shown consistently to cover between 9-12km total distance for an entire game (Andersson, Karlsen, et al., 2010; Andersson, Randers, et al., 2010; Gabbett & Mulvey, 2008; Krustrup et al., 2005; Mohr et al., 2008b), and these values have been quite stable for over a decade in both the men's and women's forms of the game (Bangsbo et al., 1991; Carling, Le Gall, & Dupont, 2012; Gabbett & Mulvey, 2008; Krustrup et al., 2005). Since a large proportion of the game consists of low-intensity walking or jogging it is important to determine the patterns of high-intensity work during matches. In this regard, the proportion of high intensity movement within games has been shown to differentiate the various levels of soccer competitions (Mohr et al., 2005, Reilly et al., 2000).

Research into player movement patterns performed during international level games compared with domestic competitions by Mohr et al. (2008) showed that while overall distances were almost identical, international players performed greater high intensity work compared to domestic players. Whilst Andersson et al. (2010) showed that players in international games covered greater distances at high intensity running and sprinting speeds than when they played in their respective domestic league matches. As the international and domestic games were played only one month apart, Andersson et al. (2010) suggest differences in player movement profiles may not be to be due to physical preparation or differences in fitness but influenced by different playing conditions, tactics or international players playing to a higher level of physical output in the more demanding international level games (Andersson, Randers, et al., 2010; Mohr, Krustrup, Andersson, Kirkendal, & Bangsbo, 2008a; Mohr et al., 2008b).

Team tactical formation in elite men's soccer influenced movement patterns as demonstrated by Bradley et al. (2011), additional research has shown that factors such as the quality of the opposition and the score-line affect locomotor activities (Bloomfield, Polman, & O'Donoghue, 2005; Lago, 2009; Lago-Penas & Lago-Ballesteros, 2011). These factors have also be researched in court-divided sports such as volleyball (Marcelino, Mesquita, & Sampaio, 2011) and court based invasion sports such as Spanish Handball (Oliveira, Gómez, & Sampaio, 2012) and show the influence the quality of the opposition, the match location and the match status (score-line) can have on the tactics employed by teams and subsequent player activity profiles. The present study of female player movement patterns during international games provided the opportunity to assess the type or quality of movement and the influence of the level of opposition has movement profiles of players.

The aims of the study were twofold: (1) to identify the movement demands and running profiles of elite level women soccer players in international competition using GPS athlete tracking devices, and (2) to examine the effect of the level of opposition, based on Federation Internationale de Football Association (FIFA) rankings, on the physical demands of the game.

Methods

Subjects

Fifteen Australian women national team players, classified as elite with an average number of international game appearances of 46±3 (± SEM), participated in the study (6 Defenders, 5 midfielders and 4 forwards). Their age, height and body mass were 23.5 ± 0.7 years, 170 ± 1 cm and 64.9 ± 1.3 kg, respectively. Players completed routine fitness testing at the start of the data collection period consisting of a Multistage Shuttle Test (MSST), countermovement vertical jump (VJ) and 20 m-sprint. The results for the group are displayed in Table 1.

Table 5-1 Descriptive performance data for the players involved in the study.

	20 m Sprint	VJ	MSST- Est. VO_{2max}
	s	*cm*	*ml.kg^{-1}.min^{-1}*
Average	3.29	48	52.1
SEM	0.02	1.1	1.1
Range	3.13- 3.46	38- 55	44.2 - 61.1

The players were informed of the experimental procedures and provided written informed consent to participate. The study was conducted according to the Declaration of Helsinki and approved by the Ethics Committee of the Australian Institute of Sport, Canberra, Australia.

Apparatus

A MinimaxX athlete tracking device (MinimaxX v2.5, Catapult, Melbourne, Australia) was placed on each player's upper back inside a pouch sewn into a sleeveless under-shirt. The MinimaxX (V2.5) athlete tracking device uses single-frequency, non-differential, commercially available GPS receivers with an update rate of 5 Hz. Jennings et al. (2010) reported a coefficient of variation of 3.8±0.6% using the same apparatus in a simulated running circuit designed to elicit similar movement patterns common to team sports (Jennings et al., 2010). The receivers provide coordinated universal time (UTC), position (longitude, latitude, altitude), Doppler shift velocity, the number of satellites used in the fix, and cumulative distance travelled. Following each game, data were downloaded using LoganPlus™ software (V4.01, Catapult Sports, Melbourne, Australia) and exported to Microsoft Excel for further analysis.

This study reports data collected on 15 players within 13 international games. Not every player wore a GPS unit every game and this resulted in a total of 58 game files. Only players completing the entire game were included in the analyses.

Locomotor movement categories were chosen in accordance with Dwyer and Gabbett (2012): standing (0–0.4 $km \cdot h^{-1}$), walking (0.5–6 $km \cdot h^{-1}$), jogging (6–12 $km \cdot h^{-1}$), running (12–19 $km \cdot h^{-1}$), and sprinting (> 19 $km \cdot h^{-1}$). These categories were analysed separately and also when combined in various ways for more meaningful comparisons of lower and higher intensity movement.

Matches and FIFA Rankings

All matches were FIFA international 'A' friendlies. The FIFA rankings for the teams at the time of the games were recorded (Federation Internationale de Football Association, 2012). Teams ranked in the top ten at the time the games were played were categorised as Group A, teams ranked from 11-25 were categorised as Group B and teams ranked less than 25 were categorised as Group C. Overall, 15 Group A game files, 10 from Group B and 33 from Group C were included in the study.

Statistical Analysis

Data are represented as mean ± SEM. Tests of normal distribution (Shapiro-Wilk's test) were conducted on all data before analysis, and data were normally distributed ($p > 0.05$). To analyse movement patterns within games, each game was broken down into 15-minute segments as well as totals for first and second halves, and the entire game. The change in distance covered within each 15-minute segment was analysed relative to the first 15-minute period for four categories of movement speeds using one-way ANOVA. Statview software was used for these analyses (SAS Institute Inc.). Where applicable, Scheefe's Post Hoc test was used to identify specific differences within the data. Probability values less than 0.05 were considered statistically significant. Eta squared (η^2) was used to determine the effect sizes of the

ANOVA results (Cohen & Cohen, 2003). The categories of η^2 are as follows: 0.01= small, 0.06 = medium and 0.14 = large effect size (Cohen & Cohen, 2003).

Variables

The dependent variable, the distance covered in meters (m) at different intensities and the following independent variables: match period, playing position and quality of opposition were analysed using one-way ANOVA.

Results

The total distance covered during a match averaged 9 631±175 m, with a 4.8% decrease in distance covered between the first and second halves respectively (4 934±78 compared to 4 695±108 m: Table 2). Table 2 also indicates a significant difference in Total Distance and HIR between the 0-15 minute period of the games and the 60-75 minute and 75-90 minute periods respectively with medium effect sizes (η^2 = 0.075 for Total Distance and η^2 = 0.046 for HIR)

Table 5-2 Movement summary data for each half and across the entire game for all game files recorded (n=58)

	0-15min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	1st Half	2nd Half	Whole Game
Total Distance (m)	1699±30	1570±30	1567±33	1595±30	1506±43*	1458±46*	4936±78	4695±108	9631±175
HIR (m)	478±24	384±22	382±22	429±23	378±26**	356±25**	1244±61	1163±71	2407±125
Sprint Distance (m)	67±6	56±6	50±6	59±7	53±7	53±8	173±15	165±18	338±30

Notes: *Significantly different to 0-15min ($P<0.05$ and $P<0.05$). **Significantly different from 0-15min ($P=0.022$ and 0.004)

Figure 5-1 shows the change in distance within the different locomotor movement categories across the game when the game time was split into 15-minute segments. The reference point was the distance travelled in the opening 15 minutes of the game. The figure illustrates increases in the distance travelled in the lowest speed categories (walking), specifically late in the first half, although the effect size was small ($\eta^2 =$ 0.02). There were generally decreases in the jogging and running patterns across the game with medium level effect sizes ($\eta^2 =$ 0.101 and 0.06, respectively), but no change in the distances covered sprinting.

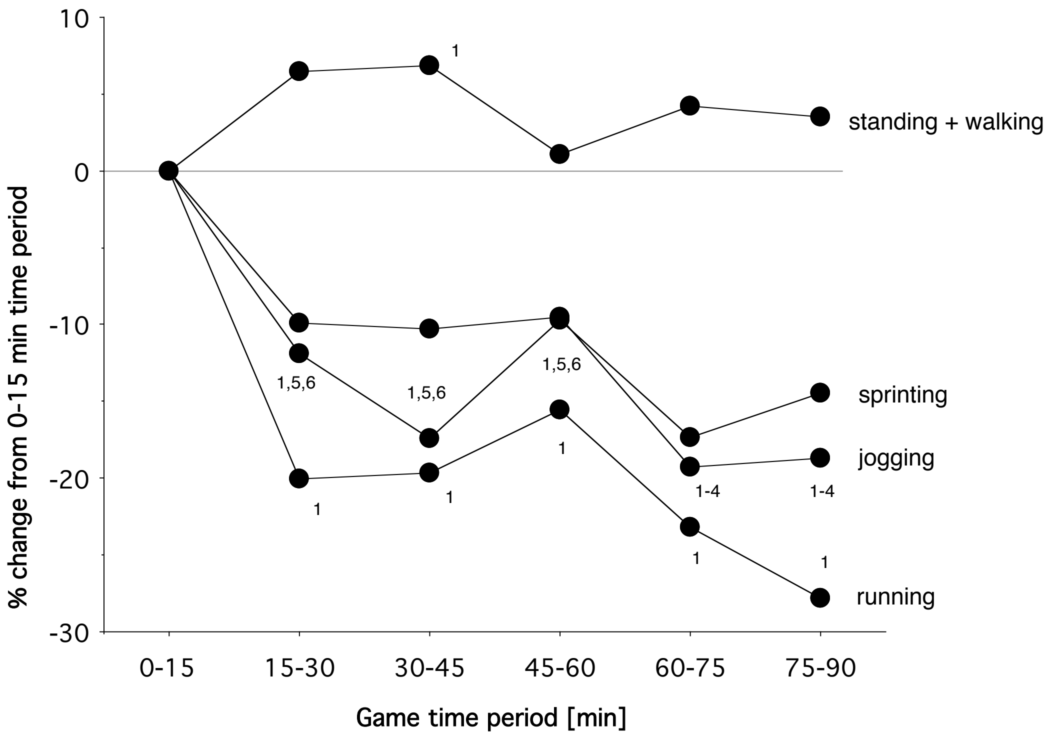


Figure 5-1 The average change in distance covered within the different locomotor movement categories across the game when the game time was split into 15 minutes periods [periods 1-6 from left to right]. Standing and walking movement categories have been combined for this analysis. The reference point was the distance travelled in the opening 15 minutes of the game. The numbers indicate significant change from the time period shown. For example, number 1 indicates the time period is different from the first time period [0-15 min].

Total, High Intensity Running, and Sprinting distances according to playing position (Defenders, Midfielders and Attackers) are displayed in Table 5-3.

There were no differences in distance covered Walking or Jogging among the positional groups. However, significant differences were found between groups for distance covered Running and Sprinting and at HIR. Post-hoc analysis showed higher values for midfielders in Total distance, HIR and Sprinting compared to defenders. Defenders also performed less sprinting than attackers. Total Distance and HIR showed large effect sizes ($\eta^2 = 0.164$ and 0.193, respectively) whilst the distance in the Sprint velocity band was medium ($\eta^2 = 0.128$).

Table 5-3 Movement summary data for the three positional categories.

	Defenders (n=13)	Midfielders (n=30)	Attackers (n=15)
Total Distance (m)	8759±284*	10150±227	9442±356
HIR (m)	1744±138§	2797±174**	2272±205
Sprint Distance (m)	188±31#	392±46	388±56

*Significantly different to Midfielders (p=0.002)
§Significantly different to Midfielders (p=0.001)
** Significantly different to Attackers (p=0.043)
#Significantly different to Midfielders (p=0.001) and Attackers (p=0.006)

When analysing movement patterns compared to the quality of the opposition, more HIR was performed when playing against opposition of similar quality (Group B) compared to teams ranked in Group A (p= 0.0206) (Figure 2). No significant differences were found for Higher Intensity Movements when playing against teams from Group C. Analysis of low speed movement indicated less distance covered in this category when playing against teams from Group B (p=0.0073) with no significant difference identified when playing against teams from Groups A or C (p=0.0.0638 and p=0.01286 respectively).

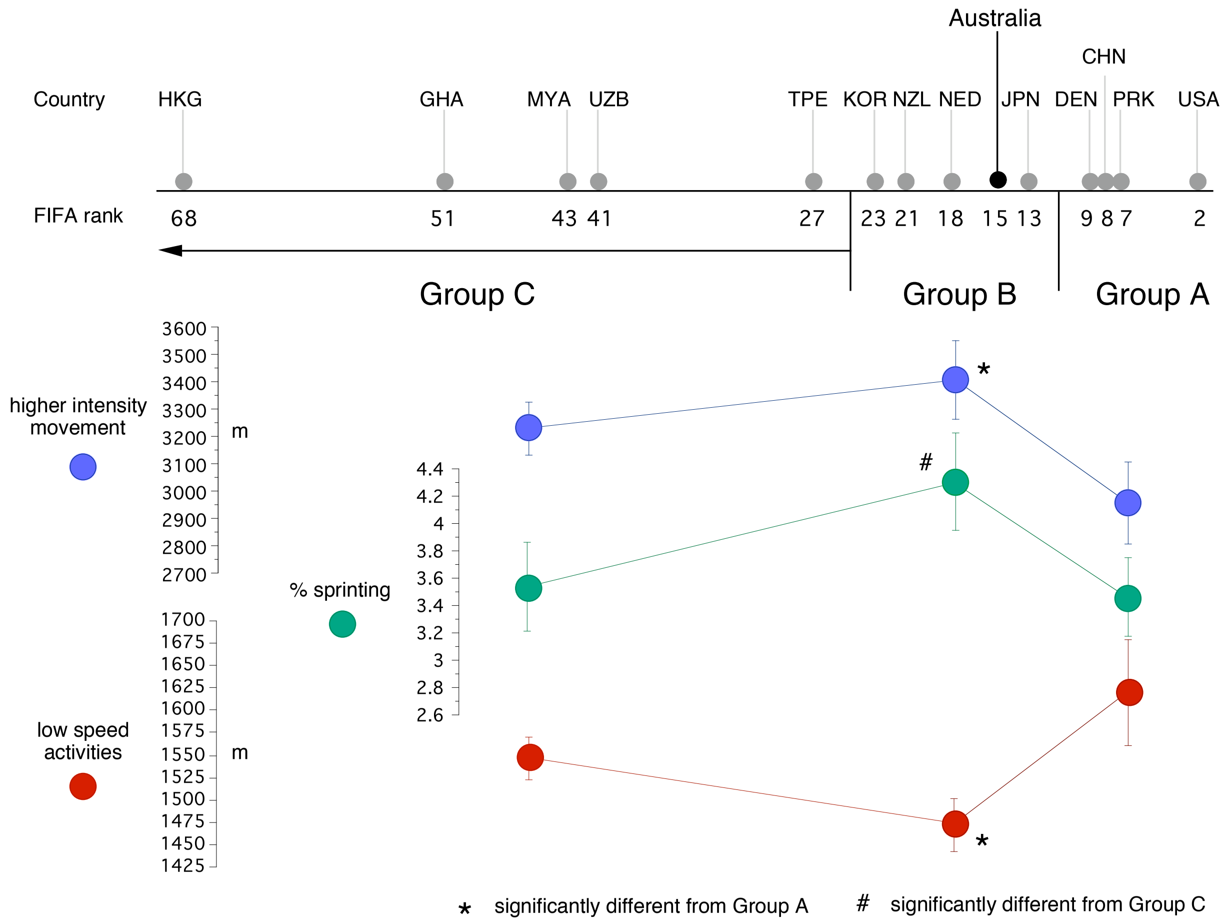


Figure 5-2 Difference between the effect of quality of opposition, as determined by FIFA rankings, on three key movement parameters. Higher intensity movement included jogging, running, and sprinting distances while low speed movement included standing and walking. Analysis was conducted using movement distances calculated for halves of all games. Values are shown as mean ± SEM.

Results show that when the total distance sprinting was expressed relative to the total distance covered (% sprinting) there was significantly more relative distance in this category playing against opposition from Group B compared to Group C ($p=0.0496$).

The higher intensity movement category and percentage of distance covered whilst sprinting resulted in a small effect size ($\eta^2 = 0.047$ and 0.038), while the low speed movement category showed a medium effect size ($\eta^2 = 0.062$).

Discussion

This study described the physical activity demands of elite Australian women soccer players in competitive international games. Additionally, this study examined the effect the level of the opposition has on a player's physical activity demands during women's international soccer games.

The present study contributes to the limited research of movement profiles in women's soccer. Previous research has shown the average distance travelled was approximately 10 070 ± 1 500 m (Andersson, Randers, et al., 2010; Gabbett & Mulvey, 2008; Mohr et al., 2008b), which is similar to the 9 630 ± 175 m found in the present study. Based on the distances recorded in the present study there appears to be little difference with previous research in elite men's soccer in total distances covered during a match (Carling et al., 2012; Mohr et al., 2008b; Mohr et al., 2003).

Previous research has reported varying results in terms of total distances covered between halves in both men and women's soccer. Andersson and colleagues (2010) reported no variance in the total distances covered between halves in both elite and domestic women's soccer players, supported by the work of Di Salvo et al. (2007), when examining the motion characteristics in elite male soccer players. However, (Burgess, Naughton, & Norton, 2006) demonstrated a decrease in total distance covered between halves in Australian national league players at similar magnitudes

(5-6%) to research conducted in Danish and South American elite players (Reilly et al., 2000; Rienzi et al., 2000).

An interesting feature of this analysis is the progressive decrease in distance covered across the game at higher intensity velocities with the exception of Sprinting, which did not change significantly. Players performed approximately 26% less high intensity running in the last 15 minutes of a game compared to the first 15 minutes of the game. Conversely, there was an increase in low speed activity of 4.4% on average compared to the first 15 min period of the game. The movement patterns for HIR across the game were similar to those found in previous male and female soccer research (Mohr et al., 2008b).

The reduction in high intensity running and the subsequent increase in low intensity activities may allow players greater opportunity for recovery in order to help maintain the distance covered at maximal intensities. This is supported by many authors who suggest running at the highest intensities are important as an indicator of physical outputs during a match than total distance (Bangsbo, Madsen, Kiens, & Richter, 1996; Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004; Rampinini, Impellizzeri, Castagna, Coutts, & Wisloff, 2009) and as suggested by Lago et al. (2010) players do not always use their maximal physical capacity for the entire match. Furthermore, it is during periods of high intensity activity that many of the significant events such as creating space and scoring opportunities occur in many field based invasion sports (for example, soccer, Australian Rules football and field hockey) (Wallace & Norton, 2014).

When looking at each playing position, defenders had significantly less sprinting distance compared to both the midfielders and the attackers. Midfielders covered more distance than the defenders and had greater running at high intensity compared to defenders. These findings support the work of Andersson et al. (2010) showing midfield players covered more distance, and had greater running proportions at high intensity and sprinting distance than defenders.

It is important to recognise, however, that variables such as playing formation can impact the movement profiles of players. For example, Bradley et al. (2011) showed that playing formation (for example, 4-4-2 or 4-3-3 or 4-5-1) influenced the amount of high intensity running and highlighted that movement patterns and running intensities varied greatly across playing positions. Furthermore they demonstrated specific roles within generalised position groupings (for example, central defenders versus wide defenders for the defending group) have vastly different bioenergetic demands.

Vilar et al. (2012) describe an ecological dynamics model to explain playing patterns in soccer. They found that attacking players were attempting to break symmetry with their nearest opponent whilst defenders tried to maintain symmetry by staying between the attacking player and the goal (Vilar, Araujo, Davids, & Button, 2012). This is supported by (Piltz & Launder, 2013) who described tactics and principles of defending in team sports where defenders use positioning to delay the attacking players movements and provide depth to prevent attacking players getting into positions between themselves and the goal. The theories and principles of defending would contribute to the current findings that defending players covered less distance sprinting compared to midfield and attacking players whilst there was a 7.7% difference in Total Distance. This notion is further supported by Bradley et al. (2011) who attribute the greater physiological load and subsequent increase in fatigue of attackers in the latter stages of matches, in part to increases in movement required to pressure and close down opponents space when unfavorably outnumbered.

The second aim examined the effect of opposition quality on movement patterns. Previous research by Mohr et al. (2008) and Andersson et al. (2010) showed that international players performed more high intensity running compared to opposition players of lesser quality. When Australia played against teams similar in ranking (Group B), players had to perform significantly more higher intensity movements and had less low speed movement compared to playing against a teams ranked higher or lower. In a study analysing situational variables from twenty-seven Spanish Premier League games from the 2005-2006 seasons, Lago et al. (2010) showed that players covered a greater total distance playing against better-ranked teams. Further analysis highlighted that the increase in distance covered playing against better-ranked opposition was an increase in distances covered at low intensity velocities (0-11 km·h^{-1}) with no significant differences found in movement categories above 11 km·h^{-1}.

These results differ to those found in other sports such as AFL that show lower ranked teams cover more distance, HIR and sprints than higher ranked teams (Wisbey et al., 2010). However, the style of play and context of the game may have a major influence in the movement patterns required (Lago et al., 2010). In games against both higher and lower ranked opposition the player density, and as such the amount of space available for players to run, may be reduced. This may be due to more players being in a smaller part of the playing field. For example, if a team is dominating possession and forcing the opposition towards their own goal line there will be a greater number of players in one half of the field, thus decreasing the available space to run. If a team is playing against an opposition of relatively equal strength the opportunities to move from the defensive half to the offensive half (and vice versa) would increase. This would decrease the player density and allow more space in which the players could run to create scoring opportunities.

Some caution is needed when interpreting these findings as a relatively small number of players and matches were analysed. This is particularly relevant given the high match-to-match variation in high intensity running (Gregson et al., 2010). However, there are limited opportunities in elite women's soccer to collect movement profile data. Compared to other women's soccer research the current study with 58 international game files analysed the present research compares favorably to authors such as Mohr et al. (2008), Andersson et al. (2010) and Gabbett and Mulvey (2008) who examined approximately 35, 24 and 12 game files. Furthermore, due to the differences in movement analysis methods, a comparison across the literature is difficult (Randers et al 2010). Randers et al. (2010) identified significant differences between video based time-motion analysis (VTM) player tracking techniques as used by research identified thus far in elite women's soccer (Andersson, Randers, et al., 2010; Gabbett & Mulvey, 2008; Krustrup et al., 2005; Krustrup, Zebis, Jensen, & Mohr, 2010; Mohr et al., 2008b) and an athlete tracking device using 5 Hz GPS as used in the present study. The research reported a 13% difference between GPS and VTM in Total Distance covered and a 23% difference in the amount of distance covered at high intensity velocities (Randers et al., 2010). Finally, in addition to the different movement analysis methods, Gabbett and Dwyer's (2012) research highlights the vast range of velocity bands and locomotor activities across the research and how difficult it is to then compare (Dwyer & Gabbett, 2012b).

In summary, the results demonstrate the movement profiles for elite Australian women soccer players are comparable to previous research conducted on elite women's soccer. The research highlights the effect of the quality of the opposition has on movement profiles in international matches.

The current findings provide valuable information for managers and fitness coaches on physical requirements across different positions and the effect the quality of the opposition has on movement profiles, which could be of use for adapting training programs. As demonstrated by the work of Bradley et al. (2011) and (Lago, Casais, Dominguez, & Sampaio, 2010b) situational variables such as the effect of different playing formations or the strength of the opposition provide contextual information to managers, fitness coaches and analysts, which can be utilised in formulating game strategies and player selection as well as the physical preparation and recovery from games. As highlighted by Lago et al. (2010) if it can be identified technical, tactical, or in this study, physical aspects are adversely affected by situational variables such as the quality of the opposition, possible causes can be examined and changes implemented to improve performance.

Acknowledgements
No sources of funding were used to assist in this study.

We would like to thank the players who participated in the study and Football Federation of Australia for their cooperation.

References

Andersson, H., Karlsen, A., Blomhoff, R., Raastad, T., & Kadi, F. (2010a). Active recovery training does not affect the antioxidant response to soccer games in elite female players. *British Journal of Nutrition*, *104*(10), 1492-1499.

Andersson, H., Raastad, T., Nilsson, J., Paulsen, G., Garthe, I., & Kadi, F. (2008). Neuromuscular fatigue and recovery in elite female soccer: Effects of active recovery. *Medicine and Science in Sports and Exercise*, *40*(2), 372-380.

Andersson, H., Randers, M., Heiner-Moller, Krustrup, P., & Mohr, M. (2010b). Elite Female Soccer Players Perform More High-Intensity Running When Playing in International Games Compared with Domestic League Games. *Journal of Strength and Conditioning Research*, *24*(4), 912-919.

Bangsbo, J., Madsen, K., Kiens, B., & Richter, E A. (1996). Effect of muscle acidity on muscle metabolism and fatigue during intense exercise in man. *The Journal of Physiology*, *495*(Pt 2), 587-596.

Bangsbo, J., Mohr, M., & Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Sciences*, *24*(7), 665-674.

Bangsbo, J., Norregaard, L., & Thorso, F. (1991). Activity Profile of Competition Soccer. *Canadian Journal of Sport Sciences-Revue Canadienne Des Sciences Du Sport*, *16*(2), 110-116.

Bloomfield, J., Polman, R., & O'Donoghue, P. (2005). Effects of score-line on team strategies in FA Premier League Soccer. *Journal of Sports Sciences*, *23*(2), 192-193.

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). High-intensity running in English FA Premier League soccer matches. *Journal of Sports Sciences*, *27*(2), 159-168.

Burgess, D.J, Naughton, G, & Norton, K.I. (2006). Profile of movement demands of national football players in Australia. *Journal of Science and Medicine in Sport*, *9*(4), 334-341.

Carling, C., Le Gall, F., & Dupont, G. (2012). Analysis of repeated high-intensity running performance in professional soccer. *Journal of Sports Sciences*, *30*(4), 325-336.

Cohen, J., & Cohen, J. (2003). Applied multiple regression/correlation analysis for the behavioral sciences. Electronic Book; Retrieved from http://ezlibproxy.unisa.edu.au/login?URL=http://site.ebrary.com/lib/unisaau/Doc? Id=10110090.

Davis, J. A., & Brewer, J. (1993). Applied Physiology of Female Soccer Players. *Sports Medicine, 16*(3), 180-189.
Dawson, B., Hopkinson, R., Appleby, B., Stewart, G., & Roberts, C. (2004). Player movement patterns and game activities in the Australian Football League. *Journal of Science and Medicine in Sport, 7*(3), 278-291.
Di Salvo, V., Baron, R., Tschan, H., Calderon Montero, F. J., Bachl, N., & Pigozzi, F. (2007). Performance characteristics according to playing position in elite soccer. *International Journal of Sports Medicine, 28*(3), 222-227.
Di Salvo, V., Baron, R., González-Haro, C., Gormasz, C., Pigozzi, F., & Bachl, N. (2010). Sprinting analysis of elite soccer players during European Champions League and UEFA Cup matches. *Journal of Sports Sciences, 28*(14), 1489-1494.
Dwyer, D. B., & Gabbett, T. J. (2012). Global positioning system data analysis: velocity ranges and a new definition of sprinting for field sport athletes. *Journal of Strength and Conditioning Research, 26*(3), 818-824.
Federation Internationale de Football Association, (FIFA). (2012). FIFA/Coca-Cola Women's World Ranking. Retrieved 2012, from
http://www.fifa.com/worldranking/rankingtable/women/index.html
Gabbett, T. J., & Mulvey, M. J. (2008). Time-Motion Analysis of Small-Sided Training Games and Competition in Elite Women Soccer Players. *Journal of Strength and Conditioning Research, 22*(2), 543-552.
Gregson, W., Drust, B., Atkinson, G., & Di Salvo, V. (2010). Match-to-Match Variability of High-Speed Activities in Premier League Soccer. *International Journal of Sports Medicine, 31*(4), 237-242.
Jennings, D., Cormack, S., Coutts, A. J., Boyd, L. J., & Aughey, R. J. (2010). Variability of GPS units for measuring distance in team sport movements. *International Journal of Sports Physiology and Performance, 5*(4), 565-569.
Krustrup, P., Mohr, M., Ellingsgaard, H., & Bangsbo, J. (2005). Physical demands during an elite female soccer game: Importance of training status. *Medicine and Science in Sports and Exercise, 37*(7), 1242-1248.
Krustrup, P., Zebis, M., Jensen, J. M., & Mohr, M. (2010). Game-Induced Fatigue Patterns in Elite Female Soccer. *Journal of Strength and Conditioning Research, 24*(2), 437-441.

Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *Journal of Sports Sciences, 27*(13), 1463.
Lago, C., Casais, L., Dominguez, E., & Sampaio, J. (2010). The effects of situational variables on distance covered at various speeds in elite soccer. *European Journal of Sport Science, 10*(2), 103-109.
Lago-Penas, C., & Lago-Ballesteros, J. (2011). Game location and team quality effects on performance profiles in professional soccer. *Journal of Sports Science and Medicine, 10*(3), 465-471.
Marcelino, R., Mesquita, I., & Sampaio, J. (2011). Effects of quality of opposition and match status on technical and tactical performances in elite volleyball. *Journal of Sports Sciences, 29*(7), 733-741.
Mohr, M., Krustrup, P., Andersson, H., Kirkendal, D., & Bangsbo, J. (2008). Match Activities of Elite Women Soccer Players at Different Performance Levels. *Journal of Strength and Conditioning Research, 22*(2), 341-349.
Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sports Sciences, 21*(7), 519-528.
Oliveira, T., Gómez, M, & Sampaio, J. (2012). Effects of game location, period, and quality of opposition in elite handball performances. *Perceptual and motor skills, 114*(3), 783.
Orendurff, M. S., Walker, J. D., Jovanovic, M., Tulchin, K. L., Levy, M., & Hoffmann, D. K. (2010). Intensity and Duration of Intermittent Exercise and Recovery during a Soccer Match. *Journal of Strength and Conditioning Research, 24*(10), 2683-2692.
Piltz, W., & Launder, A. (2013). *Play practice* (2nd ed. ed.). Champaign, IL :: Human Kinetics.
Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisloff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *Journal of Science and Medicine in Sport, 12*(1), 227-233.
Reilly, T., Bangsbo, J., & Franks, A. (2000). Anthropometric and physiological predispositions for elite soccer. *Journal of Sports Sciences, 18*(9), 669-683.
Rienzi, E., Drust, B., Reilly, T., Carter, J. E. L., & Martin, A. (2000). Investigation of anthropometric and work-rate profiles of elite South American international soccer players. *Journal of Sports Medicine and Physical Fitness, 40*(2), 162-169.

Vilar, L., Araujo, D., Davids, K., & Button, C. (2012). The Role of Ecological Dynamics in Analysing Performance in Team Sports. *Sports Medicine, 42*(1), 1-10.
Wallace, J. L., & Norton, K. I. (2013). Evolution of World Cup soccer final games 1966-2010: Game structure, speed and play patterns. *Journal of Science and Medicine in Sport*, In Press, Accepted- 06 May 2013.
Wisbey, B., Montgomery, P. G., Pyne, D. B., & Rattray, B. (2010). Quantifying movement demands of AFL football using GPS tracking. *Journal of Science and Medicine in Sport, 13*(5), 531-536.

Chapter 6- Game style in soccer: what is it and how can we measure it?

6.1 Publication Overview

As a result of Studies 1-3 a common theme was emerging through this research and supporting literature. The theme in question was adding contextual information to performance analysis information, in particular for Studies 1-3 in terms of physical performance in soccer. Studies to date have highlighted that "game style" or "playing style" of both teams participating has an influence on the physical performance of the individuals and the team. "Game style" impacts the physical, technical, tactical and psychological demands of the players and vice versa. Further research regarding the impact of "game style" highlighted that there was little understanding in the academic literature. There is often a common language, in layman's terminology assuming everyone knows what is meant by the term "game" or "playing style" yet there is little or no evidence to suggest how sport scientists, coaches, performance analysts and other practitioners might be able to better quantify these terms in peer reviewed literature.

6.2 Author Declaration for Thesis Chapter 6

Publication title: Game Style: What is it and how can we measure it?

Publication details: Submitted to *International Journal of Performance Analysis* (currently under review)

Declaration for Thesis Chapter Six

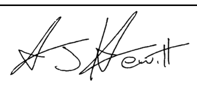
Declaration by candidate

In the case of Chapter Six, the nature and extent of my contribution to the work was the following:

Nature of contribution
I was responsible for the project design and concept. I had a significant contribution to the preparation of the manuscript. Overall I estimate the extent of my contribution of this manuscript to be 80%.

The following co-authors contributed to the work.

Name	**Nature of contribution**	**Extent of contribution (%)**	**Contributor is also a student at UC Y/N**
Kevin Norton	Project conception, manuscript preparation and editing	20	N

Candidate's Signature		**Date** **15 August 2015**

Declaration by co-authors

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;

(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	All data will be stored at the University of South Australia, School of Health Sciences, City East Campus, Adelaide. Data will be held for a period of not less than five years from the 1st August 2015.

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

	Name & Signature	**Date**
Signature 1		16 August 2015

6.3 Game style in soccer: what is it and how can we measure it?

Adam Hewitt[1,2] and Kevin Norton[1]

[1] *School of Health Science, University of South Australia, Adelaide, Australia*

[2]University *of Canberra Research Institute for Sport and Exercise, University of Canberra, Canberra, Australia*

Abstract

Game style is a term commonly used by coaches, sports scientists, performance analysts and media to describe patterns of play in team sports. However, there is a paucity of literature relating to the definition of game style, how it can be measured, or what factors influence our understanding of a team's style of play. Performance analysis research has often sought to identify factors related to probability of scoring or of game success. However, more recently there has been a shift to investigate team sports as dynamical systems and to understand of how players interact in various contextual environments and circumstances. These interactions, particularly successful, dominant or recurrent patterns, are likely to be important in forming a game style or at least play a part in our perceptions of a game style. This article proposes an initial framework of variables that can be measured and used to describe game style. The framework is based on metrics within five key moments of play: (1) Established Attack, (2) Transition from Attack to Defense, (3) Established Defense, (4) Transition from Defense to Attack, and (5) Set Pieces. These metrics have practical applications for coaches and practitioners when evaluating efforts to create or compare particular game styles. More importantly, however, they will allow performance analysts to categorise and monitor game styles over time, across leagues and age groups, and provide a deeper understanding of dynamic interactions in invasion-based field sports.

Keywords: Player tracking, playing style, match analysis, association football

1. Introduction

There is a consistency in the world of football commentary and coaching that refers to how a game 'unfolds' or what patterns of play are typically seen in competition. This language is universal, pervades virtually all field sports and has changed relatively little over time as evidenced from historical game footage. Moreover, commentators assume others know precisely what they are talking about when regularly referring to a 'game style' or 'play style'. For example, among the many hundreds possible, these types of general media and coaching statements are frequently encountered:

New Argentina coach Gerardo Martino says he will not make any drastic changes to the style of play that took it to the World Cup final. (ESPN, 2014)

''We're going to go there attacking and we're not going to sit off. We'll play our style and see if it comes off." (Horne, 2014)

Teams are often referred to by their game style as much as their results. A team, club or managers' culture may dictate game styles with colloquiums such as "Total Football" or "Tika-taka" referred to in describing a game or play style. But, what do we understand from these game style references?, what do they mean?, and are we interpreting 'game style' in a consistent way? More importantly for sports science, how can this area of sports performance become more robust, quantifiable and less colloquial, and what metrics contribute to 'game styles' or 'playing styles'?

The optimisation of team sport performance has received significant attention in research literature over the past two decades. Part of this interest involves understanding the dynamic nature and effect of contextual information, such as the interactions among players in field sports, and how it may help improve performance. Comprehensive reviews have been published on sport science disciplines and soccer such as physiology (Bangsbo, 1998; Ekblom, 1986; Reilly & Gilbourne, 2003; Stølen, Chamari, Castagna, & Wisløff, 2005), biomechanics (Lees, Asai, Andersen, Nunome, & Sterzing, 2010; Lees & Nolan, 1998), sports medicine and injuries (Junge & Dvorak, 2004; Shephard, 1999) and more recently performance analysis (Carling, 2013; Mackenzie & Cushion, 2013). The development and application of video and computer technology has now made previously unattainable systems cost-effective and easy to use (Di Salvo et al., 2006) leading to the integration of performance analysis within the coach-athlete-sport science nexus (Drust, 2010; Lago, 2009).

Performance analysis research has largely focused on key performance indicators of success including possession and passing patterns, team structures and probability of winning (Bradley, Lago-Penas, et al., 2013; Castellano et al., 2012; Lago, 2009; Lago & Martín, 2007; Lago-Ballesteros & Lago-Penas, 2010; Mackenzie & Cushion, 2013), predicting successful future performances or to characterising differences between teams or competitions (Armatas, Yiannakos, & Sileloglou, 2007; Bloomfield, Polman, & O'Donoghue, 2005; Lago, 2007; Lago, Casais, Dominguez, & Sampaio, 2010a; Lago & Martín, 2007; Lago-Ballesteros & Lago-Penas, 2010; Lago-Penas & Dellal, 2010; Pollard, Ensum, & Taylor, 2004; Yiannakos & Aramats, 2004). Technological advancements have facilitated growth of research investigating the technical and physical components of players as well as game patterns across different leagues (Bradley, Carling, et al., 2013; Dellal, Chamari, Wong, et al., 2011), competitions (Di Salvo et al., 2010) and duration (Barnes, Archer, Hogg, Bush, & Bradley, 2014; Wallace & Norton, 2014). It is this aspect of performance analysis, the description of distinguishing features of games such as ball and player movement patterns, strategies of attacking and defending play, and how teams work to maintain or regain possession of the ball, that is poorly defined and therefore difficult to categorise or compare scientifically. They may not have strict definitions but they form part of the universal language broadly describing a game style.

Research demonstrates that variables have often been measured as a result of availability rather than to develop a deeper understanding of performance (Mackenzie & Cushion, 2013). Furthermore, the literature has been shaped by a positivist paradigm whereby a reductionist approach is often used to understand a whole system, such as football success, by measuring individual parts (Brustad & RitterTaylor, 1997). This may be problematic because applying these isolated findings may not yield success in all circumstances. For example, performance analysis research frequently relies on a classical approach of linear causality whereby an explanation or success assumption is based on a naive chain of cause and effect.

While there is considerable evidence that a large proportion of research falls into this piecemeal approach, it is understandable given the relatively young age of the discipline, its reliance on rapidly evolving technologies and an acknowledgement of the complexity of team sport. However, recent developments have been more creative by describing performance within situational contexts. These include incorporating measures of potentially confounding variables such as environmental conditions, location of play on the field, opposition standard, and time in the game or across the season, which can impact associations among variables to reveal situational relationships and assist in developing a framework for measuring game style (Bradley & Noakes, 2013; Carling, 2011; Gore et al., 2008; Hewitt, Norton, & Lyons, 2014; Lago, 2009).

Identifying the position of teammates, and opposition, at each instant in time with modern tracking technologies allows further contextual information and introduces elements of strategies and tactics of playing styles. These characteristic styles, often planned and rehearsed in advance by teams, can now be analysed in depth with the aim of informing the coaching review process and enhancing performance (Frencken, Lemmink, Delleman, & Visscher, 2011; Moura et al., 2013).

Traditionally there has been a focus on the physical demands such as distances covered by players and their running velocities to enhance the specificity of training. However, new contextual information can be provided including relative distances among team-mates and opposition players, player congestion maps, probability of scoring success at different locations from goal and other details relating to interactions among the team or sub-groups (Alcock, 2010; Frencken, De Poel, Visscher, & Lemmink, 2012; Moura et al., 2013). All of these elements of play can be quantified and used to characterise a game style.

The aims of this paper are to outline methods that have been previously presented in a way that can help practitioners objectively assess patterns of play. This will aid in categorising game styles and how contextual influences impact styles, and help with comparisons among different teams and competitions, assist trend analyses over time, and benefit team strategies, player recruitment and preparation.

The aim is not simply to look at success of game styles in team sports but to suggest a framework of meaningful metrics that coaches, analysts, sport scientists and other practitioners can use to assess strategies and tactics and to characterise game styles. Without consistent and well-defined metrics, it is problematic to assess the effectiveness of team game styles or to know if and how a game style has changed over time or with new players or coaches. This paper presents concepts of what variables might be included when determining a game style in soccer and proposes a definition of game style.

2. Elements of play in field sports

2.1 Strategy, tactics and game style

The principles of field-based invasion sports can be viewed as a relationship between teams where each must coordinate its actions in order to recover, conserve, and effectively move the ball into a scoring zone (Gréhaigne & Godbout, 1995). Team sports can, therefore be considered as a function of two networks attempting to anticipate opponents attacking and defensive movements and plan its own offensive and defensive actions, using strategy and tactics.

Strategy has been defined as including all plans, principles of play or action guidelines decided upon before a match in order to organise the activity of the team and player interaction during the game (Gréhaigne & Godbout, 1995; Gréhaigne, Godbout, et al., 1997; Piltz & Launder, 2013). This may include the framework of a game style based, in part, on coaching philosophies in soccer such as whether teams aim to play a possession-based [prioritising keeping the ball away from the opposition even if it means relatively little attacking and non-offensive passing], or counter-attacking game [typically moving the ball rapidly in transition moments that often involves rapid player movement and trying to outnumber defenses]. However, tactics involve the actions voluntarily executed during the game by the players in order to adapt to the immediate requirements of an ever-changing opposition. Therefore, tactics are more likely to be continually evolving in response to varying situations or game contexts. For example, score line, time remaining, and the opposition strengths and weaknesses. (Gréhaigne & Godbout, 1995; Gréhaigne, Godbout, et al., 1997; Piltz & Launder, 2013).

Overall, soccer can be described as competition between teams involving moments of frenzied attacking movements to create imbalance in player position and numbers versus a homeostatic environment of rapid re-organisation towards control, possession and stability. Teams then reverse roles in this pattern of disorder versus order (Delgado-Bordonau & Mendez-Villanueva, 2012). Oliveira (2004) suggested that soccer teams are characterised by interacting agents that include players, coaches, and game strategies and tactics. There is obviously cooperation and coordination among players that help create a certain order and stability in an environment of physical confrontation and occasional chaotic disorder.

The visual aspect of this competition, for example, movement of players and the ball, frequency of periods of attacking asymmetry, speed of counter-attacks, the way teams try to keep possession of the ball while moving strategically towards goal-scoring areas and numerous other ingredients of field-based sports are, collectively, what we refer to as a game style. The problem is we may not all see the same elements of play, or in the same way, when we build a version of game style. Even coaches may not accurately recall aspects of their own game (Laird & Waters, 2008).

2.2 Moments of play

Using identifiable patterns of play it has been suggested there are four key repeating 'moments' during a game: Established Attack, Defensive Transition, Established Defense and Offensive Transition (Oliveira, 2004). Furthermore, research has demonstrated the significance of goal scoring opportunities arising from set pieces. Approximately 30% (Ensum, Williams, & Grant, 2000) of goals in major competitions/ leagues arise from set pieces such as corner and free kicks suggesting that Set Pieces should form the fifth key moment of the game as illustrated in Figure 6.1.

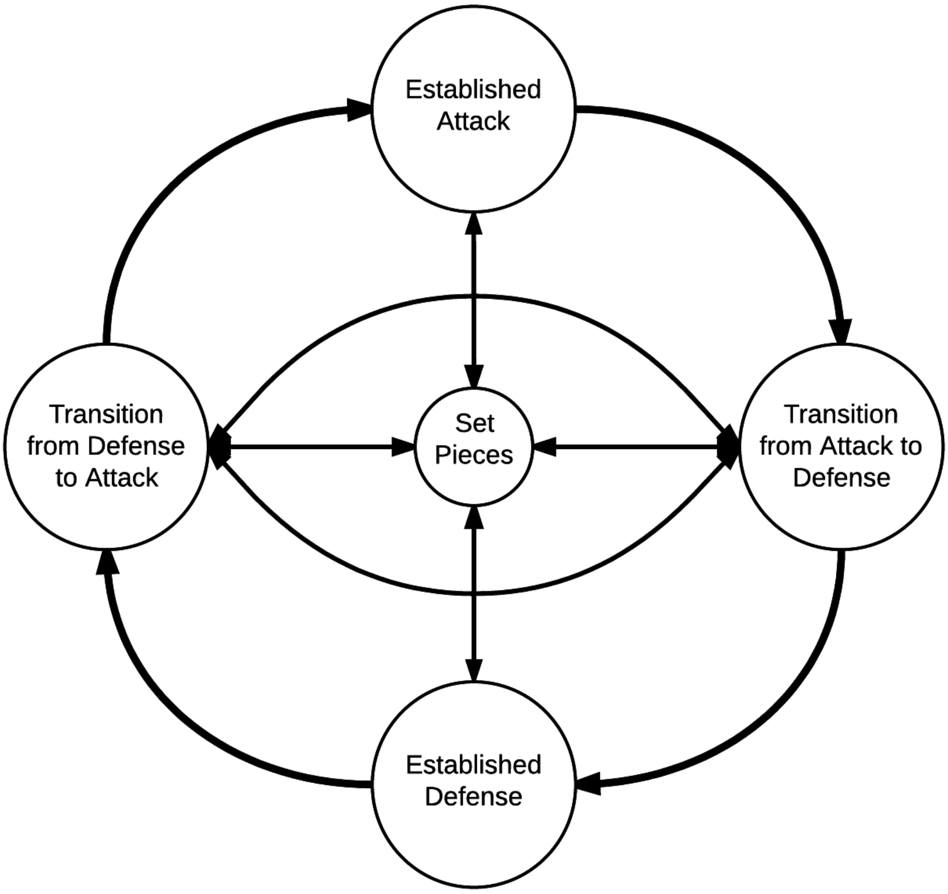


Figure 6-1 Moments of play (Adapted from Oliviera, 2004)

These moments are considered as discrete periods but are clearly able to influence other moments or elements of play (Delgado-Bordonau & Mendez-Villanueva, 2012). For example, attacking patterns may influence defensive tactics simply because of where players are located on the field relative to opposition players during a transition. However, for the purposes of this review of game style, the moments of play will generally be considered separately as one of three groups: Established Offense and Defense, Transitional Play and Set Pieces.

Breaking the game into moments of play and reviewing ways to measure patterns within these moments can help to characterise styles of play in field sport. A number of patterns within each moment of play are described in Table 6.1. These objective measures help us quantify and characterise game style although the metrics discussed are not meant to be a definitive list of all key variables.

Table 6-1 Five moments of play within a game and the key aims within each moment.

Established Offense	Transition from Attack to Defense	Established Defense	Transition from Defense to Attack	Set Pieces
• Score goals • Possession and movement of the ball • Look for space • Unbalance defense	• Press and pressure opposition on the ball to regain possession • Make opponents play backwards to force delay • Decrease space between players to either continue to press the ball carrier or to get organized to defend	• Pressure zone defense • Limit, direct and pressure opponent in order to close space • Take away wide and deep space • Provoke mistakes and win ball possession	• Pass the ball away from defensive pressure • Take advantage of defensive disorganisation • Get attackers into open spaces • Keep ball possession • rapid offensive organisation	• Attacking • Score goals • Maintain possession and create goal scoring opportunities. • Defending • Prevent goals • Regain possession

Game style will be the playing outcome, that is, what we observe when formed by the interaction of numerous play patterns occurring within these moments. The frequency of their occurrence, impact on both the moment and game outcomes, level of excitement elicited, repeatability from game to game, and predictability of play patterns and tactics within moments are all examples of how a game style will be 'created' for the observer. There are obviously many other elements within a game that can influence our interpretation of a game style. Moreover, the importance placed on any one element may also change over time, most likely heavily influenced by the degree of success associated with particular patterns of play.

Even though a team and coach may agree on and rehearse a range of play patterns within moments of the game, it is not always possible to perform these in the optimal way. Figure 2 illustrates the relationships between moments of the game and player capacities in areas of physical, technical and psychological attributes. Play patterns within moments are obviously impacted by the fitness and skill levels of the players (Bloomfield, Polman, Butterly, & O'donoghue, 2005; Carling, 2011), their level of alertness and how rapidly they anticipate movements of the ball and other players (Tedesqui & Glynn, 2013), and their decision-making capabilities throughout the game (Williams & Ericsson, 2005).

Finally, other factors can influence the frequency and type of play patterns that are important in the development of a game style. These include a coach's own principles and instructions of play within moments, training methodologies, group management and leadership philosophies, in addition to context variables such as the county's culture, influence of the club's board or owners, and supporter and media pressures. The way these factors interact in any game can also be influenced by environmental conditions, both physical, such as temperature and altitude challenges, as well as cultural when teams play in foreign countries or at opposition grounds. The relative importance, for example, of away goals in qualifying games can often impact game strategies and therefore game style (Pollard, 1986; Tenga et al., 2010).

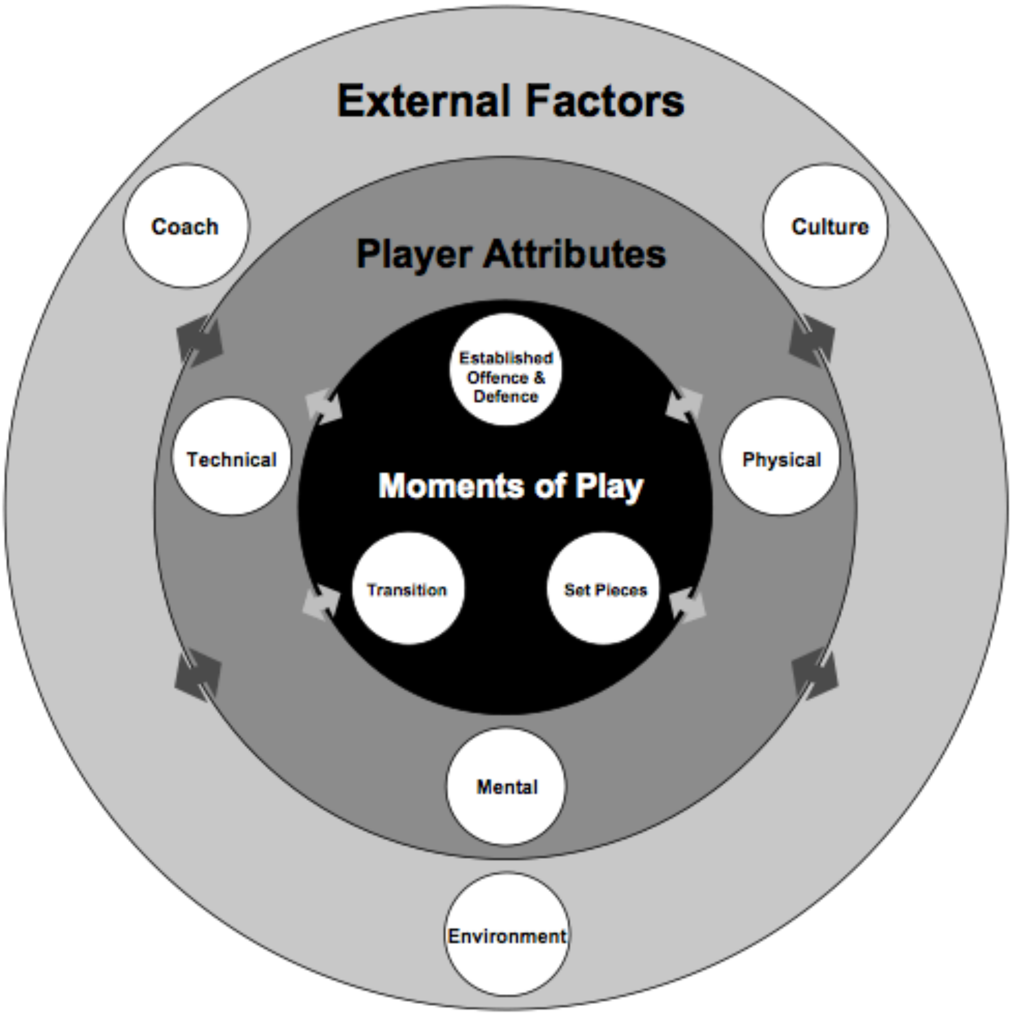


Figure 6-2 Relationships among elements that determine Game Style.

3. Measuring game style

Table 6.2 lists a number of metrics that contribute to a game style. It is unlikely that all of these metrics will be measured in a game but they are listed to represent variables that may be quantified and used to categorise a game style. They have been selected based on either an association with scoring or movement success in invasion-based sports or where characteristic and repeatable playing styles may be demonstrated.

Table 6-2. Five moments of play within a game and potential metrics within each moment that may contribute to game style.

Established Offense	Transition from Attack to Defense	Established Defense	Transition from Defense to Attack	Set Pieces
• Goal attempt • Number of passes • Possession • Passing sequences • Passing density • Passing efficiency/ accuracy	• Rate of change of Centroid and Surface Area • Player density • Location of turnover • Player speed • Distance between players • Defensive transition speed	• Surface Area • Centroid position • Distance Between players • Player density	• Ball speed • Rate of change of Centroid and Surface Area • Player density • No. and length of passes • Player speed • Offensive transition speed	• Type of set piece • Location vs success probability maps

3.1 Established Offensive and Defensive Play

Success in soccer is obviously multifactorial whereby statistics or notational analysis might reveal dominance in possession, passing, or shots on goal, for example. However, scoring goals is the ultimate determinant of success. As the number of goals scored in soccer is relatively low, research has often focused on alternative measures to assess performance of individuals and teams. Established Offensive play presented the highest frequency in goal scoring opportunities (44%), followed by set pieces (35.6%) and counterattacks (20.3%) (Yiannakos & Aramats, 2004). Conversely, a primary aim of Established Defense is to prevent goals from being scored. Predominantly, the literature has focused on success, or otherwise, from the attacking team's perspective (Bradley et al., 2011; Castellano et al., 2012; Lago, 2007, 2009; Lago-Ballesteros & Lago-Penas, 2010; Lago-Penas et al., 2010; Tenga & Sigmundstad, 2011). The research and metrics described below aim to outline important factors that may influence game style in both Established Offence and Established Defense.

3.1.1 Possession

One of the most popular technical indicators of game style is ball possession. Some studies indicate a positive correlation between retaining possession and success. However this relationship is highly complex with passing efficiency, quality of opposition and match location just some of the factors that may impact ball possession, team dominance and successful performances (Collet, 2013; Lago-Ballesteros, Lago-Peñas, & Rey, 2012).

Analysis of possession indicators in domestic leagues in England, France, Germany, Italy and Spain as well as European competitions (UEFA Champions League and Europa League) and FIFA World Cups showed significant relationships between passing, shooting and overall team success, however efficiency was also an important contributor. Efficiency measures included passing accuracy, shooting accuracy and passes-to-shots on goal ratios, and these were found to be stronger predictors of match outcome than possession time (Chassy, 2013). Obviously, when teams with high possession strategies meet in competition game styles may change because both can't retain high possession.

Teams with high possession rates may have a different game style to teams with consistently lower rates of possession, particularly given the strategies that support high possession. For example, a 'maintain possession' strategy may involve more slow play with defensive movements, less risk when passing, and greater emphasis on re-gaining possession relative to teams who might place less importance on this strategy (Gréhaigne et al., 2002; Jones, James, & Mellalieu, 2004; Wright, Atkins, Polman, Jones, & Sargeson, 2011). Some teams may exhibit differing patterns of ball possession in different parts of the field and this can also be influenced by the score line (Ridgewell, 2011). Lower possession rates in attacking zones by the leading team relative to the opposition signifies less urgency for offensive ball movement and a more conservative play style. For example, a study of corner kicks from the 2006 World Cup showed winning teams used more short corners and directed the kick away from the centre of the goal area to strategically prevent counter-attack opportunities and maintain possession (De Baranda & Lopez-Riquelme, 2012).

3.1.2 Passing

An underlying principle of self-organising systems is the structure of the group is founded on rapid, local interactions (Chassy, 2013). During Established Offense the ability of the team to move as a group is critically dependent on the passing abilities of the individuals. Possession of the ball almost always involves the ball being passed from one player to the next until it ends with a player best positioned to attempt a goal action. Although this appears a simplistic concept it ultimately involves a complex level of interaction among individuals. This is influenced by the ability to pass the ball accurately and with speed, positioning of teammates who must anticipate movement patterns, and the opposition's defensive structures. Chassy (2013) suggests two metrics that may influence a team's performance related to Established Offense. The first relates to the ability of a team to keep the ball while changing the spatial configuration to continue to look for weaknesses in the oppositions Established Defense. Players must be able to pass with precision while others create space around themselves to receive the pass from their teammate. Constantly changing the spatial configuration may limit the defense's ability to regain possession and this relies on the concentration and decision-making capacity of the players, and their fitness levels to carry out this strategy. A related factor is the ability of the team to not only pass accurately but frequently. Two principle and quantifiable features identified in relation to passing patterns were Pass density (number of passes per minute of possession), and Pass precision (number of completed passes relative to total passes)(Chassy, 2013).

There is little doubt pass accuracy is important in football success. For example, pass accuracy is higher in the period before scoring (Redwood-Brown, 2008), assists in retaining possession and progressing forward, leads to scoring opportunities, and restricts opposition possession and scoring opportunities (Redwood-Brown, 2008).

Introducing a novel method of analysis passing networks or 'flow motifs', Gyarmati, Kwak, and Rodriguez (2014) were able to distinguish a unique playing style of FC Barcelona compared to teams playing in five domestic leagues in Europe (Spanish, Italian, English, French and German first division). They were able to demonstrate passing chains focusing on the structure of the passing sequences and showed the FC Barcelona game style did not consist of random passes but rather had precise, finely constructed and repeatable interactions among players.

3.1.3 Measuring Player and Team Patterns

Successful attacking strategies involve tactics to create moments of low player density close to goal, whilst in defense creating higher density or congestion to increase pressure on players in possession (Wallace & Norton, 2014). Increasing player density during World Cup finals over almost 50 years of review was a characteristic evolutionary trend found at the highest level of soccer (Wallace & Norton, 2014). This long-term pattern suggests defensive strategies may be a game style priority rather than all-out attacking which might drive player density lower. Notwithstanding, creating moments of low player density whilst in possession or during attacking transition is supported by J. Oliveira (2004) who identified that during Established Offense major aims were to create offensive space and areas of numerical advantage. Creating space requires player speed and skill in anticipating ball movements. Lower density around offensive players increases the probability of scoring which doubles for every metre of free space around the kicker shooting for goal (Pollard et al., 2004). Conversely, defenders try to increase player density around the attacker which involves matching offensive players for speed and early anticipatory movements as well as forcing quick ball disposal and associated skill errors (Vilar, Araújo, Davids, & Button, 2012).

Adopting this game style demands high fitness, facilitating fast movement periods, accelerated recovery and repeat efforts. Advancements and availability of player tracking technologies allow physical performance variables, such as player distances and velocities to be routinely analysed (Carling et al., 2008; Castellano et al., 2012;

Cummins et al., 2013). They also provide information on the position of players at any instant in time aiding analysis of strategies, tactics and patterns of play (Frencken et al., 2012; Frencken & Lemmink, 2008; Frencken et al., 2011). Frencken and Lemmink (2008) proposed two variables that characterise the flow between the attacking and defending teams in small-sided soccer games: (1) the centroid position, and (2) the surface area of each team. The Centroid is described as the average position of the on-field players of a team and the surface area is the space covered by those players.

Wade (1996) characterises attacking teams moving towards goals to incite penetration, often with width and depth. As this takes place their centroid moves forward and can be tracked for both position and rate of change in position. Conversely, the defending team aims to delay the opposition while concentrating its own players close to the defensive goal. Therefore, its centroid position will move backwards (Frencken et al., 2011). As the attacking phase takes place the surface area will often increase as the offensive team looks to create more space while the defending team's surface area will decrease (Moura et al., 2013).

3.2 Transitions

Transition periods in field sports present both exciting opportunities and nervous vulnerabilities (Turner & Sayers, 2010). Offensive speed and outnumbering opposition defenses are key objectives for attacking success while the defensive team must rapidly re-organise because poor or slow coordination are related to conceding goals (Frencken et al., 2012; Tenga et al., 2010). Teams with a speed advantage will look to exploit this dominance and will subsequently develop a game style based on explosive speed. It is a pattern of play that becomes the hallmark of specific teams or players.

Losing a neutral ball or following a turnover there are various strategies than a team can take to defend. Vogelbein, Nopp, and Hokelmann (2014) analysed games in the German Bundesliga to demonstrate top teams recovered the ball quickest after losing it in comparison to lower ranked teams. The current score also influenced the defensive reaction time. Other research has shown the attacking side recovering ball possession as close to goal as possible to increase goal scoring opportunities

(Garganta et al., 1997; Larson, 2001). Ball recoveries closer to the attacking goal produced seven times more goals compared to ball recoveries in the defensive zones, although less than 2% of ball recoveries are achieved in attacking zones (Vogelbein et al., 2014). This aggressive form of defense is often promoted by coaches and, therefore, becomes characteristic of the team's game style.

3.3 Set-pieces

Previous research has identified that approximately one third of goals at the elite level are scored either directly or indirectly from set plays (Ensum et al., 2000; Grant, Reilly, Williams, & Borrie, 1998; Grant & Williams, 1998; Wright et al., 2011; Yiannakos & Aramats, 2004; Yiannakos & Armatas, 2006). Recent evolution shows an increase in set play efficiency (defined as more goals scored from fewer set plays) in men's domestic and international soccer, and successful teams are more efficient at scoring from set plays (Alcock, 2010; Grant & Williams, 1998). Preparation and planning of set plays from both offensive and defensive positions are important as well as having set play specialists. In many field sports, probability maps for goal scoring success versus distance and angle combinations are generated and determine the selection of play patterns (Alcock, 2010; Pollard et al., 2004; Tenga et al., 2010). For example, free kicks are the most effective set piece, especially from angles square to the goal face in all field sports (Carling et al., 2005) and closer to goal.

4. Conclusions and Applications

In this article we have attempted to provide a framework of meaningful metrics that will allow strategies, tactics and game styles to be objectively assessed.

Structured and detailed metrics facilitate assessment of evolutionary changes in the game including the impact of rule changes or using specific strategies or playing systems. Questions concerning how game styles change with new coaches or key players can also be quantified in a more consistent way.

The identification and understanding of the playing style or patterns of play of teams may have other practical implications, for example, when recruiting players who are capable of playing according to the style of the team (Gyarmati et al., 2014).

Furthermore, quantification of game styles will allow more detailed analysis into the types of training methodologies and evaluation of training compared to strategies and tactics in the competition environment. Further research is necessary to test the proposed framework and the practical implications.

Finally, we propose the following definition: *"Game style is the characteristic playing pattern demonstrated by a team during games. It will be regularly repeated in specific situational contexts such that measurement of variables reflecting game style will be relatively stable. Variables of importance are player and ball movements, interaction of players, and will generally involve elements of speed, time and space (location)"*. This definition will allow coaches, sports scientists, media and spectators a clearer understanding what is meant by the term game style.

Acknowledgements
The authors have no potential conflict of interest and no funding was obtained for the preparation of this article.

References

Alcock, A. (2010). Analysis of direct free kicks in the women's football World Cup 2007. *European Journal of Sport Science* 10, 279-284.

Armatas, V., A. Yiannakos and P. Sileloglou (2007). Relationship between time and goal scoring in soccer games: Analysis of three World Cups. *International Journal of Performance Analysis in Sport* 7, 48-58.

Bangsbo, J. (1998). The physiological profile of soccer players. *Sports Exercise and Injury* 4, 144-150.

Barnes, C., D. Archer, B. Hogg, M. Bush and P. Bradley (2014). The Evolution of Physical and Technical Performance Parameters in the English Premier League. *International Journal of Sports Medicine*.

Bloomfield, J., R. Polman, R. Butterly and P. O'donoghue (2005). Analysis of age, stature, body mass, BMI and quality of elite soccer players from 4 European Leagues. *The Journal of Sports Medicine and Physical Fitness* 45, 58-67.

Bloomfield, J., R. Polman and P. O'Donoghue (2005). Effects of score-line on team strategies in FA Premier League Soccer. *Journal of Sports Sciences* 23, 192-193.

Bradley, P., C. Carling, D. Archer, J. Roberts, A. Dodds, M. Di Mascio, D. Paul, A. G. Diaz, D. Peart and P. Krustrup (2011). The effect of playing formation on high-intensity running and technical profiles in English FA Premier League soccer matches. *Journal of Sports Sciences* 29, 821-830.

Bradley, P. S., C. Carling, A. Gomez Diaz, P. Hood, C. Barnes, J. Ade, M. Boddy, P. Krustrup and M. Mohr (2013). Match performance and physical capacity of players in the top three competitive standards of English professional soccer. *Human Movement Science* 32, 808-821.

Bradley, P. S., C. Lago-Penas, E. Rey and A. Gomez Diaz (2013). The effect of high and low percentage ball possession on physical and technical profiles in English FA Premier League soccer matches. *Journal of Sports Sciences* 31, 1261-1270.

Bradley, P. S. and T. D. Noakes (2013). Match running performance fluctuations in elite soccer: indicative of fatigue, pacing or situational influences? *Journal of Sports Sciences* 31, 1627-1638.

Brustad, R. and M. RitterTaylor (1997). Applying social psychological perspectives to the sport psychology consulting process. *Sport Psychologist* 11, 107-119.

Carling, C. (2011). Influence of opposition team formation on physical and skill-related performance in a professional soccer team. *European Journal of Sport Science* 11, 155-164.
Carling, C. (2013). Interpreting physical performance in professional soccer match-play: should we be more pragmatic in our approach? *Sports Medicine* 43, 655-663.
Carling, C., J. Bloomfield, L. Nelsen and T. Reilly (2008). The Role of Motion Analysis in Elite Soccer Contemporary Performance Measurement Techniques and Work Rate Data. *Sports Medicine* 38, 839-862.
Carling, C., A. M. Williams and T. Reilly (2005). *Handbook of soccer match analysis: A systematic approach to improving performance*, Psychology Press.
Castellano, J., D. Casamichana and C. Lago (2012). The Use of Match Statistics that Discriminate Between Successful and Unsuccessful Soccer Teams. *Journal of Human Kinetics* 31, 139-147.
Chassy, P. (2013). Team Play in Football: How Science Supports FC Barcelona's Training Strategy. *Psychology* 4, 7.
Collet, C. (2013). The possession game? A comparative analysis of ball retention and team success in European and international football, 2007–2010. *Journal of Sports Sciences* 31, 123-136.
Cummins, C., R. Orr, H. O'Connor and C. West (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports Medicine* 43, 1025-1042.
De Baranda, P. S. and D. Lopez-Riquelme (2012). Analysis of corner kicks in relation to match status in the 2006 World Cup. *European Journal of Sport Science* 12, 121-129.
Delgado-Bordonau, J. and A. Mendez-Villanueva (2012). Tactical periodization: Mourinho's best-kept secret. *Soccer NSCAA Journal* 3, 28-34.
Dellal, A., K. Chamari, D. P. Wong, S. Ahmaidi, D. Keller, R. Barros, G. N. Bisciotti and C. Carling (2011). Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. *European Journal of Sport Science* 11, 51-59.
Di Salvo, V., R. Baron, C. González-Haro, C. Gormasz, F. Pigozzi and N. Bachl (2010). Sprinting analysis of elite soccer players during European Champions League and UEFA Cup matches. *Journal of Sports Sciences* 28, 1489-1494.

Di Salvo, V., A. Collins, B. McNeill and M. Cardinale (2006). Validation of Prozone®: A new video-based performance analysis system. *International Journal of Performance Analysis in Sport* 6, 108-119.
Drust, B. (2010). Performance analysis research: meeting the challenge. *Journal of Sports Science* 28, 921-922.
Ekblom, B. (1986). Applied physiology of soccer. *Sports Medicine* 3, 50-60.
Ensum, J., A. M. Williams and A. Grant (2000). Analysis of attacking set plays in Euro 2000. *Insight* 4, 36-39.
ESPN. (2014). "Martino says Argentina won't change." ESPN FC Retrieved 01/11/14, 2014, from http://www.espnfc.com/argentina/story/1985990/gerardo-martino-vows-to-make-minimal-changes-at-argentina.
Frencken, W., H. De Poel, C. Visscher and K. Lemmink (2012). Variability of inter-team distances associated with match events in elite-standard soccer. *Journal of Sports Sciences* 30, 1207-1213.
Frencken, W. and K. Lemmink (2008). Team kinematics of small-sided soccer games: A systematic approach. *Science and Soccer VI*, 161-166.
Frencken, W., K. Lemmink, N. Delleman and C. Visscher (2011). Oscillations of centroid position and surface area of soccer teams in small-sided games. *European Journal of Sport Science* 11, 215-223.
Garganta, J., J. Maia, F. Basto, T. Reilly, J. Bangsbo and M. Hughes (1997). Analysis of goal-scoring patterns in European top level soccer teams. *Science and football III*, 246-250.
Gore, C., P. McSharry, A. Hewitt and P. Saunders (2008). Preparation for football competition at moderate to high altitude. *Scandinavian Journal of Medicine & Science in Sports* 18, 85-95.
Grant, A., T. Reilly, A. M. Williams and P. Borrie (1998). Analysis of the goals scored in the 1998 World Cup. *Insight* 1, 18-20.
Grant, A. and A. M. Williams (1998). Analysis of corner kicks. *Insight* 1, 25-26.
Grehaigne, J., D. Marchal and E. Duprat (2002). Regaining possession of the ball in the defensive area in soccer. *Science and Football IV*, 112.
Grehaigne, J.-F., D. Bouthier and B. David (1997). Dynamic-system analysis of opponent relationships in collective actions in soccer. *Journal of Sports Sciences* 15, 137-149.

Gréhaigne, J.-F. and P. Godbout (1995). Tactical knowledge in team sports from a constructivist and cognitivist perspective. *Quest* 47, 490-505.
Grehaigne, J.-F., P. Godbout and D. Bouthier (1997). Performance assessment in team sports. *Journal of Teaching in Physical Education* 16, 500-516.
Gyarmati, L., H. Kwak and P. Rodriguez (2014). Searching for a Unique Style in Soccer. 2014 KDD Workshop on Large-Scale Sports Analytics, New York City.
Hewitt, A., K. Norton and K. Lyons (2014). Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking. *Journal of Sports Sciences*, 1-7.
Horne, B. (2014). "Western Sydney accuse Al-Hilal coach of lacking respect in the ACL final." Illawarra Mercury Retrieved 1/11/14, 2014, from http://www.illawarramercury.com.au/story/2650890/wanderers-vow-to-make-acl-rivals-pay/?cs=302.
Jones, P., N. James and S. D. Mellalieu (2004). Possession as a performance indicator in soccer. *International Journal of Performance Analysis in Sport* 4, 98-102.
Junge, A. and J. Dvorak (2004). Soccer injuries. *Sports Medicine* 34, 929-938.
Lago, C. (2007). Are winners different from losers? Performance and chance in the FIFA World Cup Germany 2006. *International Journal of Performance Analysis in Sport* 7, 36-47.
Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *Journal of Sports Sciences* 27, 1463.
Lago, C., L. Casais, E. Dominguez and J. Sampaio (2010). The effects of situational variables on distance covered at various speeds in elite soccer. *European Journal of Sport Science* 10, 103-109.
Lago, C. and R. Martín (2007). Determinants of possession of the ball in soccer. *Journal of Sports Sciences* 25, 969-974.
Lago-Ballesteros, J. and C. Lago-Penas (2010). Performance in team sports: Identifying the keys to success in soccer. *Journal of Human Kinetics* 25, 85-91.
Lago-Ballesteros, J., C. Lago-Peñas and E. Rey (2012). The effect of playing tactics and situational variables on achieving score-box possessions in a professional soccer team. *Journal of Sports Sciences* 30, 1455-1461.

Lago-Penas, C. and A. Dellal (2010). Ball possession strategies in elite soccer according to the evolution of the match-score: the influence of situational variables. *Journal of Human Kinetics* 25, 93-100.
Lago-Penas, C., J. Lago-Ballesteros, A. Dellal and M. Gomez (2010). Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. *Journal of Science and Medicine in Sport* 9, 288-293.
Laird, P. and L. Waters (2008). Eyewitness recollection of sport coaches. *International Journal of Performance Analysis in Sport* 8, 76-84.
Larson, O. (2001). Charles Reep: A major influence on British and Norwegian football. *Soccer and Society* 2, 58-78.
Lees, A., T. Asai, T. B. Andersen, H. Nunome and T. Sterzing (2010). The biomechanics of kicking in soccer: A review. *Journal of Sports Sciences* 28, 805-817.
Lees, A. and L. Nolan (1998). The biomechanics of soccer: a review. *Journal of Sports Sciences* 16, 211-234.
Mackenzie, R. and C. Cushion (2013). Performance analysis in football: a critical review and implications for future research. *Journal of Sports Sciences* 31, 639-676.
Moura, F. A., L. E. B. Martins, R. O. Anido, P. R. C. Ruffino, R. M. Barros and S. A. Cunha (2013). A spectral analysis of team dynamics and tactics in Brazilian football. *Journal of Sports Sciences* 31, 1568-1577.
Oliveira, J. G. (2004). Conhecimento específico em futebol : contributos para a definição de uma matriz dinâmica do processo ensino aprendizagem-treino do jogo (Specific knowledge in football : contributions to the definition of a dynamic array of the teaching -learning training game). Masters, Universidade do Porto.
Piltz, W. and A. Launder (2013). *Play practice*. Champaign, IL :, Human Kinetics.
Pollard, R. (1986). Home advantage in soccer: A retrospective analysis. *Journal of Sports Sciences* 4, 237-248.
Pollard, R., J. Ensum and S. Taylor (2004). Estimating the probability of a shot resulting in a goal: The effects of distance, angle and space. *International Journal of Soccer and Science* 2, 50-55.
Redwood-Brown, A. and F. A. (2008). Passing patterns before and after goal scoring in League Soccer. *International Journal of Performance Analysis in Sport* 8, 172-182.
Reilly, T. and D. Gilbourne (2003). Science and football: a review of applied research in the football codes. *Journal of Sports Sciences* 21, 693-705.

Ridgewell, A. (2011). Passing patterns before and after scoring in the 2010 FIFA World Cup. *International Journal of Performance Analysis in Sport* 11, 562-574.
Shephard, R. J. (1999). Biology and medicine of soccer: an update. *Journal of Sports Sciences* 17, 757-786.
Stølen, T., K. Chamari, C. Castagna and U. Wisløff (2005). Physiology of soccer. *Sports Medicine* 35, 501-536.
Tedesqui, R. A. and B. A. Glynn (2013). "Focus on What?": Applying Research Findings on Attentional Focus for Elite-Level Soccer Coaching. *Journal of Sport Psychology in Action* 4, 122-132.
Tenga, A., I. Holme, L. T. Ronglan and R. Bahr (2010). Effect of playing tactics on goal scoring in Norwegian professional soccer. *Journal of Sports Sciences* 28, 237-244.
Tenga, A. and E. Sigmundstad (2011). Characteristics of goal-scoring possessions in open play: Comparing the top, in-between and bottom teams from professional soccer league. *International Journal of Performance Analysis in Sport* 11, 545-552.
Turner, B. and M. Sayers (2010). The influence of transition speed on event outcomes in a high performance football team. *International Journal of Performance Analysis in Sport* 10, 207-220.
Vilar, L., D. Araujo, K. Davids and C. Button (2012). The Role of Ecological Dynamics in Analysing Performance in Team Sports. *Sports Medicine* 42, 1-10.
Vilar, L., D. Araújo, K. Davids and C. Button (2012). The role of ecological dynamics in analysing performance in team sports. *Sports Medicine* 42, 1-10.
Vogelbein, M., S. Nopp and A. Hokelmann (2014). Defensive transition in soccer - are prompt possession regains a measure of success? A quantitative analysis of German Fussball-Bundesliga 2010/2011. *Journal of Sports Sciences* 32, 1076-1083.
Wade, A. (1996). *Principles of Team Play*, Reedswain Inc.
Wallace, J. L. and K. I. Norton (2014). Evolution of World Cup soccer final games 1966-2010: game structure, speed and play patterns. *Journal of Science and Medicine in Sport* 17, 223-228.
Williams, A. M. and K. A. Ericsson (2005). Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach. *Human Movement Science* 24, 283-307.
Wright, C., S. Atkins, R. Polman, B. Jones and L. Sargeson (2011). Factors associated with goals and goal scoring opportunities in professional soccer. *International Journal of Performance Analysis in Sport* 11, 438-449.

Yiannakos, A. and V. Aramats (2004). Evaluation of the goal scoring patterns in European Championship in Portugal. *International Journal of Performance Analysis in Sport* 6, 178-188.
Yiannakos, A. and V. Armatas (2006). Evaluation of the goal scoring patterns in European Championship in Portugal. *International Journal of Performance Analysis in Sport* 6, 178-188.

Chapter 7- Discussion and Conclusions

7.1 Summary of findings

The information presented in this thesis provides an insight into performance analysis in soccer and how player-tracking technology can be applied in a variety of contexts. The first study provided a detailed comparison of four different match analysis systems that are widely used in both research and applied settings in the evaluation of movement profiles during soccer games and trainings. Acknowledging that there are differences between the match analysis systems and that caution must be used if trying to compare information between systems, the second and third studies applied the use of player tracking technology to expand the knowledge base of movement demands in women's soccer. Furthermore, these studies demonstrated how contextual information can be used to elaborate on information gathered. More specifically, the third study examined the influence that the opposition's ranking had on the physical demands of Australian women soccer players. The final study sought to bring together themes from *Studies 1-3* through a concept that was discussed in some form in each study; specifically, the influence that game style has on performance measures in soccer. In this section the major findings from these studies will be discussed in reference to the related literature and research that has been published following the completion of this work.

7.1.2 Comparison on match analysis methods

With a range of match analysis techniques being used throughout the literature in both men's and women's soccer, it was important to determine how GPS compared to the other methods of analysis. Prior to this thesis, researchers and practitioners had investigated the validity and reliability of the individual methods of analysis such as: time-motion video-based analysis (Bangsbo et al., 1991; Mohr et al., 2003), GPS at both 1 Hz and 5 Hz (Coutts & Duffield, 2010; Edgecomb & Norton, 2006; Jennings et al., 2010; Waldron, Worsfold, Twist, & Lamb, 2011) and semi-automated multiple camera based systems (Di Salvo et al., 2006), however no study had been conducted using all four methods during the game of soccer. The main finding was that there were discrepancies between the different methods, therefore caution should be used if trying to compare results from different systems, and different motion analysis systems should not be used interchangeably. In the applied sport setting, such as a professional soccer club in the English Premier League, the interchange of data from different systems is inevitable as some clubs use GPS based player tracking technology in the training environment and automated camera based systems such as ProZone for matches. The mixed used of motion analysis systems is problematic, as can be seen by the results of *Study One*, however there is no single motion analysis system currently used in both the training and competition environments in elite professional soccer clubs.

A limitation of *Study One*, and that of nearly all of the validation studies involving match analysis methods and technology, is the lack of a true criterion measure. Researchers have attempted to validate components of player tracking in the simplest form, by measuring linear distance for example, which may have good criterion methods, such as calibrated measuring wheel or tape measure to determine linear distances covered. However, by attempting to validate these isolated components, and as such making the movements less game and sport specific, has resulted in poor ecological validity. To increase this and make the movements more game like there is a lack of criterion methods to compare to. A further limitation of *Study One* was the stadium that the game was carried out in. As was previously discussed, GPS technology relies on a low HDOP resulting from a spread of satellites along the horizon with additional satellites overhead. With some stadia, a high HDOP is more likely as there is a limited view of the sky due to a narrow opening above the playing surface.

There have been two recent studies comparing match analysis technologies, observing similar findings to *Study One* and concluded caution should be exercised when using different technologies interchangeably (Buchheit et al., 2014; Harley, Lovell, Barnes, Portas, & Weston, 2011). However, in comparing a semi-automatic multiple-camera based system, two GPS systems and a local positioning measurement technology, Buchheit et al. (2014) was able to elicit calibration equations that may allow sport scientists to interchange data from different tracking systems.

7.1.3 Movement Profiles in Women's Soccer

Although there is an increase in the research of movement profiles in women's soccer, there is still a disproportionate gap in the literature with the number of studies reporting the match performance characteristics of male players, far outweighing the number of studies on female players. Both *Study Two* and *Study Three* add to the body of knowledge regarding the physical demands of elite level women soccer players.

The results of *Study Two* report data derived from GPS based player-tracking devices in women's soccer. Previous physical performance analysis results had utilised video-based time motion analysis (Andersson et al., 2008; Andersson, Randers, et al., 2010; Gabbett & Mulvey, 2008; Krustrup et al., 2005; Mohr et al., 2008b). *Study Two* was able to use the application of a novel player tracking system and reported physical performance data including total distances covered 9 140±1 030 m, distances covered at high intensity running (>16 $km \cdot h^{-1}$) 900±190 m and distances covered sprinting 280±80m. Although not a primary aim of this research, the results of *Study Two* also include the individual game results, main playing formations used by each team during the game and the total distance covered, as can be seen in see Table 4-2. The findings of *Study Two* indicated that the distances covered by the Australian women's soccer players may have been less than the total distances reported in the literature by Krustrup et al. (2005), however these differences may be due to differences in playing style, match analysis systems or the physical capacity of the players.

Study Three provided further insight to the physical demands of women's soccer and provided new understanding into the effect the strength of the opposition has on the physical demands. A significant application of this research is the influence opposition rank on the physical demands of the players. Overall the players from the Australian women's soccer team had to perform more running at higher intensities and less at low intensities when playing opposition of a similar ranking compared to playing teams ranked higher or lower. This information can be used by coaches, sport scientists and other practitioners in the preparation of players training plans,

individualised player management strategies, team selection and even in developing strategy and tactics for upcoming opponents.
The literature surrounding match analysis in the men's game has increased with the growth and availability of technological advancements concerning player tracking. This evolution has seen motion and match analysis evolve from the early research of Reilly and Thomas (1976) using hand notation analysis, to Withers et al. (1982), (Bangsbo & Mohr, 2005; Bangsbo et al., 2006) and the early work with video-based time motion analysis and then the introduction of miniaturisation of GPS units (Coutts & Duffield, 2010; Edgecomb & Norton, 2006; Jennings et al., 2010) in parallel with semi-automatic multiple camera based systems (Bradley et al., 2011; Bradley, Carling, et al., 2013; Buchheit et al., 2014; Carling, 2010; Di Salvo et al., 2010; Gregson et al., 2010). Further advancements in player tracking technology have seen the emergence of local positioning measurement systems, which may provide greater accuracy and even the ability to track players indoors (Buchheit et al., 2014; Frencken, Lemmink, & Delleman, 2010). However, this evolutionary process has not been followed in the women's game. One of the limitations for further research in the physical demands in games for women's soccer is access to technology such as semi-automatic multiple camera based systems, due to costs and stadia requirements for cameras to be installed.

A limitation of the work presented in *Study Two* and *Study Three* was the limited access to GPS units, which resulted in not all players being tracked in all games. Although not every player was tracked in every game, the sample size for *Study Three* was, until the recent work of Bradley et al. (2014), one of the largest cohorts of match analysis data available with fifty eight game files being used to provide detailed player and position specific averages to increase the knowledge in the game demands of elite women's soccer. Recently Bradley et al. (2014) reported a study comparing 59 female and 54 male soccer players during UEFA Champions League matches using semi-automatic multiple camera-based analysis. The research highlighted that male players covered more total distance, distance at higher speed thresholds (calculated as >15 km·h^{-1}) and greater distance covered during the most intense 5 min period of the match (>15 km·h^{-1}). Further comparisons to the findings of *Study Two* and *Three* is difficult due to the differences in match analysis systems as outlined in *Study One*. Bradley et al. (2014) also do not report absolute total distances for the match, with the analysis focusing on the gender differences.

7.1.4 Applying Contextual Information in Match Analysis

As outlined in *Studies One* through *Three*, the physiological demands of soccer have been studied intensively using a range of methodologies in both men's and women's soccer. However, it was identified in *Study Two* and *Study Three* that other factors may influence the physiological output of players during games. Situational variables such as match location (i.e. such as playing at home or away), match status (i.e. whether the team is winning, losing or drawing), quality of the opposition (strong or weak) and the style of play (of each team) all may influence the physical demands of the game (Lago et al., 2010b; Lago-Ballesteros et al., 2012; Lago-Penas & Dellal, 2010; Pratas, Volossovitch, & Ferreira, 2012).

Study Three aimed to investigate one of the situational variables mentioned above, the quality of the opposition and its effects on movement demands in elite women's soccer. Previous literature shows that the application of situational variables and movement demands in elite women's soccer has not been investigated. As such *Study Three* provides a novel application of movement analysis in women's soccer. A limitation of *Study Three*, as previously identified, was the inability to collect data on every player in every game. Although every attempt was made to ensure a balanced spread of positions in each game, there were data that was not able to be included in the final analysis due to substitutions of players or in some cases technological faults resulting in missing data. A further limitation is that only data from one team was able to be collected. As previously indicated, the dynamic nature of invasion based team sports suggests that the opposition's movement on an individual, sub-unit and team level directly influences the movement demands of each player within a team. Having the match analysis data from both teams may help provide a greater depth of understanding regarding the influence the strength of opposition has on the movement demands of elite women's soccer players.

7.1.5 Playing style

The concluding remarks in each of the previous studies of this thesis identify that game or playing style of either the team in question or the opposition may have a significant impact on the physiological demands of the game. This has further been identified in the literature and is a common finding in the concluding comments of research surrounding match analysis and the factors that may influence performance. *Study Four* is the first paper of its kind to attempt to identify what game style (playing style) is and how it may be quantified.

Coaches, media, spectators and sport scientists classify games as exhibiting specific patterns or visual characteristics that allow the categorisation of game styles. Each of these groups use personal and professional experience and knowledge of the game to create opinions on a team's game style. The irony is in the inconsistencies of what people use to frame their understanding of game style. In this article we have attempted to provide a framework of meaningful metrics that will allow strategies, tactics and game styles to be objectively assessed. Modern technologies are available to allow routine measurement at the highest levels.

The aim of *Study Four* was not to look for causation nor to define the most "successful" styles of play but to introduce concepts and a framework that can evolve to quantify playing style. A secondary aim of *Study Four* was that the concepts presented could be applied not only for soccer at the elite level, but the categories and metrics can be applied to a large range of competition standards and across a number of invasion based field sports. Figure 7-1 below demonstrates that regardless of the sources of data available, it can all be categorised into the five key moments of play. This data may be derived during competition or training environments. Once the data has been categorised into the moments of play it can be analysed for differences between teams, or for the same team over time. This information can be further utilised to examine the individual moments (i.e. within Established Offense were there trends for a team to play a more possession based play or more direct based on the metrics collected). The applications of quantifying playing style include being able to objectively analyse an opposition's style of play, rather than relying on a coach's intuition or opinion on how a team may play, being able to categorise and quantify aspects of game style may lead to a greater understanding of how a team plays. Similarly, the ability to objectively quantify playing style will allow coaches new evaluation tools to monitor a team's style of play from week to week and over periods of time. In-depth knowledge of the game style of a team will provide coaches with a greater understanding of the individual requirements of players to execute the style. This will also enhance the ability to recruit players that meet the needs of the team. Administrators at clubs and organisations will be able to track and assess the evolution and changes to playing styles. For instance, does a change in coach change the style of play? Administrators may also be able to look at the effect of rule changes or the interpretation of rules has on aspects of playing style. Finally, the style of play in competition is the result of the training completed on and off the field. Having a greater understanding and being able to quantify the playing style could lead to improved training methods. The integration of game based drills through the manipulation of field dimensions and playing numbers has been shown to influence the physical and technical components of players in training (Dellal, Chamari, Owen, et al., 2011; Dellal, Hill-Haas, Lago-Penas, & Chamari, 2011; Hill-Haas, Coutts, Dawson, & Rowsell, 2010; Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011). Being able to quantify playing style will allow coaches to manipulate drills to elicit specific aspects of the game style.

Structured and detailed metrics facilitate the assessment of evolutionary changes in the game including the impact of rule changes or using specific strategies or playing systems. Furthermore, the identification and understanding of the playing style or patterns of play of teams may have other practical implications, for example, when recruiting players who are capable of playing according to the style of the team (Gyarmati et al., 2014).

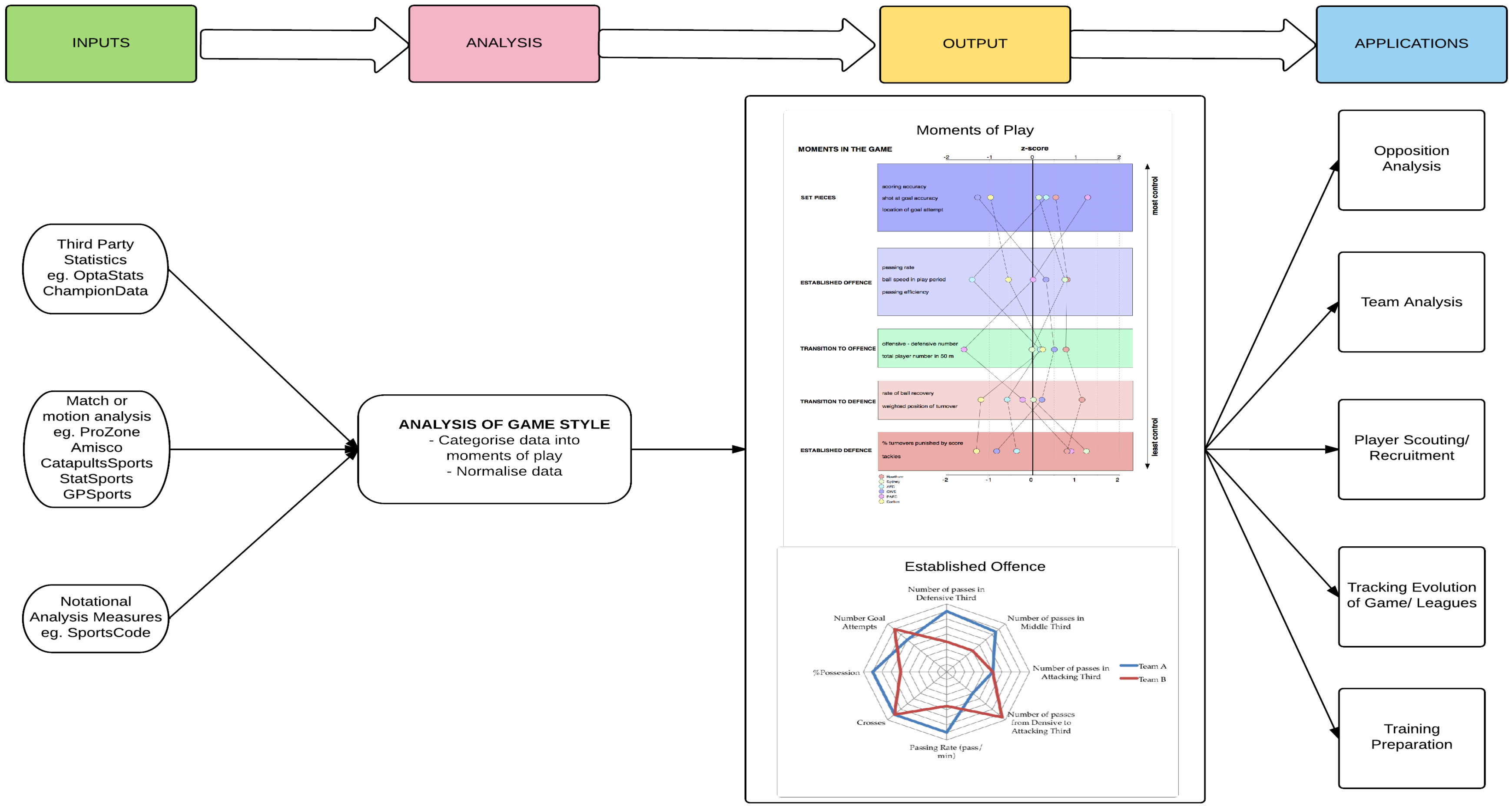


Figure 7-1- Analysis and application of analysis of game style

The process of quantifying game style is outlined in Figure 7-1. One of the aims of the model is to allow any data source available to be used in the quantification of game style. Professional clubs such as English Premier League teams may have considerable more access to match and motion analysis data than a semi-professional club. However, once the data is collected it able to be categorised in to one of the 5 moments of play. The analysis of the moments of play in the example outlined in Figure 7-1 uses a z-score analysis to normalize the data against a pre-determined mean to make comparison of each of the moments of play easier. This analysis will allow coaches, support staff etc. to compare a team's performance to other teams against the mean of the teams analysed. For example, this may be other teams in a competition, comparing one team against themselves over a number of games, benchmarking against another team or within a holistic club example to benchmark the 'first' team against 'reserves' and youth teams to compare game style within a club structure. Within a moment of play, for example Established Offence, further comparisons of metrics can be made in the form of radial graphs or similar data visualisations to evaluate game style.

Further research is required in the development of metrics that are sensitive to the subtle differences that may be required to identify unique patterns of play that make up game style. A limitation of Study Four is that we were not able to identify if a specific metric in our group of metrics is more influential in the quantification of game style. Game style is often discussed as an overarching philosophy of strategy and tactics. However, during the ebb and flow of a game there may be periods where certain elements of game style change, for better or worse. The ability to quantify these peaks and troughs throughout a game may provide greater tactical information to coaches to provide greater probability of success.

7.2 Practical Applications

The practical applications of this thesis are:

1. Each of the four player tracking methods used in *Study One* (GPS 5 Hz, GPS 1 Hz, video-based time-motion analysis and semi-automated computer based tracking) were able to quantify movement demands and changes in the demands over the course of a soccer match.
2. Practitioners should use caution when comparing different methods of match analysis techniques.
3. Australian international women soccer players cover approximately 9 631 ± 175m of which 338 ± 30 m is at velocities considered sprinting (>19 $km\cdot h^{-1}$). Furthermore, differences in the physical demands of the game were highlighted based on the positions of players categorised as Defenders, Midfielders or Attackers. Coaches, sports scientists and practitioners can use this information in the planning and preparation of training and the identification of players for different positions. The physical demands of soccer are part of a complex and dynamic system including technical and tactical abilities, these findings add to the requirements of the physical aspect of elite women's soccer.
4. Although descriptive data provides coaches and practitioners with a base level of knowledge that can be used in player preparation it is imperative that contextual information is integrated with the analysis.
5. The level of opposition is an important consideration in the player management of training loads. The impact of playing against different levels of opposition was previously not quantified. Coaches may have assumed that playing against a lower ranked opponent was easier less physically demanding game, however *Study Three* demonstrates this was not necessarily the case. Study 3 illustrated the physical demands for games against opponents ranked lower, higher or of similar ranking (see Figure 5-2). These findings can be used to further refine player management strategies, especially in tournament-based games (i.e. World Cup or Olympic Games).

6. The quantification of game style will enable players, coaches and sport scientists to gain a unique insight in to opposition analysis, and ensuring training drills mimic game demands: tactically, physically, technically and psychologically.
7. The quantification of game style will also lead to coaches having an objective understanding of position specific requirements from a physical, tactical and technical view point. This will also help to guide team selections and opposition tactics.
8. The introduction of definition of game style will aid key stakeholders, such as coaches, support staff and media, have a better understanding what is meant by the term game style and what factors may influence it.

7.3 Conclusion

Performance analysis in soccer is an integral part of the player-coach nexus. Player tracking technology such as GPS has been shown to provide information that can provide descriptive data to quantify movement patterns and physical load in training and competition environments. Although this information alone has been shown to provide substantial and useful information to coaches and sport scientists alike, an emerging area of research is to provide more contextual information. Success in team sports are multifactorial and should not necessarily be looked at as cause and effect. An overarching influence of movement demands, contextual information such as environmental conditions etc. is the influence of game or playing style. This concept is an exciting and novel area that will further complement sport science and coaching practices. A team's style of play is a culmination of the physical, technical and tactical components. Thus far, the description of game style has been based on subjective coaching philosophy with no framework to help quantify and track a team's style of play. The ability to define metrics that can be categorised into moments of play allows coaches and sport scientists to measure changes in playing style and improve coaching and training philosophies by quantifying and ensuring the physical, technical and tactical demands of competition are being replicated and enhanced in the training environment.

References

Alcock, A. (2010). Analysis of direct free kicks in the women's football World Cup 2007. *European Journal of Sport Science, 10*(4), 279-284.

Andersson, H., Karlsen, A., Blomhoff, R., Raastad, T., & Kadi, F. (2010). Active recovery training does not affect the antioxidant response to soccer games in elite female players. *British Journal of Nutrition, 104*(10), 1492-1499.

Andersson, H., Raastad, T., Nilsson, J., Paulsen, G., Garthe, I., & Kadi, F. (2008). Neuromuscular fatigue and recovery in elite female soccer: Effects of active recovery. *Medicine and Science in Sports and Exercise, 40*(2), 372-380.

Andersson, H., Randers, M., Heiner-Moller, Krustrup, P., & Mohr, M. (2010). Elite Female Soccer Players Perform More High-Intensity Running When Playing in International Games Compared with Domestic League Games. *Journal of Strength and Conditioning Research, 24*(4), 912-919.

Armatas, V., Yiannakos, A., & Sileloglou, P. (2007). Relationship between time and goal scoring in soccer games: Analysis of three World Cups. *International Journal of Performance Analysis in Sport, 7*(2), 48-58.

Atkinson, G., & Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine, 26*(4), 217-238.

Aughey, R. J., Hammond, K., Varley, M. C., Schmidt, W. F., Bourdon, P. C., Buchheit, M., Simpson, B., Garvican-Lewis, L. A., Kley, M., Soria, R., Sargent, C., Roach, R. D., Claros, J. C. J., Wachsmuth, N., & Gore, C, J. (2013). Soccer activity profile of altitude versus sea-level natives during acclimatisation to 3600 m (ISA3600). *British Journal of Sports Medicine, 47*(Suppl 1), i107-i113.

Bangsbo, J. (1998). The physiological profile of soccer players. *Sports Exercise and Injury, 4*(4), 144-150.

Bangsbo, J., Iaia, F. M., & Krustrup, P. (2007). Metabolic Response and Fatigue in Soccer. *International Journal of Sports Physiology and Performance, 2*(2), 111-127.

Bangsbo, J., Madsen, K., Kiens, B., & Richter, E. A. (1996). Effect of muscle acidity on muscle metabolism and fatigue during intense exercise in man. *The Journal of Physiology, 495*(Pt 2), 587-596.

Bangsbo, J., & Mohr, M. (2005). Variations In Running Speeds And Recovery Time After A Sprint During Top-class Soccer Matches. *Medicine and Science in Sports and Exercise, 37*, S87-S87.

Bangsbo, J., Mohr, M., & Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Sciences, 24*(7), 665-674.

Bangsbo, J., Norregaard, L., & Thorso, F. (1991). Activity Profile of Competition Soccer. *Canadian Journal of Sport Sciences-Revue Canadienne Des Sciences Du Sport, 16*(2), 110-116.

Bangsbo, J., & Peitersen, B. (2000). *Soccer systems & strategies*. Champaign, IL.: Human Kinetics.

Barnes, C., Archer, D., Hogg, B., Bush, M., & Bradley, P. (2014). The Evolution of Physical and Technical Performance Parameters in the English Premier League. *International Journal of Sports Medicine*(EFirst).

Baumgartner, T. A. (1989). Norm-referenced measurement: reliability. *Measurement concepts in physical education and exercise science, 20*, 45-47.

Bialkowski, A., Lucey, P., Carr, P., Yue, Y., Sridharan, S., & Matthews, I. (2014, December). Large-Scale Analysis of Soccer Matches using Spatiotemporal Tracking Data. In *Data Mining (ICDM), 2014 IEEE International Conference on* (pp. 725-730). IEEE.

Bloomfield, J., Polman, R., Butterly, R., & O'donoghue, P. (2005). Analysis of age, stature, body mass, BMI and quality of elite soccer players from 4 European Leagues. *The Journal of Sports Medicine and Physical Fitness, 45*(1), 58-67.

Bloomfield, J., Polman, R., & O' Donoghue, P. G. (2004). Analysis of quality of four major European soccer leagues. *Journal of Sports Sciences, 22*(6), 501-502.

Bloomfield, J., Polman, R., & O'Donoghue, P. (2005). Effects of score-line on team strategies in FA Premier League Soccer. *Journal of Sports Sciences, 23*(2), 192-193.

Bouthier, D., Gréhaigne, J.-F., & Godbout, P. (1999). The foundations of tactics and strategy in team sports. *Journal of Teaching in Physical Education, 18*, 159-174.

Bradley, P., Carling, C., Archer, D., Roberts, J., Dodds, A., Di Mascio, M., . . . Krustrup, P. (2011). The effect of playing formation on high-intensity running and technical profiles in English FA Premier League soccer matches. *Journal of Sports Sciences, 29*(8), 821-830.

Bradley, P., Carling, C., Gomez Diaz, A., Hood, P., Barnes, C., Ade, J., . . . Mohr, M. (2013). Match performance and physical capacity of players in the top three competitive standards of English professional soccer. *Human Movement Science, 32*(4), 808-821.

Bradley, P., Dellal, A., Mohr, M., Castellano, J., & Wilkie, A. (2014). Gender differences in match performance characteristics of soccer players competing in the UEFA Champions League. *Human Movement Science, 33*, 159-171.

Bradley, P., Lago-Penas, C., Rey, E., & Gomez Diaz, A. (2013). The effect of high and low percentage ball possession on physical and technical profiles in English FA Premier League soccer matches. *Journal of Sports Sciences, 31*(12), 1261-1270.

Bradley, P., & Noakes, T. D. (2013). Match running performance fluctuations in elite soccer: indicative of fatigue, pacing or situational influences? *Journal of Sports Sciences, 31*(15), 1627-1638.

Bradley, P., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). High-intensity running in English FA Premier League soccer matches. *Journal of Sports Sciences, 27*(2), 159-168.

Brustad, R., & RitterTaylor, M. (1997). Applying social psychological perspectives to the sport psychology consulting process. *Sport Psychologist, 11*(1), 107-119.

Buchheit, M., Allen, A., Poon, T. K., Modonutti, M., Gregson, W., & Di Salvo, V. (2014). Integrating different tracking systems in football: multiple camera semi-automatic system, local position measurement and GPS technologies. *Journal of Sports Sciences*(ahead-of-print), 1-14.

Buchheit, M., Mendez-Villanueva, A., Delhomel, G., Brughelli, M., & Ahmaidi, S. (2010). Improving Repeated Sprint Ability in Young Elite Soccer Players: Repeated Shuttle Sprints Vs. Explosive Strength Training. *Journal of Strength and Conditioning Research, 24*(10), 2715-2722.

Burgess, D. J., Naughton, G., & Norton, K. I. (2006). Profile of movement demands of national football players in Australia. *Journal of Science and Medicine in Sport, 9*(4), 334-341.

Carling, C. (2010). Analysis of physical activity profiles when running with the ball in a professional soccer team. *Journal of Sports Sciences, 28*(3), 319-326.

Carling, C. (2011). Influence of opposition team formation on physical and skill-related performance in a professional soccer team. *European Journal of Sport Science, 11*(3), 155-164.

Carling, C. (2013). Interpreting physical performance in professional soccer match-play: should we be more pragmatic in our approach? *Sports Medicine, 43*(8), 655-663.

Carling, C., Bloomfield, J., Nelsen, L., & Reilly, T. (2008). The Role of Motion Analysis in Elite Soccer Contemporary Performance Measurement Techniques and Work Rate Data. *Sports Medicine, 38*(10), 839-862.

Carling, C., Dupont, G., & Le Gall, F. (2011). The Effect of a Cold Environment on Physical Activity Profiles in Elite Soccer Match-Play. *International Journal of Sports Medicine, 32*(7), 542-545. doi: Doi 10.1055/S-0031-1273711

Carling, C., Le Gall, F., & Dupont, G. (2012). Analysis of repeated high-intensity running performance in professional soccer. *Journal of Sports Sciences, 30*(4), 325-336.

Carling, C., Williams, A. M., & Reilly, T. (2005). *Handbook of soccer match analysis: A systematic approach to improving performance*: Psychology Press.

Castellano, J., Alvarez-Pastor, D., & Bradley, P. S. (2014). Evaluation of Research Using Computerised Tracking Systems (Amisco® and Prozone®) to Analyse Physical Performance in Elite Soccer: A Systematic Review. *Sports Medicine, 44*(5), 701-712.

Castellano, J., Casamichana, D., Calleja-González, J., San Román, J., & Ostojic, S. M. (2011). Reliability and accuracy of 10 Hz GPS devices for short-distance exercise. *Journal of Sports Science & Medicine, 10*(1), 233.

Castellano, J., Casamichana, D., & Lago, C. (2012). The Use of Match Statistics that Discriminate Between Successful and Unsuccessful Soccer Teams. *Journal of Human Kinetics, 31*, 139-147.

Chassy, P. (2013). Team Play in Football: How Science Supports FC Barcelona's Training Strategy. *Psychology, 4*(09), 7.

Collet, C. (2013). The possession game? A comparative analysis of ball retention and team success in European and international football, 2007–2010. *Journal of Sports Sciences, 31*(2), 123-136.

Coutts, A. J., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport, 13*(1), 133-135.

Cummins, C., Orr, R., O'Connor, H., & West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports Medicine, 43*(10), 1025-1042.

Cushion, C., Nelson, L., Armour, K., Lyle, J., Jones, R., Sandford, R., & O'Callaghan, C. (2010). Coach learning and development: A review of literature. *Leeds: Sports Coach UK*.

Davis, J. A., & Brewer, J. (1993). Applied Physiology of Female Soccer Players. *Sports Medicine, 16*(3), 180-189.

Dawson, B., Hopkinson, R., Appleby, B., Stewart, G., & Roberts, C. (2004). Player movement patterns and game activities in the Australian Football League. *Journal of Science and Medicine in Sport, 7*(3), 278-291.

De Baranda, P. S., & Lopez-Riquelme, D. (2012). Analysis of corner kicks in relation to match status in the 2006 World Cup. *European Journal of Sport Science, 12*(2), 121-129.

Delgado-Bordonau, J., & Mendez-Villanueva, A. (2012). Tactical periodization: Mourinho's best-kept secret. *Soccer NSCAA Journal, 3*, 28-34.

Dellal, A., Chamari, K., Owen, A. L., Wong, D. P., Lago-Penas, C., & Hill-Haas, S. (2011). Influence of technical instructions on the physiological and physical demands of small-sided soccer games. *European Journal of Sport Science, 11*(5), 341-346. doi: Doi 10.1080/17461391.2010.521584

Dellal, A., Chamari, K., Wong, D. P., Ahmaidi, S., Keller, D., Barros, R., . . . Carling, C. (2011). Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. *European Journal of Sport Science, 11*(1), 51-59.

Dellal, A., Hill-Haas, S., Lago-Penas, C., & Chamari, K. (2011). Small-Sided Games in Soccer: Amateur Vs. Professional Players' Physiological Responses, Physical, and Technical Activities. *Journal of Strength and Conditioning Research, 25*(9), 2371-2381. doi: Doi 10.1519/Jsc.0b013e3181fb4296

Di Salvo, V., Baron, R., González-Haro, C., Gormasz, C., Pigozzi, F., & Bachl, N. (2010). Sprinting analysis of elite soccer players during European Champions League and UEFA Cup matches. *Journal of Sports Sciences, 28*(14), 1489-1494.

Di Salvo, V., Baron, R., Tschan, H., Calderon Montero, F. J., Bachl, N., & Pigozzi, F. (2007). Performance characteristics according to playing position in elite soccer. *International Journal of Sports Medicine, 28*(3), 222-227.

Di Salvo, V., Collins, A., McNeill, B., & Cardinale, M. (2006). Validation of Prozone®: A new video-based performance analysis system. *International Journal of Performance Analysis in Sport, 6*(1), 108-119.

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of High Intensity Activity in Premier League Soccer. *International Journal of Sports Medicine, 30*(3), 205-212. doi: 10.1055/s-0028-1105950

Dobson, B. P., & Keogh, J. W. (2007). Methodological issues for the application of time-motion analysis research. *Strength & Conditioning Journal, 29*(2), 48-55.

Drust, B. (2010). Performance analysis research: meeting the challenge. *Journal of Sports Science, 28*(9), 921-922. doi: 10.1080/02640411003740769

Drust, B., Atkinson, G., & Reilly, T. (2007). Future perspectives in the evaluation of the physiological demands of soccer. *Sports Medicine, 37*(9), 783-805.

Drust, B., Reilly, T., & Rienzi, E. (1998). Analysis of work rate in soccer. *Sports Exercise and Injury, 4*(4), 151-155.

Duffield, R., Reid, M., Baker, J., & Spratford, W. (2010). Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *Journal of Science and Medicine in Sport, 13*(5), 523-525.

Dunbar, G. M. J., & Treasure, D. (2004). An analysis of fitness profiles as a function of playing position and playing level in three English Premier League clubs. *Journal of Sports Science, 22*(6), 539-540.

Dvorak, J., & Racinais, S. (2010). Training and playing football in hot environments. *Scandinavian Journal of Medicine and Science in Sports, 20 Suppl 3*, iv-v. doi: 10.1111/j.1600-0838.2010.01203.x

Dwyer, D. B., & Gabbett, T. J. (2012a). Global Positioning System Data Analysis: Velocity Ranges and a New Definition of Sprinting for Field Sport Athletes. *Journal of Strength and Conditioning Research, 26*(3), 818-824. doi: Doi 10.1519/Jsc.0b013e3182276555

Dwyer, D. B., & Gabbett, T. J. (2012b). Global positioning system data analysis: velocity ranges and a new definition of sprinting for field sport athletes. *Journal of Strength and Conditioning Research, 26*(3), 818-824.

Edgecomb, S. J., & Norton, K. I. (2006). Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian Football. *Journal of Science and Medicine in Sport, 9*(1-2), 25-32.

Ekblom, B. (1986). Applied physiology of soccer. *Sports Medicine, 3*(1), 50-60.
Ensum, J., Williams, A. M., & Grant, A. (2000). Analysis of attacking set plays in Euro 2000. *Insight, 4*, 36-39.
ESPN. (2014). Martino says Argentina won't change. *ESPN FC.* Retrieved 01/11/14, 2014, from http://www.espnfc.com/argentina/story/1985990/gerardo-martino-vows-to-make-minimal-changes-at-argentina
Fahmy, M. (2011). *Increase participation and competitions*. Paper presented at the 5th Women's Football Symposium, Frankfurt. http://www.fifa.com/mm/document/footballdevelopment/women/01/51/51/64/presentation_increaseparticipation_e.pdf
Federation Internationale de Football Association, F. (2012). FIFA/Coca-Cola Women's World Ranking. Retrieved 2012, from http://www.fifa.com/worldranking/rankingtable/women/index.html
Frencken, W., De Poel, H., Visscher, C., & Lemmink, K. (2012). Variability of inter-team distances associated with match events in elite-standard soccer. *Journal of Sports Sciences, 30*(12), 1207-1213. doi: 10.1080/02640414.2012.703783
Frencken, W., & Lemmink, K. (2008). Team kinematics of small-sided soccer games: A systematic approach. *Science and Soccer VI*, 161-166.
Frencken, W., Lemmink, K., Delleman, N., & Visscher, C. (2011). Oscillations of centroid position and surface area of soccer teams in small-sided games. *European Journal of Sport Science, 11*(4), 215-223.
Frencken, W., Lemmink, K. A. P. M., & Delleman, N. J. (2010). Soccer-specific accuracy and validity of the local position measurement (LPM) system. *Journal of Science and Medicine in Sport, 13*(6), 641-645.
Gabbett, T. J. (2010). GPS analysis of elite women's field hockey training and competition. *The Journal of Strength & Conditioning Research, 24*(5), 1321-1324.
Gabbett, T. J., Jenkins, D. G., & Abernethy, B. (2012). Physical demands of professional rugby league training and competition using microtechnology. *Journal of Science and Medicine in Sport, 15*(1), 80-86.
Gabbett, T. J., & Mulvey, M. J. (2008). Time-Motion Analysis of Small-Sided Training Games and Competition in Elite Women Soccer Players. *Journal of Strength and Conditioning Research, 22*(2), 543-552.

Gaines, C. (2014). NBA tops all sport leagues with highest average salaries for players. Retrieved 20/11/14, 2014, from http://www.businessinsider.com.au/chart-nba-average-salary-2014-4

Garganta, J., Maia, J., Basto, F., Reilly, T., Bangsbo, J., & Hughes, M. (1997). Analysis of goal-scoring patterns in European top level soccer teams. *Science and football III*, 246-250.

Garvican, L. A., Hammond, K., Varley, M. C., Gore, C. J., Billaut, F., & Aughey, R. J. (2014). Lower Running Performance and Exacerbated Fatigue in Soccer Played at 1600 m. *International Journal of Sports Physiology and Performance, 9*(3), 397-404.

Gore, C., McSharry, P., Hewitt, A., & Saunders, P. (2008). Preparation for football competition at moderate to high altitude. *Scandinavian Journal of Medicine & Science in Sports, 18*(s1), 85-95.

Grant, A., Reilly, T., Williams, A. M., & Borrie, P. (1998). Analysis of the goals scored in the 1998 World Cup. *Insight, 1*(2), 18-20.

Grant, A., & Williams, A. M. (1998). Analysis of corner kicks. *Insight, 1*(3), 25-26.

Gregson, W., Drust, B., Atkinson, G., & Di Salvo, V. (2010). Match-to-Match Variability of High-Speed Activities in Premier League Soccer. *International Journal of Sports Medicine, 31*(4), 237-242.

Gréhaigne, J.-F., Bouthier, D., & David, B. (1997). Dynamic-system analysis of opponent relationships in collective actions in soccer. *Journal of Sports Sciences, 15*(2), 137-149.

Gréhaigne, J.-F., & Godbout, P. (1995). Tactical knowledge in team sports from a constructivist and cognitivist perspective. *Quest, 47*(4), 490-505.

Gréhaigne, J.-F., Godbout, P., & Bouthier, D. (1997). Performance assessment in team sports. *Journal of Teaching in Physical Education, 16*, 500-516.

Gréhaigne, J.-F., Marchal, D., & Duprat, E. (2002). Regaining possession of the ball in the defensive area in soccer. *Science and Football IV*, 112.

Gréhaigne, J.-F., Richard, J.-F. o., & Griffin, L. L. (2005). *Teaching and learning team sports and games*. New York: RoutledgeFalmer.

Gyarmati, L., Kwak, H., & Rodriguez, P. (2014). *Searching for a Unique Style in Soccer.* Paper presented at the 2014 KDD Workshop on Large-Scale Sports Analytics, New York City.

Harley, J. A., Lovell, R. J., Barnes, C. A., Portas, M. D., & Weston, M. (2011). The interchangeability of global positioning system and semiautomated video-based performance data during elite soccer match play. *The Journal of Strength & Conditioning Research, 25*(8), 2334-2336.

Helgerud, J., Engen, L. C., Wisloff, U., & Hoff, J. (2001). Aerobic endurance training improves soccer performance. *Medicine and Science in Sports and Exercise, 33*(11), 1925-1931.

Hewitt, A., Norton, K., & Lyons, K. (2014). Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking. *Journal of Sports Sciences*(ahead-of-print), 1-7.

Hewitt, A., Withers, R., & Lyons, K. (2008). Match analyses of australian international female soccer players using an athlete tracking device. *Science and Football VI*, 224.

Hill-Haas, S. V., Coutts, A. J., Dawson, B. T., & Rowsell, G. J. (2010). Time-Motion Characteristics and Physiological Responses of Small-Sided Games in Elite Youth Players: The Influence of Player Number and Rule Changes. *Journal of Strength and Conditioning Research, 24*(8), 2149-2156. doi: Doi 10.1519/Jsc.0b013e3181af5265

Hill-Haas, S. V., Dawson, B., Impellizzeri, F. M., & Coutts, A. J. (2011). Physiology of Small-Sided Games Training in Football A Systematic Review. *Sports Medicine, 41*(3), 199-220. doi: Doi 10.2165/11539740-000000000-00000

Horne, B. (2014). Western Sydney accuse Al-Hilal coach of lacking respect in the ACL final. *Illawarra Mercury.* Retrieved 1/11/14, 2014, from http://www.illawarramercury.com.au/story/2650890/wanderers-vow-to-make-acl-rivals-pay/?cs=302

Hughes, C. (1973). *Tactics and teamwork*. Wakefield: E.P. Publishing.

Hughes, M., Robertson, K., & Nicholson, A. (1988). Comparison of patterns of play of successful and unsuccessful teams in the 1986 World Cup for soccer. In T. Reilly & A. Lees (Eds.), *Science and Football. The proceedings from the First World Congress on Science and Football* (pp. 363-367). London: E. & FN Spon.

Jennings, D., Cormack, S., Coutts, A. J., Boyd, L. J., & Aughey, R. J. (2010). Variability of GPS units for measuring distance in team sport movements. *International Journal of Sports Physiology and Performance, 5*(4), 565-569.

Johnson, K., & Murphy, A. (2010). Passing and goal scoring characteristics in the Australian A-League. *Journal of Science and Medicine in Sport, 12*, e118.

Jones, P., James, N., & Mellalieu, S. D. (2004). Possession as a performance indicator in soccer. *International Journal of Performance Analysis in Sport*, *4*(1), 98-102.

Junge, A., & Dvorak, J. (2004). Soccer injuries. *Sports Medicine, 34*(13), 929-938.

Kan, A., Shiokawa, M., Okihara, K., Soon Choi, C., Usui, S., & Yanagihara, T. (2004). The movement of players and the team: comparing two games, Japan versus UAE and a J-League game. *Journal of Sports Sciences, 22*(6), 508-509.

Krustrup, P., & Bangsbo, J. (2001). Physiological demands of top-class soccer refereeing in relation to physical capacity: effect of intense intermittent exercise training. *Journal of Sports Sciences, 19*(11), 881-891.

Krustrup, P., Mohr, M., Ellingsgaard, H., & Bangsbo, J. (2005). Physical demands during an elite female soccer game: Importance of training status. *Medicine and Science in Sports and Exercise, 37*(7), 1242-1248.

Krustrup, P., Zebis, M., Jensen, J. M., & Mohr, M. (2010). Game-Induced Fatigue Patterns in Elite Female Soccer. *Journal of Strength and Conditioning Research, 24*(2), 437-441.

Kunz, M. (2007). Big Count. *FIFA Magazine.* Retrieved 3/11/14, 2014, from http://www.fifa.com/mm/document/fifafacts/bcoffsurv/emaga_9384_10704.pdf

Lachow, I. (1995). The GPS dilemma: balancing military risks and economic benefits. *International Security*, 126-148.

Lago, C. (2007). Are winners different from losers? Performance and chance in the FIFA World Cup Germany 2006. *International Journal of Performance Analysis in Sport*, *7*(2), 36-47.

Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *Journal of Sports Sciences, 27*(13), 1463.

Lago, C., Casais, L., Dominguez, E., & Sampaio, J. (2010). The effects of situational variables on distance covered at various speeds in elite soccer. *European Journal of Sport Science, 10*(2), 103-109.

Lago, C., & Martín, R. (2007). Determinants of possession of the ball in soccer. *Journal of Sports Sciences, 25*(9), 969-974.

Lago-Ballesteros, J., & Lago-Penas, C. (2010). Performance in team sports: Identifying the keys to success in soccer. *Journal of Human Kinetics, 25*, 85-91.

Lago-Ballesteros, J., Lago-Peñas, C., & Rey, E. (2012). The effect of playing tactics and situational variables on achieving score-box possessions in a professional soccer team. *Journal of Sports Sciences, 30*(14), 1455-1461.

Lago-Penas, C., & Dellal, A. (2010). Ball possession strategies in elite soccer according to the evolution of the match-score: the influence of situational variables. *Journal of Human Kinetics, 25*, 93-100.

Lago-Penas, C., & Lago-Ballesteros, J. (2011). Game location and team quality effects on performance profiles in professional soccer. *Journal of Sports Science and Medicine, 10*(3), 465-471.

Lago-Penas, C., Lago-Ballesteros, J., Dellal, A., & Gomez, M. (2010). Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. *Journal of Science and Medicine in Sport, 9*, 288-293.

Laird, P., & Waters, L. (2008). Eyewitness recollection of sport coaches. *International Journal of Performance Analysis in Sport, 8*(1), 76-84.

Lames, M., & McGarry, T. (2007). On the search for reliable performance indicators in game sports. *International Journal of Performance Analysis in Sport, 7*(1), 62-79.

Larson, O. (2001). Charles Reep: A major influence on British and Norwegian football. *Soccer and Society, 2*(3), 58-78.

Larsson, P. (2003). Global positioning system and sport-specific testing. *Sports Medicine, 33*(15), 1093-1101.

Lees, A., Asai, T., Andersen, T. B., Nunome, H., & Sterzing, T. (2010). The biomechanics of kicking in soccer: A review. *Journal of Sports Sciences, 28*(8), 805-817.

Lees, A., & Nolan, L. (1998). The biomechanics of soccer: a review. *Journal of Sports Sciences, 16*(3), 211-234.

Lucey, P., Oliver, D., Carr, P., Roth, J., & Matthews, I. (2013, August). Assessing team strategy using spatiotemporal data. In *Proceedings of the 19th ACM SIGKDD international conference on Knowledge discovery and data mining* (pp. 1366-1374). ACM.

Luhtanen, P., Korhonen, V., & Ilka, A. (1997). A new notational analysis system with special reference to the comparison of Brazil and its opponents in the World Cup in 1994. In T. Reilly, J. Bangsbo & M. Hughes (Eds.), *Science and Football*

III. Proceedings of the Third World Congress of Science and Football (pp. 229-232). London: E. & F. N. Spon.

Mackenzie, R., & Cushion, C. (2013). Performance analysis in football: a critical review and implications for future research. *Journal of Sports Sciences, 31*(6), 639-676.

MacLeod, H., Morris, J., Nevill, A., & Sunderland, C. (2009). The validity of a non-differential global positioning system for assessing player movement patterns in field hockey. *Journal of Sports Sciences, 27*(2), 121-128.

Marcelino, R., Mesquita, I., & Sampaio, J. (2011). Effects of quality of opposition and match status on technical and tactical performances in elite volleyball. *Journal of Sports Sciences, 29*(7), 733-741.

Mohr, M., Krustrup, P., Andersson, H., Kirkendal, D., & Bangsbo, J. (2008a). Match activities of elite women soccer players at different performance levels. *Journal of Strength and Conditioning Research, 22*(2), 341-349. doi: 10.1519/JSC.0b013e318165fef6

Mohr, M., Krustrup, P., Andersson, H., Kirkendal, D., & Bangsbo, J. (2008b). Match Activities of Elite Women Soccer Players at Different Performance Levels. *Journal of Strength and Conditioning Research, 22*(2), 341-349.

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *J Sports Sci, 21*(7), 519-528.

Mohr, M., Krustrup, P., & Bangsbo, J. (2005). Fatigue in soccer: A brief review. *Journal of Sports Sciences, 23*(6), 593-599. doi: Doi 10.1080/02640410400021286

Mohr, M., Mujika, I., Santisteban, J., Randers, M. B., Bischoff, R., Solano, R., . . . Krustrup, P. (2010). Examination of fatigue development in elite soccer in a hot environment: a multi-experimental approach. *Scandinavian Journal of Medicine & Science in Sports, 20*, 125-132.

Moura, F. A., Martins, L. E. B., Anido, R. O., Ruffino, P. R. C., Barros, R. M., & Cunha, S. A. (2013). A spectral analysis of team dynamics and tactics in Brazilian football. *Journal of Sports Sciences, 31*(14), 1568-1577.

Oliveira, J. (2004). *Conhecimento específico em futebol : contributos para a definição de uma matriz dinâmica do processo ensino aprendizagem-treino do jogo (Specific knowledge in football : contributions to the definition of a dynamic array of the teaching -learning* *training game).* (Masters), Universidade do Porto. Retrieved from http://hdl.handle.net/10216/53821

Oliveira, T., Gómez, M., & Sampaio, J. (2012). Effects of game location, period, and quality of opposition in elite handball performances. *Perceptual and motor skills, 114*(3), 783.

Olsen, E. (1988). An analysis of goal scoring strategies in the world championship in Mexico, 1986. In T. Reilly & A. Lees (Eds.), *Science and Football. The proceedings from the First World Congress on Science and Football* (pp. 373-376). London: E. & FN Spon.

Orendurff, M. S., Walker, J. D., Jovanovic, M., Tulchin, K. L., Levy, M., & Hoffmann, D. K. (2010). Intensity and Duration of Intermittent Exercise and Recovery during a Soccer Match. *Journal of Strength and Conditioning Research, 24*(10), 2683-2692.

Ozanian, M. (2014). The world's most valuable soccer teams. Retrieved 20/11/14, 2014, from http://www.forbes.com/sites/mikeozanian/2014/05/07/the-worlds-most-valuable-soccer-teams-3/

Ozgunen, K. T., Kurdak, S. S., Maughan, R. J., Zeren, C., Korkmaz, S., Yazici, Z., . . . Dvorak, J. (2010). Effect of hot environmental conditions on physical activity patterns and temperature response of football players. *Scandinavian Journal of Medicine and Science in Sports, 20 Suppl 3*, 140-147.

Piltz, W., & Launder, A. (2013). *Play practice* (2nd ed. ed.). Champaign, IL :: Human Kinetics.

Pollard, R. (1986). Home advantage in soccer: A retrospective analysis. *Journal of Sports Sciences, 4*(3), 237-248.

Pollard, R., Ensum, J., & Taylor, S. (2004). Estimating the probability of a shot resulting in a goal: The effects of distance, angle and space. *International Journal of Soccer and Science, 2*(1), 50-55.

Power, K., Dunbar, G. M. J., & Treasure, D. (2005). Differences in Fitness and Psychological Markers as a Function of Playing Level and Position in Two English Premier League Football Clubs. In T. Reilly, J. Cabri & D. Araújo (Eds.), *Science and Football V. The proceedings of the Fifth World Congress on Science and Football* (pp. 129-133). London: Routledge.

Pratas, J., Volossovitch, A., & Ferreira, A. (2012). The Effect of Situational Variables on Teams' Performance in Offensive Sequences Ending in a Shot on Goal. A Case Study. *Open Sports Sciences Journal, 5*, 193-199.

Rampinini, E., Coutts, A. J., Castagna, C., Sassi, R., & Impellizzeri, F. M. (2007). Variation in top level soccer match performance. *International Journal of Sports Medicine, 28*(12), 1018-1024.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisloff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *Journal of Science and Medicine in Sport, 12*(1), 227-233. doi: S1440-2440(07)00248-4 [pii] 10.1016/j.jsams.2007.10.002

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisløff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: Effect of fatigue and competitive level. *Journal of Science and Medicine in Sport, 12*(1), 227-233.

Redwood-Brown, A. (2008). Passing patterns before and after goal scoring in League Soccer. *International Journal of Performance Analysis in Sport, 8*, 172-182.

Reilly, T. (1997). Energetics of high-intensity exercise (soccer) with particular reference to fatigue. *Journal of Sports Sciences, 15*(3), 257-263. doi: Doi 10.1080/026404197367263

Reilly, T., Bangsbo, J., & Franks, A. (2000). Anthropometric and physiological predispositions for elite soccer. *Journal of Sports Sciences, 18*(9), 669-683.

Reilly, T., & Gilbourne, D. (2003). Science and football: a review of applied research in the football codes. *Journal of Sports Sciences, 21*(9), 693-705.

Reilly, T., & Thomas, V. (1976). A motion analysis of work-rate in different positional roles in professional football match-play. *Journal of Human Movement Studies, 2*(2), 87-97.

Ridgewell, A. (2011). Passing patterns before and after scoring in the 2010 FIFA World Cup. *International Journal of Performance Analysis in Sport, 11*(3), 562-574.

Rienzi, E., Drust, B., Reilly, T., Carter, J. E. L., & Martin, A. (2000). Investigation of anthropometric and work-rate profiles of elite South American international soccer players. *Journal of Sports Medicine and Physical Fitness, 40*(2), 162-169.

Robertson, S. J., Burnett, A. F., & Cochrane, J. (2014). Tests examining skill outcomes in sport: A systematic review of measurement properties and feasability. *Sports Medicine*, 44(4), 501-518.

Sampaio, J., & Maçãs, V. (2004). Differences in football players' fatigue after a sprint test across different levels of competition. *Journal of Sports Sciences, 22*(6), 561.

Sarmento, H., Marcelino, R., Anguera, M. T., CampaniCo, J., Matos, N., & LeitAo, J. C. (2014). Match analysis in football: a systematic review. *Journal of Sports Sciences, 32*(20), 1831-1843. doi: 10.1080/02640414.2014.898852

Schutz, Y., & Chambaz, A. (1997). Could a satellite-based navigation system (GPS) be used to assess the physical activity of individuals on earth? *European Journal of Clinical Nutrition, 51*(5), 338-339.

Shephard, R. J. (1999). Biology and medicine of soccer: an update. *Journal of Sports Sciences, 17*(10), 757-786.

Spencer, M., Lawrence, S., Rechichi, C., Bishop, D., Dawson, B., & Goodman, C. (2004). Time–motion analysis of elite field hockey, with special reference to repeated-sprint activity. *Journal of Sports Sciences, 22*(9), 843-850.

Stølen, T., Chamari, K., Castagna, C., & Wisløff, U. (2005). Physiology of soccer. *Sports Medicine, 35*(6), 501-536.

Tedesqui, R. A., & Glynn, B. A. (2013). "Focus on What?": Applying Research Findings on Attentional Focus for Elite-Level Soccer Coaching. *Journal of Sport Psychology in Action, 4*(2), 122-132.

Tenga, A., Holme, I., Ronglan, L. T., & Bahr, R. (2010). Effect of playing tactics on goal scoring in Norwegian professional soccer. *Journal of Sports Sciences, 28*(3), 237-244.

Tenga, A., & Sigmundstad, E. (2011). Characteristics of goal-scoring possessions in open play: Comparing the top, in-between and bottom teams from professional soccer league. *International Journal of Performance Analysis in Sport, 11*(3), 545-552.

Townshend, A. D., Worringham, C. J., & Stewart, I. B. (2008). Assessment of speed and position during human locomotion using nondifferential GPS. *Medicine and Science in Sports and Exercise, 40*(1), 124-132.

Turner, B., & Sayers, M. (2010). The influence of transition speed on event outcomes in a high performance football team. *International Journal of Performance Analysis in Sport, 10*(3), 207-220.

Varley, M. C., Fairweather, I. H., & Aughey, R. J. (2012). Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. *Journal of Sports Sciences, 30*(2), 121-127.

Vilar, L., Araujo, D., Davids, K., & Button, C. (2012). The Role of Ecological Dynamics in Analysing Performance in Team Sports. *Sports Medicine, 42*(1), 1-10.

Vogelbein, M., Nopp, S., & Hokelmann, A. (2014). Defensive transition in soccer - are prompt possession regains a measure of success? A quantitative analysis of German Fussball-Bundesliga 2010/2011. *Journal of Sports Sciences, 32*(11), 1076-1083.

Wade, A. (1996). *Principles of Team Play*: Reedswain Inc.

Waldron, M., Worsfold, P., Twist, C., & Lamb, K. (2011). Concurrent validity and test-retest reliability of a global positioning system (GPS) and timing gates to assess sprint performance variables. *Journal of Sports Sciences, 29*(15), 1613-1619.

Wallace, J. L., & Norton, K. I. (2014). Evolution of World Cup soccer final games 1966-2010: game structure, speed and play patterns. *Journal of Science and Medicine in Sport, 17*(2), 223-228.

Williams, A. M., & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach. *Human Movement Science, 24*(3), 283-307.

Williamson, D. (1991). *Belles of the ball: The Early History of Women's Association Football*. Devon, England: R&D Associates.

Wisbey, B., Montgomery, P. G., Pyne, D. B., & Rattray, B. (2010). Quantifying movement demands of AFL football using GPS tracking. *Journal of Science and Medicine in Sport, 13*(5), 531-536. doi: Doi 10.1016/J.Jsams.2009.09.002

Withers, R., Maricic, Z., Wasilewski, S., & Kelly, L. (1982). Match analysis of Australian professional soccer players. *Journal of Human Movement Studies, 8*, 159-176.

Witte, T., & Wilson, A. (2004). Accuracy of non-differential GPS for the determination of speed over ground. *Journal of Biomechanics, 37*(12), 1891-1898.

Wright, C., Atkins, S., Polman, R., Jones, B., & Sargeson, L. (2011). Factors associated with goals and goal scoring opportunities in professional soccer. *International Journal of Performance Analysis in Sport, 11*(3), 438-449.

Yiannakos, A., & Armatas, V. (2006). Evaluation of the goal scoring patterns in European Championship in Portugal. *International Journal of Performance Analysis in Sport, 6*, 178-188.

Appendices

9. List of Original Publications arising throughout the candidature and the order they will appear in the appendices:

9.1 ***Hewitt, A****, Norton, KI, & Lyons, K, 2014, 'Game Style: what is it and how can we measure it?' International Journal of Performance Analysis in Sport (Submitted for publication)*

9.2 Randers, MB, Mujika, I, ***Hewitt, A****, Santisteban, J, Bischoff, R, Solano, R, Zubillaga, A, Peltola, E, Krustrup, P, and Mohr, M, 2010 'Application of four different football match analysis systems: a comparative study', Journal of Sport Sciences, Vol. 28, no. 2, pp. 171-182.*

9.3 ***Hewitt, A****, Norton, KI & Lyons, K 2014, 'Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking', Journal of Sport Sciences, vol. 32, no. 20, pp. 1874-1880.*

9.4 ***Hewitt, A****, Withers, R, and Lyons, K, 2007, 'Match analyses of Australian international women soccer players using an athlete tracking device', Science and Football VI: The Proceedings of the Sixth World Congress on Science and Football. Eds. Reilly & Korkuszuz, Routledge: London, pp. 224-228*

9.5 Gore, C. J., P. E. McSharry, ***Hewitt, A.J****., and Saunders, P.U. (2008). "Preparation for football competition at moderate to high altitude." Scandinavian Journal of Medicine & Science in Sports, 18 Supplement 1: 85-95.*

9.6 Mohr, M., Mujika, I., Santisteban, J., Randers, M. B., Bischoff, R., Solano, R., ***Hewitt, A.,*** *Zubillaga, A., Peltola, E. and Krustrup, P. (2010), Examination of fatigue development in elite soccer in a hot environment: a multi-experimental approach. Scandinavian Journal of Medicine & Science in Sports, 20: 125–132.*

Game style in soccer: what is it and how can we measure it?

Adam Hewitt[1,2] and Kevin Norton[1]

[1] *School of Health Science, University of South Australia, Adelaide, Australia*

[2]Universty *of Canberra Research Institute for Sport and Exercise, University of Canberra, Canberra, Australia*

Abstract

Game style is a term commonly used by coaches, sports scientists, performance analysts and media to describe patterns of play in team sports. Performance analysis research has often sought to identify factors related to probability of scoring or of game success. However, more recently there has been a shift to investigate team sports as dynamical systems and to understand of how players interact in various contextual environments and circumstances. These interactions, particularly successful, dominant or recurrent patterns, are likely to be important in forming a game style or at least play a part in our perceptions of a game style. This article proposes an initial framework of variables that can be measured and used to describe game style. The framework is based on metrics within five key moments of play: (1) Established Attack, (2) Transition from Attack to Defense, (3) Established Defense, (4) Transition from Defense to Attack, and (5) Set Pieces. These metrics have practical applications for coaches and practitioners when evaluating efforts to create or compare particular game styles. More importantly, however, they will allow performance analysts to categorise and monitor game styles over time, across leagues and age groups, and provide a deeper understanding of dynamic interactions in invasion-based field sports.

Keywords: Player tracking, playing style, match analysis, association football

1. Introduction

There is a consistency in the world of football commentary and coaching that refers to how a game 'unfolds' or what play patterns are typically seen in competition. This language is universal, pervades virtually all field sports and has changed relatively little over time as evidenced from historical game footage. Moreover, commentators assume others know precisely what they are talking about when regularly referring to a 'game style' or 'play style'. For example, among the many hundreds possible, these types of general media and coaching statements are frequently encountered:

New Argentina coach Gerardo Martino says he will not make any drastic changes to the style of play that took it to the World Cup final. (ESPN 2014)

''We're going to go there attacking and we're not going to sit off. We'll play our style and see if it comes off." (Horne 2014)

Teams are often referred to by their game style as much as their results. A team, club or managers culture may dictate game styles with colloquiums such as "Total Football" or "Tika-taka" referred to in describing a game or play style. But, what do we understand of these game style references, what do they mean and are we interpreting 'game style' in a consistent way? More importantly for sports science, how can this area of sports performance become more robust, quantifiable and less colloquial, and what metrics contribute to 'game plans' or 'playing styles'?

Optimising team sport performance has received significant attention in research literature over the past two decades. To assess performance a selection, or combination, of variables that aim to evaluate outcomes have been reported (Hughes & Bartlett, 2002). Part of this interest involves understanding dynamic systems such as the interactions among players in field sports, and how it may help improve performance. Comprehensive reviews have been published on sport science disciplines and soccer such as physiology (Ekblom 1986, Bangsbo 1998, Reilly and Gilbourne 2003, Stølen, Chamari et al. 2005), biomechanics (Lees and Nolan 1998, Lees, Asai et al. 2010), sports medicine and injuries (Shephard 1999, Junge and Dvorak 2004) and more recently performance analysis (Carling 2013, Mackenzie and

Cushion 2013). The development and application of video and computer technology has now made previously unattainable systems cost-effective and easy to use (Di Salvo, Collins et al. 2006) leading to the integration of performance analysis within the coach-athlete-sport science nexus (Lago 2009, Drust 2010).

Performance analysis research has largely focused on key performance indicators of success including possession and passing patterns, team structures and probability of winning (Lago and Martín 2007, Lago 2009, Lago-Ballesteros and Lago-Penas 2010, Castellano, Casamichana et al. 2012, Bradley, Lago-Penas et al. 2013, Mackenzie and Cushion 2013, Hughes & Bartlett, 2002), predicting successful future performances or to characterise differences between teams or competitions (Pollard, Ensum et al. 2004, Yiannakos and Aramats 2004, Bloomfield, Polman et al. 2005, Armatas, Yiannakos et al. 2007, Lago 2007, Lago and Martín 2007, Lago, Casais et al. 2010, Lago-Ballesteros and Lago-Penas 2010, Lago-Penas and Dellal 2010). Technological advancements have facilitated growth of research investigating the technical and physical components of players as well as game patterns across different leagues (Dellal, Chamari et al. 2011, Bradley, Carling et al. 2013), competitions (Di Salvo, Baron et al. 2010) and time (Barnes, Archer et al. 2014, Wallace and Norton 2014). Hughes and Bartlett (2002) suggest that for performance indicators to be useful they need to relate to successful performance or outcome, however, it is this aspect of performance analysis, the description of distinguishing features of games such as ball and player movement patterns, strategies of attacking and defending play, and how teams work to maintain or regain possession of the ball, that is poorly defined and therefore difficult to categorise or compare scientifically. Despite this, these game qualities are typically referred to by those in sport and which have a currency in conversation in the media, by coaches and among the general population. They may not have strict definitions but they form part of the universal language broadly describing a game style.

Research demonstrates that variables have often been measured as a result of availability rather than to develop a deeper understanding of performance (Mackenzie and Cushion (2013). Furthermore, the literature has been shaped by a positivist paradigm whereby a simplistic approach is often used to understand a whole system, such as football success, by measuring individual parts (Brustad and RitterTaylor 1997). This may be problematic because applying these isolated findings may not yield success in all circumstances. For example, performance analysis research frequently relies on a classical approach of linear causality whereby an explanation or success assumption is based on a naive chain of cause and effect. While there is considerable evidence that a large proportion of research falls into this piecemeal approach, it is understandable given the relatively young age of the discipline, its reliance on rapidly evolving technologies and an acknowledgement of the complexity of team sport. However, recent developments have been more creative by describing performance within situational contexts. These include incorporating measures of potentially confounding variables such as environmental conditions, location of play on the field, opposition standard, and time in the game or across the season, which can impact associations among variables to reveal situational relationships and assist in developing a framework for measuring game style (Gore, McSharry et al. 2008, Lago 2009, Carling 2011, Bradley and Noakes 2013, Hewitt, Norton et al. 2014).

Identifying the position of teammates, and opposition, at each instant in time with modern tracking technologies allows further contextual information and introduces elements of strategies and tactics of playing styles. These characteristic styles, often planned and rehearsed in advance by teams, can now be analysed in depth with the aim of informing the coaching review process and enhancing performance (Frencken, Lemmink et al. 2011, Moura, Martins et al. 2013). There has traditionally been a focus on physical demands such as player distances covered and velocities to enhance the specificity of training. However, new contextual information can be provided including relative distances among team-mates and opposition players, player congestion maps, probability of scoring success at different locations from goal and other details relating to interactions among the team or sub-groups (Alcock 2010, Frencken, De Poel et al. 2012, Moura, Martins et al. 2013). All of these elements of play can be quantified and used to characterize a game style.

The aims of this paper are to outline methods that have been previously presented in a way that can help practitioners objectively assess patterns of play. This will aid in categorisation of game styles and how contextual influences impact styles, help with comparisons among different teams and competitions, assist trend analyses over time, and benefit team strategies, player recruitment and preparation.

The aim is not simply to look at success of playing styles in team sports but to suggest a framework of meaningful metrics that coaches, analysts, sport scientists and other practitioners can use to assess strategies and tactics and to characterise game styles. Without consistent and well-defined metrics, it is problematic to assess the effectiveness of team game styles or to know if and how a game style has changed over time or with new players or coaches. This paper presents concepts of what variables might be included when determining a game style in soccer and proposes a definition of game style.

2. Elements of play in field sports

2.1 Strategy, tactics and game style

The principles of field-based invasion sports can be viewed as a relationship between teams where each must coordinate its actions in order to recover, conserve, and effectively move the ball into a scoring zone (Gréhaigne and Godbout 1995). Wade (1996) identified three principle phases of soccer: Attack, defense and preparation or midfield play. Team sports can, therefore be considered as a function of two networks attempting to anticipate opponents attacking and defensive movements and plan its own offensive and defensive actions, using strategy and tactics.

The simplest consideration in the effective analysis of tactics and strategy in soccer is ball possession (Wade 1996). Defensively when a team loses possession of the ball, players must think defensively. The defending teams aim is to regain possession of the ball, restrict the attacking teams' time on the ball and prevent goal scoring opportunities (Wade 1996). Similarly, when a team is in possession, each player of the team is in attack, with the aim of maintaining possession and progressing the ball to a goal scoring opportunity (Wade 1996).

2.1.1 Offensive principles

Penetration: Offensive phases of play involve a key aim to have players move into positions towards the offensive zone of the field in order to receive the ball or score (Costa et al. 2009; Wade 1996). Penetration is achieved successfully through overtaking defensive opponents and moving goal side along with being able to cause imbalance in the defensive structures through ball and player movements (Clemente et al. 2014; Piltz & Launder 2013).

Offensive Coverage: the support provided to the player with possession in terms of providing a range of passing options (Costa et al. 2009). Presenting as a passing option is done so in conjunction with leading away from or towards the ball carrier depending on the location on the field of the ball and the defensive position of the opposition (Clemente et al 2014). By supporting players with a range of passing options this allows for quick ball movement and the ability to evade defensive pressure by being able to pass the ball off and hence avoid losing possession of the ball (Piltz & Launder 2013).

Width and Depth: players must utilize the offensive space by increasing the surface area over which the team is spread (Costa et al. 2009; Wade 1996; Piltz & Launder 2013). This will allow players to drag defenders to less critical areas and make space for teammates to move in to as the space will be created within the critical zones with a lower player density (Clemente et al. 2014).

2.1.2 Defensive Principles

Delay: The initial defensive principle is to delay the opposition's offensive play, restricting passing options and limiting space available by immediately applying defensive pressure one the opposition gain possession (Costa et al. 2009; Wade 1996). In order to do this positioning is crucial and relies on remaining goal side of the offensive players (Clemente et al. 2014).

Concentration: increasing the player density (or concentrating the defensive area) by having additional players in strategic defensive positions increases the effectiveness of defensive structures (Costa et al 2009; Piltz & Launder 2013). Thus limiting offensive passing options as it takes away space available for players to move into and forces them to play in less critical areas, along with increasing the chance of regaining ball possession (Bangsbo & Peitersen 2002; Clemente et al. 2014).

2.1.3 Strategy and Tactics

Strategy has been defined as including all plans, principles of play or action guidelines decided upon before a match in order to organise the activity of the team and player interaction during the game (Gréhaigne and Godbout 1995, Grehaigne, Godbout et al. 1997, Piltz and Launder 2013). This may include the framework of a game style based, in part, on coaching philosophies in soccer such as whether teams aim to play a possession-based [prioritising keeping the ball away from the opposition even if it means relatively little attacking and non-offensive passing], or counter-attacking game [typically moving the ball rapidly in transition moments that often involves rapid player movement and trying to outnumber defenses], and what roles and instructions are agreed upon for various positions. However tactics involve the actions voluntarily executed during the game by the players in order to adapt to the immediate requirements of an ever-changing opposition. Therefore, tactics are more likely to be continually evolving in response to varying situations or game contexts, for example, score line, time remaining, and the opposition strengths and weaknesses (Gréhaigne and Godbout 1995, Grehaigne, Godbout et al. 1997, Piltz and Launder 2013).

Overall, soccer can be described as competition between teams involving moments of frenzied attacking movements to create imbalance in player position and numbers versus a homeostatic environment of rapid re-organisation towards control, possession and stability. Teams then reverse roles in this pattern of disorder versus order (Delgado-Bordonau and Mendez-Villanueva 2012). Oliveira (2004) suggests soccer teams are dynamic systems characterised by interacting agents that include players, coaches, and game strategies and tactics. There is obviously cooperation and coordination among players that help create a certain order and stability in an environment of physical confrontation and occasional chaotic disorder.

The visual aspect of this competition, for example, movement of players and the ball, frequency of periods of attacking asymmetry, speed of counter-attacks, the way teams try to keep possession of the ball while moving strategically towards goal-scoring areas and numerous other ingredients of field-based sports are, collectively, what we refer to as a game style. The problem is we may not all see the same elements of play, or in the same way, when we build a version of game style. Even coaches may not accurately recall aspects of their own game (Laird and Waters 2008).

2.2 Moments of play

Using identifiable patterns of play it has been suggested there are four key repeating 'moments' during a game: Established Attack, Defensive Transition, Established Defense and Offensive Transition (Oliveira 2004). Furthermore, research has demonstrated the significance of goal scoring opportunities arising from set pieces. Approximately 30% (Ensum, Williams et al. 2000) of goals in major competitions/ leagues arise from set pieces such as corner and free kicks suggesting that Set Pieces should form the fifth key moment of the game as illustrated in Figure 1.

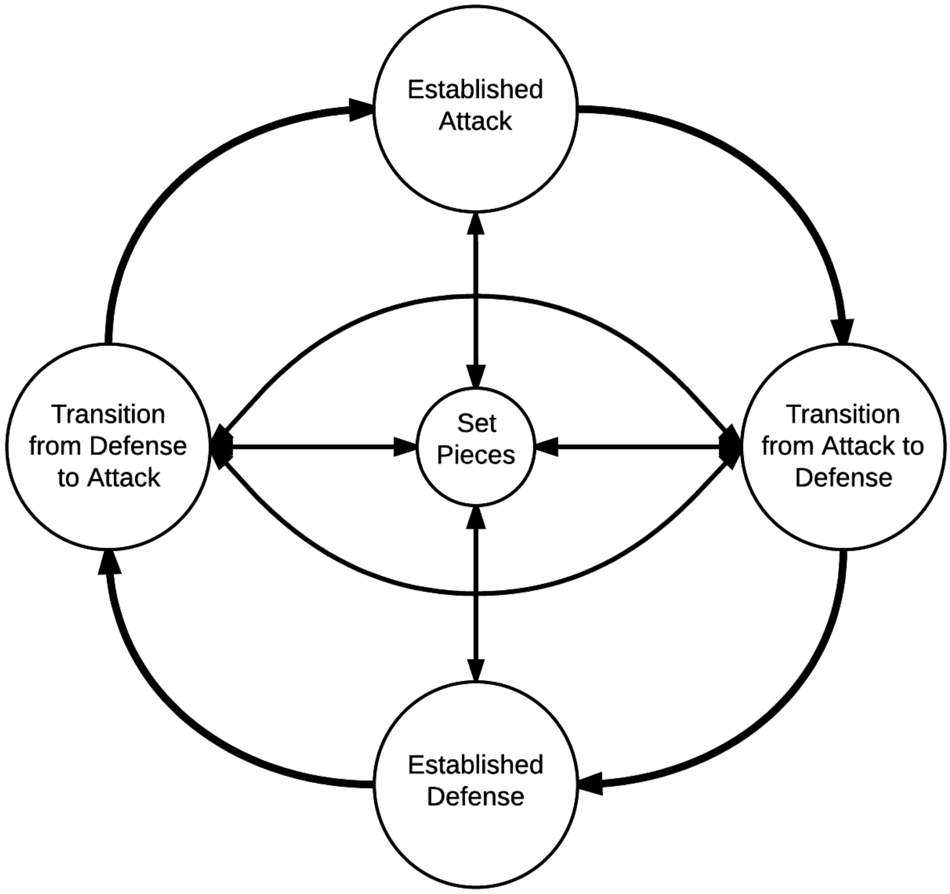


Figure 2. Five moments of play

These moments are considered as discrete periods but are clearly able to influence other moments or elements of play (Delgado-Bordonau and Mendez-Villanueva 2012). This is supported by dynamic systems theory where the actions of individuals and sub-groups can influence other component's actions and decisions (Grehaigne, Bouthier et al. 1997, Vilar, Araujo et al. 2012). For example, attacking patterns may influence defensive tactics simply because of where players are located on the field relative to opposition players during a transition. However, for the purposes of this review of game style, the moments of play will generally be considered separately as one of three groups: Established Offense and Defense, Transitional Play and Set Pieces.

Breaking the game into moments of play and reviewing ways to measure patterns within these moments can help to characterise styles of play in field sport. Game style will be the playing outcome, that is, what we observe when formed by the interaction of numerous play patterns occurring within these moments. The frequency of their occurrence, impact on both the moment and game outcomes, level of excitement elicited, repeatability from game to game, and predictability of play patterns and tactics within moments are all examples of how a game style will be 'created' for the observer. There are obviously many other elements within a game that can influence our interpretation of a game style. Moreover, the importance placed on any one element may also change over time, most likely heavily influenced by the degree of success associated with particular patterns of play.

2.5 Tactical and technical performance in soccer

Although successful performance in soccer match play requires superior levels of physical fitness to sustain a high work rate during matches, it is perhaps the synthesis of the physical, technical and tactical skill level that usually separates successful soccer players and team performance at the elite levels of competition.

Studies comparing tactical characteristics of successful versus unsuccessful soccer teams during matches have shown various traits for success (Garganta et al., 1997; Hughes, Robertson, & Nicholson, 1988; Luhtanen, Korhonen, & Ilka, 1997; Olsen, 1988; Tenga, Holme, Ronglan, & Bahr, 2010; Tenga & Sigmundstad, 2011). It was shown that successful teams at the 1986 FIFA Men's World Cup had more kicks and shots at goal inside the penalty area, less fouls, more use and possession of the ball in the midfield area of the pitch and more touches per possession (Hughes et al., 1988). Olsen (1988) investigated 52 matches of the 1986 World Cup and found successful teams to have less dribbling into a scoring position on the field, more single touches of the ball before shooting at goal, a high incidence of goals with less than two preceding passes. During the 1990 World Cup, Luhtanen (1997) investigated the tactical characteristics of successful teams. This study showed successful teams had more offensive actions, more offensive attacks where the ball was not lost, greater number of passes to the centre of the field, more scoring attempts, shots on goal and greater numbers of goals. Garganta et al. (1997) found successful teams changed the rhythm of the game from fast to slow ball movements, varied their attacking methods and had different direct and indirect styles of play. More recently, a study based on 177 matches from the 2002, 2006 and 2010 FIFA World Cups revealed that the variables which related to attacking play and best differentiated between winning, drawing and losing teams were total shots, shots on target and ball possession. Defensive “success” was characterised by teams with less total shots received and shots on target received (Castellano, Casamichana, & Lago, 2012; Lago-Penas et al., 2010).

These investigations on the technical and tactical aspects of soccer match play demonstrate that teams apply different tactics, team formations and ball movements to win matches (Castellano et al., 2012; Garganta et al., 1997; Lago-Penas et al., 2010; Luhtanen et al., 1997; Tenga et al., 2010; Tenga & Sigmundstad, 2011). These tactics are likely to impact the movement patterns and the physiological demands of match play. The tactical style of play and skill level of players, therefore, should also be considered when analysing the performance of soccer players during a match.

2.6 Factors affecting on-field physical performance of elite soccer

2.6.1 Match Conditions

Each soccer match is played against a unique opposition, often with subtle and sometimes significantly different tactical styles of play. Furthermore, matches are played in different environmental conditions against opponents of varying skill level. Each of these factors may impact the movements made by players on the field. This section, therefore, discusses the different match conditions that should be considered when analysing performance.

2.6.1.1 Playing Position

A number of studies have reported on the fitness capacities of players of various playing positions and formations (Bangsbo et al., 1991; Bradley et al., 2011; Carling, 2011; Di Salvo et al., 2007; Reilly & Thomas, 1976). In a large-scale study into the motion characteristics of top class soccer players, Di Salvo et al. (2007) analysed 300 male players from the top Spanish League using a computerised match analysis system. The results indicated midfield players covered a significantly greater total distance than defenders and forwards (Di Salvo et al., 2007).

Using a multiple-camera computerised tracking system, Carling et al. (2011) analysed 45 matches from the highest men's competition in France over three season to investigate the effect a team's playing formation has on the physical demands of players. Using one team as a reference team playing a 4-3-3 or 4-5-1 system of play, opposition formations of 4-4-2, 4-3-3 or 4-5-1, and 4-3-2-1 were compared to assess the impact on physical indicators such as total distance covered, high intensity running (14.4-19.7 km.h-1), very high intensity running (>19.8 km.h-1), and technical indicators such as the number of passes and the number of touches per possession. Overall, it was suggested that the opposition's team formation had little impact on the reference team's physical performance (Carling et al., 2011). However, there were differences in the skill-demands according to the opponent's formation that may have applications in the technical and tactical preparation of teams.

Bradley et al. (2011) examined the effect of 3 playing formations 4-4-2, 4-3-3 and 4-5-1 on high-intensity running and technical performance. Twenty English Premier League games were analysed using a multiple-camera computerised tracking system. Overall ball possession and high-intensity running did not differ between 4-4-2, 4-3-3 and 4-5-1 formations. However when looking at different playing positions in the formations, it was shown that attackers in a 4-3-3 performed more high-intensity running than attackers in 4-4-2 and 4-5-1 formation (Bradley et al., 2011).

In summary, the literature demonstrates that playing position and formation is an important factor to consider when analysing the physical performance of a soccer player. However, only Carling et al. (2011) and Bradley et al. (2011) utilised additional contextual information such as the playing formation of both teams to examine its affects on the physical requirements of different playing positions.

2.6.1.2 Competition level

When analysing the on-field performance of soccer players during match play, the standard of competition may be of influence. Numerous studies have shown a difference in the physical capacities and characteristics of players in various leagues around the world (Bloomfield et al., 2004; Dunbar & Treasure, 2004; Rienzi, Drust, Reilly, Carter, & Martin, 2000). When comparing between different divisions of specific leagues, there also appears to be a difference in physical capacity. For example,, first team players performed better than reserve team players across three English Premier League clubs in a battery of physical performance tests including lactate threshold testing as a measure of aerobic fitness, 20 m sprint test (speed), vertical jump (leg power), Illinois agility test (agility) and repeat speed consisting of 8x40m efforts (anaerobic) (Dunbar & Treasure, 2004; Power, Dunbar, & Treasure, 2005). Similar differences in the physical characteristics between age groups were reported in a study of 146 Portuguese soccer players using a 7x34 m repeated sprint test which was able to determine differences between groups of players across various age and ability levels ranging from First Division down to under 12 players (Sampaio & Maçās, 2004).

Research has highlighted teams competing in the European leagues covering more total distance in games compared to teams from Japan and South American Leagues (Kan et al., 2004; Bangsbo et al., 1991; Rienzi et al., 2000). Japanese players playing in lower ranked leagues have been recorded as running less than 7 000 m in a game (Kan et al., 2004) compared to their European counterparts who run 8 000-10 000 m (Bangsbo et al., 1991; Rienzi et al., 2000). Kan et al. (2004) also found the average speed of Japanese players to be faster for teams in an international match versus a domestic Japanese League match. A study by Rienzi et al. (2000) found differences in work rates on the field between leagues with South American players covering 1 500 m less distance than English Premier League players. The discrepancies in the total distance covered in games between leagues maybe due to the physical fitness of players in the top European leagues being superior or differences in the style of play that may limit the amount of running in games, or most likely to be a combination of both of these factors.

A more recent study compared the match performance and physical capacity of players in the top three competitive standards of English soccer (Bradley, Carling, et al., 2013; Carling, 2011). Match performance data including total distance covered, high-intensity running distances and the amount of distance covered sprinting, from players in the FA Premier League, Championship, and League 1 using a multiple-camera system were analysed. In addition, a subsection of players of the three leagues performed the Yo-Yo intermittent endurance test level 2 (Yo-Yo IE2) to determine physical capacity. The results indicated that players in League 1 and the Championship performed more high-intensity running than those in the Premier League. Technical indicators such as pass completion, frequency of forward and total passes, balls received and average touches per possession were higher in the Premier League compared to lower standards. There were no differences in the results of Yo-Yo IE2 across the three leagues. The data demonstrated that high-intensity running distance was greater in players at lower compared to higher competitive standards despite a similar physical capacity in a subsample of players in each standard (Bradley, Carling, et al., 2013; Carling, 2011).

There are some discrepancies in the literature relating to the physical capacities of players in different professional soccer leagues, and its affect on players' ability to physically perform during a match. Studies by Dunbar and Treasure (2004), Power et al. (2005) and Sampaio & Maçās (2004) indicated that players from higher levels of competition peformed better in a series of tests designed to assess speed, power, aerobic endurance and repeated speed. However no game based performance indicators such as the number of sprints, distance covered at high intensity or total distance covered was reported. Bradley et al. (2013) and Carling (2011) showed that there was no difference in Yo-Yo IE2 results in players sampled from the three highest levels of competition in England. However there were differences in the match related performance indicators with players in the lower two levels of competition completing more high intensity running than those players from the highest level. This would suggest that factors other than physical capacity (as measured by Yo-Yo IE2) determine the amount of high intensity running in a game, factors such as strategy, tactics and style of play may be of equal importance.

2.6.1.3 Environmental conditions

Matches and training for soccer are often performed in unfavourable environmental conditions. High altitude, heat, humidity and cold have been identified as factors that may affect soccer performance (Carling, Dupont, & Le Gall, 2011; Dvorak & Racinais, 2010). Previous investigations into on-field performance have shown that the work rates of players are affected by environmental conditions (Ekblom, 1986).

The final soccer match of the 2008 Olympic Games in Beijing was played at 12:00pm local time. Thirty minutes prior to the game commencing the wet-bulb-globe temperature (WBGT) was 34.3 °C, indicating a high health risk at rest, without taking into account the effect on elite soccer performance (Dvorak & Racinais, 2010). High ambient temperatures resulted in a 54% decrease in high intensity running in the final 15-min period compared to the first in a friendly game played by Spanish professional soccer players in hot conditions (31 °C) (Mohr et al., 2010). Similarly, in two games played by Turkish semi-professional players in moderate heat (34 °C) or high heat (36 °C), high intensity running performance in the second half of the high heat game was shown to be substantially compromised with a mean decrease of 19% compared to the moderate heat conditions (Ozgunen et al., 2010). Although the average ambient temperatures in the moderate heat and high heat conditions only differ by 2 °C there was a 23% difference in relative humidity between the 2 games. Ozgunen et al. (2010) calculated the Heat Index (HI) score, an index combining both air temperature and relative humidity to determine the human-perceived equivalent temperature, to be significantly different ($P<0.001$) at 35±1 and 49±1 °C between moderate and high heat conditions respectively. Factors such as thermal stress and dehydration were linked to the decrease in running performance over the course of the games played in hot conditions (Ozgunen et al., 2010).

A number of competitions are played during periods of colder ambient temperatures that may affect the on-field physical performance of soccer players (Carling et al., 2011). However, the physical activity profiles of professional soccer players in four temperature ranges (≤5 °C, 6-10 °C, 11-20 °C and ≥21 °C), Carling, Dupont and Le Gall (2011) suggested that there was no decrease in physical performance in cold conditions.

In addition to temperature and humidity, the physical performance of soccer players is also likely to be affected by playing at moderate to high levels of altitude (Aughey et al., 2013; Garvican et al., 2014; Gore, McSharry, Hewitt, & Saunders, 2008). A review of approximately 100 years of matches from World Cup Qualifying matches held in the South American region illustrate that football competition at moderate/high altitude (>2 000 m) favors the home team (Gore et al., 2008). A comparison of sea-level and high altitude performance (La Paz: 3 600 m) of elite youth soccer players showed that high altitude reduced the total distance covered compared to sea-level performance (Aughey et al., 2013). The study included sea-level based players and players normally residing at altitude however the reduced running performance when playing at high altitude was similar for both groups (Aughey et al., 2013). Even moderate altitude (1 600 m) was shown to negatively influence the total distance covered by 28 youth soccer players compared to sea level performance (Garvican et al., 2014).

In summary, environmental conditions such as heat and humidity and altitude may significantly influence the physical performance of soccer with colder temperatures having less effect. However research has focused on the physical performance rather than effect of these conditions on the technical or tactical performance of soccer matches.

2.6.1.4 Match strategy and tactics

In any invasion based team sport there appears to be a natural sequence of events where players are either defenders or attackers in connection with configurations of play (Gréhaigne, Richard, & Griffin, 2005). Gréhaigne et al. (2005) differentiate between the concepts of “attack” and “offense”, and identifies that there is a defensive aspect to attack. When a team is in “attack”, the offensive aspect is scoring or attempting to score, whilst maintaining possession or conserving the ball is suggested to be the defensive aspect of an attacking play. Attempting to recover possession or putting pressure on the opposition to regain possession is seen as the offensive side of the defence. Finally, defending the goal relates to the defensive actions of the defence (Gréhaigne et al., 2005).

Invasion based team sport, such as soccer, display teams closely coordinated within a given set of rules, focused on winning the match (Gréhaigne et al., 2005). Furthermore, each team must coordinate offensive and defensive aspects of attacking and defending with the primary aim of scoring and preventing scores respectively (Gréhaigne et al., 2005).

To plan and coordinate individual players within a team, coaches use strategy and tactics. These terms are sometimes used interchangeably, however, it is necessary to delineate and understand the differences between these terms. Bouthier, Gréhaigne, and Godbout (1999) outline the components of strategy referring to plans, principles of play or guidelines established before a match. Conversely, tactics involve events executed during the game in order to adapt to the immediate requirements of the opposition. Furthermore, Gréhaigne et al. (2005) outlines the two key components of strategy to be elements predetermined in advance for the team to organise itself (e.g. background play, team composition) and secondly, positional instruction assigned to an individual during training prior to the match. Whereas, tactics relate to the individual response taken in reaction to an opponent in a game and the adjustment of the team to the conditions of play.

Hughes (1973) stated that there is no system of play that will overcome inaccurate passing or poor shooting and that a team's loss is usually not because of a formation or system (i.e. 4-3-3) although spectators and media sometimes indicate otherwise. Bangsbo and Peitersen (2000) describe styles of play as "the characteristic way in which a team uses a system of play. Selecting a style of play should take into account the playing qualities a team possesses."

Currently playing style is primarily based on coaching philosophies (Hughes, 1973). Bangsbo and Peitersen (2000) outline four playing styles that describe the attacking aspect of the game:

5) Systematic build up of play or possession based play: characterised by many passes between players in the defensive third and the middle third of the playing field, trying to maintain possession for long periods of play, moving players into the attacking third of the field to establish longer periods of play per possession.

6) Direct Play: a team consciously plays the ball quickly forward into the attacking third and tries to create goal-scoring opportunities. A primary aim of direct play is that the opposition's defense is often somewhat disorganised at the moment the ball is regained.
7) Counterattacking Play: fast, direct counterattack with few players, initiated as soon as possession is regained, followed by a quick forward pass. In the instant of passing, one or two players should rush forward to support the player who receives the ball in plenty of space.
8) Total Soccer: a term first used to refer to the Dutch team's style of play in the 1974 World Cup, a style of play where the players switch positions during the build-up play in an attempt to confuse defenders.

Bangsbo and Peitersen (2000) outline three defensive styles:

4) Collective Defensive Style or Block Defending: characterised by consistent zonal marking in the defensive half of the pitch.
5) Low-Pressure: a team on losing possession, consciously retreats into its own half of the playing field
6) Pressure Play: an offensive style of defense where the team tries to win possession as quickly as possible and close to the opposition's goal as possible.

The description of playing styles by Bangsbo and Peitersen doesn't include any methods as to how it would be possible to quantify the characteristics of playing style and continues by stating that the style of play of a team should be influenced by the playing qualities without outlining what these qualities might be and which qualities are better suited to different playing styles.

Often soccer teams are not only remembered for the championships or trophies won, but also for the way they played. The "total football" played by the Netherlands, Barcelona and Spain's "tika-taka" possession based football or the defensive mindset of Italy are a few examples of styles of play that are as much a part of those teams' signature style as the success of the teams. However, the analysis and quantification of the impact of strategy, tactics and playing style in soccer is scarce in the scientific literature. The majority of research has focused on descriptive studies of physical characteristics of sub-populations of players or discrete events looking for cause and effect results. When analysing the physical performance of soccer players, the tactics of the game needs to be taken into account.

The locomotion characteristics of players have been extensively described, however none of these studies have documented the style of play. The influence of different styles of play on the location, running patterns and work rates for each playing position is poorly understood. Different styles of play that have been employed by professional soccer teams include playing with an emphasis on retaining possession, slowing down the speed of the game, delaying attacking moves until opportunities to attack are presented or playing with an emphasis on speed of movement. Although little research has been undertaken on the effects of different styles of play on work rate this may provide some explanation as to why there can be large variations in distances travelled by elite division one players (6 600 – 12 000 m) during matches played in different international leagues (Withers et al., 1982; Rienzi et al., 2000; Kan et al., 2004).

Even though a team and coach may agree on and rehearse a range of play patterns within moments of the game, it is not always possible to perform these in the optimal way. Figure 2 illustrates the relationships between moments of the game and player capacities in areas of physical, technical and psychological attributes. Play patterns within moments are obviously impacted by the fitness and skill levels of the players (Bloomfield, Polman et al. 2005, Carling 2011), their level of alertness and how rapidly they anticipate movements of the ball and other players (Tedesqui and Glynn 2013) , and their decision-making capabilities throughout the game (Williams and Ericsson 2005).

Finally, other factors can influence the frequency and type of play patterns that are important in the development of a game style. These include a coach's own principles and instructions of play within moments, training methodologies, group management and leadership philosophies, in addition to context variables such as the county's culture, influence of the club's board or owners, and supporter and media pressures. The way these factors interact in any game can also be influenced by environmental conditions, both physical, such as temperature and altitude challenges, as well as cultural when teams play in foreign countries or at opposition grounds. The relative importance, for example, of away goals in qualifying games can often impact game strategies and therefore game style (Pollard 1986, Tenga, Holme et al. 2010).

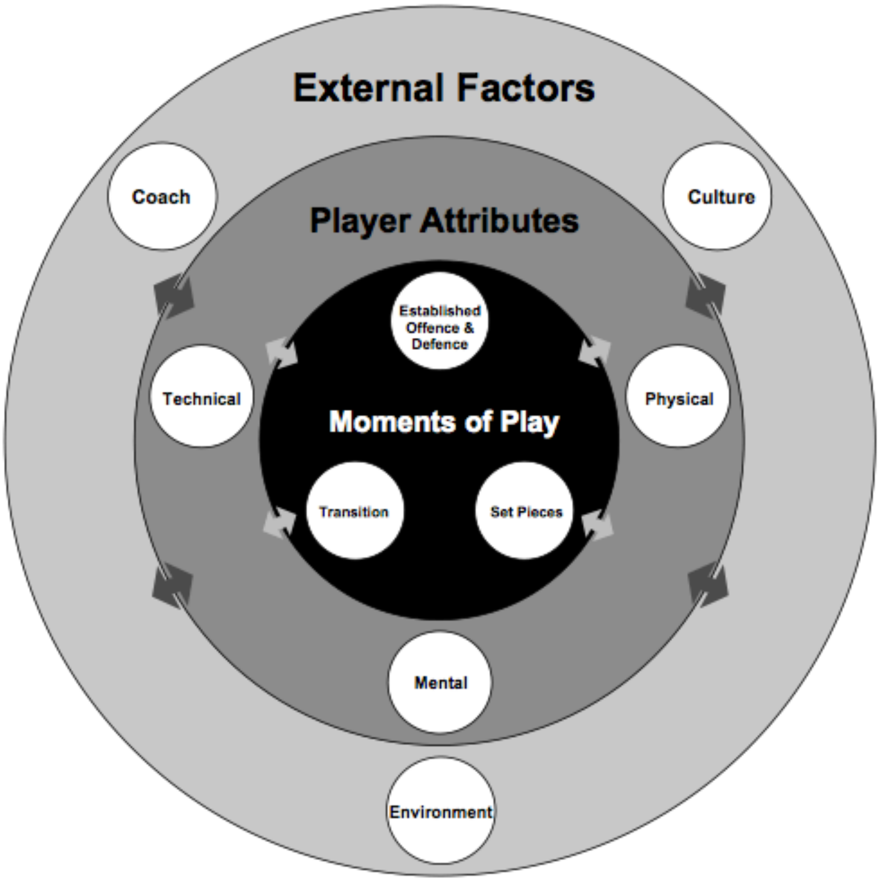


Figure 2. Relationships between elements that determine Game Style.

3. Measuring game style

3.1 Established Offensive and Defensive Play

Success in soccer is obviously multifactorial whereby statistics or notational analysis might reveal dominance in possession, passing, or shots on goal, for example. However, scoring goals is the ultimate determinant of success. As the number of goals scored in soccer is relatively low, research has often focused on alternative measures to assess performance of individuals and teams. Established Offensive play presented the highest frequency in goal scoring opportunities (44%), followed by set pieces (35.6%) and counterattacks (20.3%)

(Yiannakos and Aramats 2004). Conversely, a primary aim of Established Defense is to prevent goals from being scored. Predominantly, the literature has focused on success, or otherwise, from the attacking team's perspective (Lago 2007, Lago 2009, Lago-Ballesteros and Lago-Penas 2010, Lago-Penas, Lago-Ballesteros et al. 2010, Bradley, Carling et al. 2011, Tenga and Sigmundstad 2011, Castellano, Casamichana et al. 2012). The research and metrics described below aim to outline important factors that may influence game style in both Established Offence and Established Defense.

Table 3. Below lists a number of metrics that contribute to a game style. It is unlikely that all of these metrics will be measured in a game but they are listed to represent variables that may be quantified and used to categorise a game style. They have been selected based on either an association with scoring or movement success in invasion-based sports or where characteristic and repeatable playing styles may be demonstrated.

Established Offense	Transition from Attack to Defence	Established Defence	Transition from Defense to Attack	Set Pieces
• Goal attempt • Number of passes • Possession • Passing sequences • Passing density • Passing efficiency / accuracy	• Rate of change of Centroid and Surface Area • Player density • Location of turnover • Player speed • Distance between players • Defensive transition speed	• Surface Area • Centroid position • Distance Between players • Player density	• Ball speed • Rate of change of Centroid and Surface Area • Player density • No. and length of passes • Player speed • Offensive transition speed	• Type of set piece • Location vs success probabilit y maps

3.1.1 Possession

One of the most popular technical indicators of game style is ball possession. Some studies indicate a positive correlation between the retaining possession and success. However this relationship is highly complex with passing efficiency, quality of opposition and match location just some of the factors that may impact ball possession, team dominance and successful performances (Lago-Ballesteros, Lago-Peñas et al. 2012, Collet 2013).

Analysis of possession indicators in domestic leagues in England, France, Germany, Italy and Spain as well as European competitions (UEFA Champions League and Europa League) and FIFA World Cups showed significant relationships between passing, shooting and overall team success, however efficiency was also an important contributor. Efficiency measures included passing accuracy, shooting accuracy and passes-to-shots on goal ratios, and these were found to be stronger predictors of match outcome than possession time (Chassy 2013). Obviously, when teams with high possession strategies meet in competition game styles may change because both can't retain high possession.

Teams with high possession rates may have a different game style to teams with consistently lower rates of possession, particularly given the strategies that support high possession. For example, a 'maintain possession' strategy may involve more slow play with defensive movements, less risk when passing, and greater emphasis on re-gaining possession relative to teams who might place less importance on this strategy (Grehaigne, Marchal et al. 2002, Jones, James et al. 2004, Wright, Atkins et al. 2011). Some teams may exhibit differing patterns of ball possession in different parts of the field and this can also be influenced by the score line (Ridgewell 2011). Lower possession rates in attacking zones by the leading team relative to the opposition signifies less urgency for offensive ball movement and a more conservative play style. For example, a study of corner kicks from the 2006 World Cup showed winning teams used more short corners and directed the kick away from the centre of the goal area to strategically prevent counter-attack opportunities and maintain possession (De Baranda and Lopez-Riquelme 2012).

3.1.2 Passing

An underlying principle of self-organising systems is the structure of the group is founded on rapid, local interactions (Chassy 2013). During Established Offense the ability of the team to move as a group is critically dependent on the passing abilities of the individuals. Possession of the ball almost always involves the ball being passed from one player to the next until it ends with a player best positioned to attempt a goal action. Although this appears a simplistic concept it ultimately involves a complex level of interaction among individuals. This is influenced by the ability to pass the ball accurately and with speed, positioning of teammates who must anticipate movement patterns, and the opposition's defensive structures. Early research conducted by Reep and Benjamin (1968) investigated how goals were scored in soccer. Over 3000 games were analysed between 1953 and 1968 with data collected examining the goals scored and the length of the passing sequences (Reep & Benjamin, 1968). The main findings from this work indicated that approximately 80% of goals were a result of three passes or less and that a goal is scored from every 10 attempts. Later research of the 1990 FIFA World Cup indicated that successful teams with passing sequences of greater than five passes produced more goals per possession than sequences of shorter passing sequences (Hughes & Franks, 2005).

Chassy (2013) suggests two metrics that may influence a team's performance related to Established Offense. The first relates to the ability of a team to keep the ball while changing the spatial configuration to continue to look for weaknesses in the oppositions Established Defense. Players must be able to pass with precision while others create space around themselves to receive the pass from their teammate. Constantly changing the spatial configuration may limit the defense's ability to regain possession and this relies on the concentration and decision-making capacity of the players, and their fitness levels to carry out this strategy. A related factor is the ability of the team to not only pass accurately but frequently. Two principle and quantifiable features identified in relation to passing patterns were Pass density (number of passes per minute of possession), and Pass precision (number of completed passes relative to total passes)(Chassy 2013).

There is little doubt pass accuracy is important in football success. For example, pass accuracy is significantly higher in the period before scoring (Redwood-Brown 2008), assists in retaining possession and progressing forward, leads to scoring opportunities, and restricts opposition possession and scoring opportunities (Redwood-Brown 2008).

Introducing a novel method of analysis passing networks or 'flow motifs', Gyarmati, Kwak et al. (2014) were able to distinguish a unique playing style of FC Barcelona compared to teams playing in five domestic leagues in Europe (Spanish, Italian, English, French and German first division). They were able to demonstrate passing chains focusing on the structure of the passing sequences and showed the FC Barcelona play style did not consist of random passes but rather had precise, finely constructed and repeatable interactions among players.

3.1.3 Measuring Player and Team Patterns

Successful attacking strategies involve tactics to create moments of low player density close to goal, whilst in defense creating higher density or congestion to increase pressure on players in possession (Wallace and Norton 2014). Increasing player density during World Cup finals over almost 50 years of review was a characteristic evolutionary trend found at the highest level of soccer (Wallace and Norton 2014). This long-term pattern suggests defensive strategies may be a play style priority rather than all-out attacking which might drive player density lower. Notwithstanding, creating moments of low player density whilst in possession or during attacking transition is supported by Oliveira (2004) who identified that during Established Offense major aims were to create offensive space and areas of numerical advantage. Creating space requires player speed and skill in anticipating ball movements. Lower density around offensive players increases the probability of scoring which doubles for every metre of free space around the kicker shooting for goal (Pollard, Ensum et al. 2004). Conversely, defenders try to increase player density around the attacker which involves matching offensive players for speed and early anticipatory movements as well as forcing quick ball disposal and associated skill errors (Vilar, Araújo et al. 2012).

Adopting this game style demands high fitness, facilitating fast movement periods, accelerated recovery and repeat efforts. Advancements and availability of player tracking technologies allow physical performance variables, such as player distances and velocities to be routinely analysed (Carling, Bloomfield et al. 2008, Castellano, Casamichana et al. 2012, Cummins, Orr et al. 2013). They also provide information on the position of players at any instant in time aiding analysis of strategies, tactics and patterns of play (Frencken and

Lemmink 2008, Frencken, Lemmink et al. 2011, Frencken, De Poel et al. 2012). Frencken and Lemmink (2008) proposed two variables that characterise the flow between the attacking and defending teams in small-sided soccer games: (1) the Centroid position, and (2) the Surface area of each team. The Centroid is described as the average position of the on-field players of a team and the Surface area is the space covered by those players.

Wade (1996) characterises attacking teams moving towards goals to incite penetration, often with width and depth. As this takes place their Centroid moves forward and can be tracked for both position and rate of change in position. Conversely, the defending team aims to delay the opposition while concentrating its own players close to the defensive goal. Therefore, its Centroid position will move backwards (Frencken, Lemmink et al. 2011). As the attacking phase takes place the Surface area will often increase as the offensive team looks to create more space while the defending team's Surface area will decrease (Moura, Martins et al. 2013).

3.2 Transitions

Transition periods in field sports present both exciting opportunities and nervous vulnerabilities (Turner and Sayers 2010). Offensive speed and outnumbering opposition defenses are key objectives for attacking success while the defensive team must re-organise rapidly because poor or slow coordination are related to conceding goals (Tenga, Holme et al. 2010, Frencken, De Poel et al. 2012). Teams with a speed advantage will look to exploit this dominance and will subsequently develop a game style based on explosive speed by gifted players. It is a pattern of play that becomes the hallmark of specific teams or players.

Losing a neutral ball or following a turnover there are various strategies than a team can take to defend. Vogelbein, Nopp et al. (2014) analysed games in the German Bundesliga to demonstrate top teams recovered the ball quickest after losing it in comparison to lower ranked teams. The current score also influenced the defensive reaction time. Other research has shown recovering ball possession as close to goal as possible to increase goal scoring opportunities (Garganta, Maia et al. 1997, Larson 2001). Ball recoveries closer to the attacking goal produced seven times more goals compared to ball recoveries in the defensive zones, although less than 2% of ball recoveries are achieved in attacking zones (Vogelbein, Nopp et al. 2014). This aggressive form of defense is often promoted by coaches and, therefore, becomes characteristic of the team's game style.

3.3 Set-pieces

Previous research has identified that approximately one third of goals at the elite level are scored either directly or indirectly from set plays (Grant, Reilly et al. 1998, Grant and Williams 1998, Ensum, Williams et al. 2000, Yiannakos and Aramats 2004, Yiannakos and Armatas 2006, Wright, Atkins et al. 2011). Recent evolution shows an increase in set play efficiency (defined as more goals scored from fewer set plays) in men's domestic and international soccer, and successful teams are more efficient at scoring from set plays (Grant and Williams 1998, Alcock 2010). Analysis of play patterns in World Cup soccer final games from 1966 through to 2010 showed that the time taken for a free kick increased from 13 s in 1966 to 20 s in 2010 (Wallace & Norton 2014). Even more significant is that Wallace and Norton (2014) demonstrate that in free kicks resulting in a direct shot on goal increase from 38 s in 1966 to 63 s in 2010. This further emphasizes the preparation and planning of set plays from both offensive and defensive positions are important as well as having set play specialists.

In many field sports probability maps for goal scoring success versus distance and angle combinations are generated and determine the selection of play patterns (Pollard, Ensum et al. 2004, Alcock 2010, Tenga, Holme et al. 2010). For example, free kicks are the most effective set piece, especially from angles square to the goal face in all field sports (Carling, Williams et al. 2005) and closer to goal.

A study of all 64 games of the 2006 FIFA World Cup demonstrated an average of 10.2 corner kicks per game (Baranda & Lopez-Riquleme 2012) which is similar to the 2000 UEFA European Championships which saw an average of 10.9 corner kicks per game and the findings of Wallace and Norton (2014) in an analysis of set pieces for all FIFA World Cup final games from 1966 to 2010 with an average of 10.2 corner kicks per game. To maximize a teams chances of scoring, Hill and Hughes (2001) suggest corner kicks should be played with curl, above head height and an attempt on goal should be made as soon as possible.

4. Conclusions and Applications

There are numerous examples of coaches, media, spectators and sport scientists alike classifying games as exhibiting specific patterns or visual characteristics that allow the categorisation of game styles. The irony is in the inconsistencies of what people use to frame their understanding of game style. In this article we have attempted to provide a framework of meaningful metrics that will allow strategies, tactics and game styles to be objectively assessed.

Structured and detailed metrics facilitate assessment of evolutionary changes in the game including the impact of rule changes or using specific strategies or playing systems. Questions concerning how game styles change with new coaches or key players can also be quantified in a more consistent way.

The identification and understanding of the playing style or patterns of play of teams may have other practical implications, for example, when recruiting players who are capable of playing according to the style of the team (Gyarmati, Kwak et al. 2014). Furthermore, quantification of game styles will allow more detailed analysis into the types of training methodologies and evaluation of training compared to strategies and tactics in the competition environment.

Finally, we propose the following definition: *"Game style is the characteristic playing pattern demonstrated by a team during games. It will be regularly repeated in specific situational contexts such that measurement of variables reflecting game style will be relatively stable. Variables of importance are player and ball movements and interaction of players"*. This definition will allow coaches, sports scientists, media and spectators a clearer understanding what is meant by the term game style.

Acknowledgements

The authors have no potential conflict of interest and no funding was obtained for the preparation of this article.

References

Alcock, A. (2010). Analysis of direct free kicks in the women's football World Cup 2007. **European Journal of Sport Science** 10, 279-284.

Armatas, V., A. Yiannakos and P. Sileloglou (2007). Relationship between time and goal scoring in soccer games: Analysis of three World Cups. **International Journal of Performance Analysis in Sport** 7, 48-58.

Bangsbo, J. (1998). The physiological profile of soccer players. **Sports Exercise and Injury** 4, 144-150.

Barnes, C., D. Archer, B. Hogg, M. Bush and P. Bradley (2014). The Evolution of Physical and Technical Performance Parameters in the English Premier League. **International Journal of Sports Medicine**.

Bloomfield, J., R. Polman, R. Butterly and P. O'donoghue (2005). Analysis of age, stature, body mass, BMI and quality of elite soccer players from 4 European Leagues. **The Journal of Sports Medicine and Physical Fitness** 45, 58-67.

Bloomfield, J., R. Polman and P. O'Donoghue (2005). Effects of score-line on team strategies in FA Premier League Soccer. **Journal of Sports Sciences** 23, 192-193.

Bradley, P., C. Carling, D. Archer, J. Roberts, A. Dodds, M. Di Mascio, D. Paul, A. G. Diaz, D. Peart and P. Krustrup (2011). The effect of playing formation on high-intensity running and technical profiles in English FA Premier League soccer matches. **Journal of Sports Sciences** 29, 821-830.

Bradley, P. S., C. Carling, A. Gomez Diaz, P. Hood, C. Barnes, J. Ade, M. Boddy, P. Krustrup and M. Mohr (2013). Match performance and physical capacity of players in the top three competitive standards of English professional soccer. **Human Movement Science** 32, 808-821.

Bradley, P. S., C. Lago-Penas, E. Rey and A. Gomez Diaz (2013). The effect of high and low percentage ball possession on physical and technical profiles in English FA Premier League soccer matches. **Journal of Sports Sciences** 31, 1261-1270.

Bradley, P. S. and T. D. Noakes (2013). Match running performance fluctuations in elite soccer: indicative of fatigue, pacing or situational influences? **Journal of Sports Sciences** 31, 1627-1638.

Brustad, R. and M. RitterTaylor (1997). Applying social psychological perspectives to the sport psychology consulting process. **Sport Psychologist** 11, 107-119.

Carling, C. (2011). Influence of opposition team formation on physical and skill-related performance in a professional soccer team. **European Journal of Sport Science** 11, 155-164.
Carling, C. (2013). Interpreting physical performance in professional soccer match-play: should we be more pragmatic in our approach? **Sports Medicine** 43, 655-663.
Carling, C., J. Bloomfield, L. Nelsen and T. Reilly (2008). The Role of Motion Analysis in Elite Soccer Contemporary Performance Measurement Techniques and Work Rate Data. **Sports Medicine** 38, 839-862.
Carling, C., A. M. Williams and T. Reilly (2005). **Handbook of soccer match analysis: A systematic approach to improving performance**, Psychology Press.
Castellano, J., D. Casamichana and C. Lago (2012). The Use of Match Statistics that Discriminate Between Successful and Unsuccessful Soccer Teams. **Journal of Human Kinetics** 31, 139-147.
Chassy, P. (2013). Team Play in Football: How Science Supports FC Barcelona's Training Strategy. **Psychology** 4, 7.
Collet, C. (2013). The possession game? A comparative analysis of ball retention and team success in European and international football, 2007–2010. **Journal of Sports Sciences** 31, 123-136.
Cummins, C., R. Orr, H. O'Connor and C. West (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. **Sports Medicine** 43, 1025-1042.
De Baranda, P. S. and D. Lopez-Riquelme (2012). Analysis of corner kicks in relation to match status in the 2006 World Cup. **European Journal of Sport Science** 12, 121-129.
Delgado-Bordonau, J. and A. Mendez-Villanueva (2012). Tactical periodization: Mourinho's best-kept secret. **Soccer NSCAA Journal** 3, 28-34.
Dellal, A., K. Chamari, D. P. Wong, S. Ahmaidi, D. Keller, R. Barros, G. N. Bisciotti and C. Carling (2011). Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. **European Journal of Sport Science** 11, 51-59.
Di Salvo, V., R. Baron, C. González-Haro, C. Gormasz, F. Pigozzi and N. Bachl (2010). Sprinting analysis of elite soccer players during European Champions League and UEFA Cup matches. **Journal of Sports Sciences** 28, 1489-1494.

Di Salvo, V., A. Collins, B. McNeill and M. Cardinale (2006). Validation of Prozone®: A new video-based performance analysis system. **International Journal of Performance Analysis in Sport** 6, 108-119.
Drust, B. (2010). Performance analysis research: meeting the challenge. **Journal of Sports Science** 28, 921-922.
Ekblom, B. (1986). Applied physiology of soccer. **Sports Medicine** 3, 50-60.
Ensum, J., A. M. Williams and A. Grant (2000). Analysis of attacking set plays in Euro 2000. **Insight** 4, 36-39.
ESPN. (2014). "Martino says Argentina won't change." ESPN FC Retrieved 01/11/14, 2014, from http://www.espnfc.com/argentina/story/1985990/gerardo-martino-vows-to-make-minimal-changes-at-argentina.
Frencken, W., H. De Poel, C. Visscher and K. Lemmink (2012). Variability of inter-team distances associated with match events in elite-standard soccer. **Journal of Sports Sciences** 30, 1207-1213.
Frencken, W. and K. Lemmink (2008). Team kinematics of small-sided soccer games: A systematic approach. **Science and Soccer VI**, 161-166.
Frencken, W., K. Lemmink, N. Delleman and C. Visscher (2011). Oscillations of centroid position and surface area of soccer teams in small-sided games. **European Journal of Sport Science** 11, 215-223.
Garganta, J., J. Maia, F. Basto, T. Reilly, J. Bangsbo and M. Hughes (1997). Analysis of goal-scoring patterns in European top level soccer teams. **Science and football III**, 246-250.
Gore, C., P. McSharry, A. Hewitt and P. Saunders (2008). Preparation for football competition at moderate to high altitude. **Scandinavian Journal of Medicine & Science in Sports** 18, 85-95.
Grant, A., T. Reilly, A. M. Williams and P. Borrie (1998). Analysis of the goals scored in the 1998 World Cup. **Insight** 1, 18-20.
Grant, A. and A. M. Williams (1998). Analysis of corner kicks. **Insight** 1, 25-26.
Grehaigne, J., D. Marchal and E. Duprat (2002). Regaining possession of the ball in the defensive area in soccer. **Science and Football IV**, 112.
Grehaigne, J.-F., D. Bouthier and B. David (1997). Dynamic-system analysis of opponent relationships in collective actions in soccer. **Journal of Sports Sciences** 15, 137-149.

Gréhaigne, J.-F. and P. Godbout (1995). Tactical knowledge in team sports from a constructivist and cognitivist perspective. **Quest** 47, 490-505.

Grehaigne, J.-F., P. Godbout and D. Bouthier (1997). Performance assessment in team sports. **Journal of Teaching in Physical Education** 16, 500-516.

Gyarmati, L., H. Kwak and P. Rodriguez (2014). Searching for a Unique Style in Soccer. 2014 KDD Workshop on Large-Scale Sports Analytics, New York City.

Hewitt, A., K. Norton and K. Lyons (2014). Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking. **Journal of Sports Sciences**, 1-7.

Horne, B. (2014). "Western Sydney accuse Al-Hilal coach of lacking respect in the ACL final." Illawarra Mercury Retrieved 1/11/14, 2014, from http://www.illawarramercury.com.au/story/2650890/wanderers-vow-to-make-acl-rivals-pay/?cs=302.

Jones, P., N. James and S. D. Mellalieu (2004). Possession as a performance indicator in soccer. **International Journal of Performance Analysis in Sport** 4, 98-102.

Junge, A. and J. Dvorak (2004). Soccer injuries. **Sports Medicine** 34, 929-938.

Lago, C. (2007). Are winners different from losers? Performance and chance in the FIFA World Cup Germany 2006. **International Journal of Performance Analysis in Sport** 7, 36-47.

Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. **Journal of Sports Sciences** 27, 1463.

Lago, C., L. Casais, E. Dominguez and J. Sampaio (2010). The effects of situational variables on distance covered at various speeds in elite soccer. **European Journal of Sport Science** 10, 103-109.

Lago, C. and R. Martín (2007). Determinants of possession of the ball in soccer. **Journal of Sports Sciences** 25, 969-974.

Lago-Ballesteros, J. and C. Lago-Penas (2010). Performance in team sports: Identifying the keys to success in soccer. **Journal of Human Kinetics** 25, 85-91.

Lago-Ballesteros, J., C. Lago-Peñas and E. Rey (2012). The effect of playing tactics and situational variables on achieving score-box possessions in a professional soccer team. **Journal of Sports Sciences** 30, 1455-1461.

Lago-Penas, C. and A. Dellal (2010). Ball possession strategies in elite soccer according to the evolution of the match-score: the influence of situational variables. **Journal of Human Kinetics** 25, 93-100.
Lago-Penas, C., J. Lago-Ballesteros, A. Dellal and M. Gomez (2010). Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. **Journal of Science and Medicine in Sport** 9, 288-293.
Laird, P. and L. Waters (2008). Eyewitness recollection of sport coaches. **International Journal of Performance Analysis in Sport** 8, 76-84.
Larson, O. (2001). Charles Reep: A major influence on British and Norwegian football. **Soccer and Society** 2, 58-78.
Lees, A., T. Asai, T. B. Andersen, H. Nunome and T. Sterzing (2010). The biomechanics of kicking in soccer: A review. **Journal of Sports Sciences** 28, 805-817.
Lees, A. and L. Nolan (1998). The biomechanics of soccer: a review. **Journal of Sports Sciences** 16, 211-234.
Mackenzie, R. and C. Cushion (2013). Performance analysis in football: a critical review and implications for future research. **Journal of Sports Sciences** 31, 639-676.
Moura, F. A., L. E. B. Martins, R. O. Anido, P. R. C. Ruffino, R. M. Barros and S. A. Cunha (2013). A spectral analysis of team dynamics and tactics in Brazilian football. **Journal of Sports Sciences** 31, 1568-1577.
Oliveira, J. G. (2004). Conhecimento específico em futebol : contributos para a definição de uma matriz dinâmica do processo ensino aprendizagem-treino do jogo (Specific knowledge in football : contributions to the definition of a dynamic array of the teaching -learning training game). Masters, Universidade do Porto.
Piltz, W. and Launder, A. (2013). **Play practice**. Champaign, IL :, Human Kinetics.
Pollard, R. (1986). Home advantage in soccer: A retrospective analysis. **Journal of Sports Sciences** 4, 237-248.
Pollard, R., J. Ensum and S. Taylor (2004). Estimating the probability of a shot resulting in a goal: The effects of distance, angle and space. **International Journal of Soccer and Science** 2, 50-55.
Redwood-Brown, A. (2008). Passing patterns before and after goal scoring in FA Premier League Soccer. **International Journal of Performance Analysis in Sport** 8, 172-182.
Reilly, T. and D. Gilbourne (2003). Science and football: a review of applied research in the football codes. **Journal of Sports Sciences** 21, 693-705.

Ridgewell, A. (2011). Passing patterns before and after scoring in the 2010 FIFA World Cup. **International Journal of Performance Analysis in Sport** 11, 562-574.
Shephard, R. J. (1999). Biology and medicine of soccer: an update. **Journal of Sports Sciences** 17, 757-786.
Stølen, T., K. Chamari, C. Castagna and U. Wisløff (2005). Physiology of soccer. **Sports Medicine** 35, 501-536.
Tedesqui, R. A. and B. A. Glynn (2013). "Focus on What?": Applying Research Findings on Attentional Focus for Elite-Level Soccer Coaching. **Journal of Sport Psychology in Action** 4, 122-132.
Tenga, A., I. Holme, L. T. Ronglan and R. Bahr (2010). Effect of playing tactics on goal scoring in Norwegian professional soccer. **Journal of Sports Sciences** 28, 237-244.
Tenga, A. and E. Sigmundstad (2011). Characteristics of goal-scoring possessions in open play: Comparing the top, in-between and bottom teams from professional soccer league. **International Journal of Performance Analysis in Sport** 11, 545-552.
Turner, B. and M. Sayers (2010). The influence of transition speed on event outcomes in a high performance football team. **International Journal of Performance Analysis in Sport** 10, 207-220.
Vilar, L., D. Araujo, K. Davids and C. Button (2012). The Role of Ecological Dynamics in Analysing Performance in Team Sports. **Sports Medicine** 42, 1-10.
Vilar, L., D. Araújo, K. Davids and C. Button (2012). The role of ecological dynamics in analysing performance in team sports. **Sports Medicine** 42, 1-10.
Vogelbein, M., S. Nopp and A. Hokelmann (2014). Defensive transition in soccer - are prompt possession regains a measure of success? A quantitative analysis of German Fussball-Bundesliga 2010/2011. **Journal of Sports Sciences** 32, 1076-1083.
Wade, A. (1996). **Principles of Team Play**, Reedswain Inc.
Wallace, J. L. and K. I. Norton (2014). Evolution of World Cup soccer final games 1966-2010: game structure, speed and play patterns. **Journal of Science and Medicine in Sport** 17, 223-228.
Williams, A. M. and K. A. Ericsson (2005). Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach. **Human Movement Science** 24, 283-307.
Wright, C., S. Atkins, R. Polman, B. Jones and L. Sargeson (2011). Factors associated with goals and goal scoring opportunities in professional soccer. **International Journal of Performance Analysis in Sport** 11, 438-449.

Yiannakos, A. and V. Aramats (2004). Evaluation of the goal scoring patterns in European Championship in Portugal. **International Journal of Performance Analysis in Sport** 6, 178-188.
Yiannakos, A. and V. Armatas (2006). Evaluation of the goal scoring patterns in European Championship in Portugal. **International Journal of Performance Analysis in Sport** 6, 178-188.

Appendix 9.2

This appendix has been removed due to copyright restrictions.

This appendix is available as:

Randers, M.B., Mujika, I., Hewitt, A., Santisteban, J., Bischoff, R., Solano, R., Zubillaga, A., Peltola, E., Krustrup, P., and Mohr, M. (2010) Application of four different football match analysis systems: a comparative study. *Journal of Sports Sciences*. 28(2): 171-182.

Links to this chapter:

Print	http://lrmprod.canberra.edu.au/record=b1880443~S4
UC Online subscribed content	http://ezproxy.canberra.edu.au/login?url=http://www.tandfonline.com/doi/abs/10.1080/02640410903428525
DOI	10.1080/02640410903428525

Abstract

Using a video-based time–motion analysis system, a semi-automatic multiple-camera system, and two commercially available GPS systems (GPS-1; 5 Hz and GPS-2; 1 Hz), we compared activity pattern and fatigue development in the same football match. Twenty football players competing in the Spanish second and third divisions participated in the study. Total distance covered during the match for the four systems was as follows: 10.83 ± 0.77 km (semi-automatic multiple-camera system, n = 20), 9.51 ± 0.74 km (video-based time–motion analysis system, n = 17), 10.72 ± 0.70 km (GPS-1, n = 18), and 9.52 ± 0.89 km (GPS-2, n = 13). Distance covered by high-intensity running for the four systems was as follows: 2.65 ± 0.53 km (semi-automatic multiple-camera system), 1.61 ± 0.37 km (video-based time–motion analysing system), 2.03 ± 0.60 km (GPS-1), and 1.66 ± 0.44 km (GPS-2). Distance covered by sprinting for the four systems was as follows: 0.38 ± 0.18 km (semi-automatic multiple-camera system), 0.42 ± 0.17 km (video-based time–motion analysing system), 0.37 ± 0.19 km (GPS-1), and 0.23 ± 0.16 km (GPS-2). All four systems demonstrated greater ($P < 0.05$) total distance covered and high-intensity running in the first 15-min period and less ($P < 0.05$) total distance covered and high-intensity running during the last 15-min period than all other 15-min intervals, with a reduction ($P < 0.05$) in high-intensity running from the first to the last 15-min period of 46 ± 19%, 37 ± 26%, 50 ± 26%, and 45 ± 27% for the semi-automatic multiple-camera system, video-based time–motion analysis system, GPS-1, and GPS-2, respectively. Our results show that the four systems were able to detect similar performance decrements during a football game and can be used to study game-induced fatigue. Rather large between-system differences were present in the determination of the absolute distances covered, meaning that any comparisons of results between different match analysis systems should be done with caution.

Appendix 9.3

This appendix has been removed due to copyright restrictions.

This appendix is available as:

Hewitt, A., Norton, K. and Lyons, K. (2014) Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking. *Journal of Sports Sciences*. 32(20): 1874-1880.

Links to this chapter:

Print	http://lrmprod.canberra.edu.au/record=b1880443~S4
UC Online subscribed content	http://ezproxy.canberra.edu.au/login?url=http://www.tandfonline.com/doi/abs/10.1080/02640414.2014.898854
DOI	10.1080/02640414.2014.898854

Abstract

Movement patterns in elite men's soccer have been reported in depth, but less research exists for women's soccer. Aims of the study were to identify the movement profiles of elite women soccer players in international competition and examine the effect the level of opposition, based on Federation Internationale de Football Association (FIFA) rankings, had on the physical demands of the game. MinimaxX athlete tracking devices were used by 15 players during 13 international matches against opponent teams of varying ability. Total distance covered averaged 9292 ± 175 m. There was a decrease in high-intensity running (HIR) in the 60- to 75-min and 75- to 90-min periods compared to the 0- to 15-min period of 22.4% and 26.1%, respectively ($P = 0.022$, $P = 0.004$) although sprint distances remained unchanged across game periods. HIR distances covered were significantly greater for midfielders versus defenders, while defenders had lower sprinting compared to both midfielders and attackers. Stronger opponents elicited less HIR and greater low-speed activity (LSA) compared to playing teams of similar or lower ranking. These results are important to coaches to prepare players for international competition and show the differing demands required depending on the ability of the opponents.

Appendix 9.4

This appendix has been removed due to copyright restrictions.

This appendix is available as:

Hewitt, A., Withers, R., and Lyons, K. (2007) Match analyses of Australian international women soccer players using an athlete tracking device. In T. Reilly and F. Korkuszuz (eds), *Science and Football VI: The Proceedings of the Sixth World Congress on Science and Football*. (pp. 224-228). London: Routledge.

Links to this chapter:

Print	http://lrmprod.canberra.edu.au/record=b1880443~S4

UNIVERSITY OF CANBERRA
AUSTRALIA'S CAPITAL UNIVERSITY

Appendix 9.5

This appendix has been removed due to copyright restrictions.

This appendix is available as:

Gore, C. J., McSharry, P. E., Hewitt, A.J., and Saunders, P.U. (2008) Preparation for football competition at moderate to high altitude. *Scandinavian Journal of Medicine & Science in Sports*. 18(Supplement 1): 85-95.

Links to this chapter:

Print	http://lrmprod.canberra.edu.au/record=b1880443~S4
UC Online subscribed content	http://ezproxy.canberra.edu.au/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=34546532
DOI	10.1111/j.1600-0838.2008.00836.x

Abstract

Analysis of ∼100 years of home-and-away South American World Cup matches illustrate that football competition at moderate/high altitude (>2000 m) favors the home team, although this is more than compensated by the likelihood of sea-level teams winning at home against the same opponents who have descended from altitude. Nevertheless, the home team advantage at altitudes above ∼2000 m may reflect that traditionally, teams from sea level or low altitude have not spent 1–2 weeks acclimatizing at altitude. Despite large differences between individuals, in the first few days at high altitude (e.g. La Paz, 3600 m) some players experience symptoms of acute mountain sickness (AMS) such as headache and disrupted sleep, and their maximum aerobic power (VO2max) is ∼25% reduced while their ventilation, heart rate and blood lactate during submaximal exercise are elevated. Simulated altitude for a few weeks before competition at altitude can be used to attain partial ventilatory acclimation and ameliorated symptoms of AMS. The variety of simulated altitude exposures usually created with enriched nitrogen mixtures of air include resting or exercising for a few hours per day or sleeping ∼8 h/night in hypoxia. Preparation for competition at moderate/high altitude by training at altitude is probably superior to simulated exposure; however, the optimal duration at moderate/high altitude is unclear. Preparing for 1–2 weeks at moderate/high altitude is a reasonable compromise between the benefits associated with overcoming AMS and partial restoration of VO2max vs the likelihood of detraining.

UNIVERSITY OF CANBERRA
AUSTRALIA'S CAPITAL UNIVERSITY

Appendix 9.6

This appendix has been removed due to copyright restrictions.

This appendix is available as:

Mohr, M., Mujika, I., Santisteban, J., Randers, M. B., Bischoff, R., Solano, R., Hewitt, A., Zubillaga, A., Peltola, E. and Krustrup, P. (2010) Examination of fatigue development in elite soccer in a hot environment: a multi-experimental approach. *Scandinavian Journal of Medicine & Science in Sports*. 20(3): 125-132.

Links to this chapter:

Print	http://lrmprod.canberra.edu.au/record=b1880443~S4
UC Online subscribed content	http://ezproxy.canberra.edu.au/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=64719571
DOI	10.1111/j.1600-0838.2010.01217.x

Abstract

The study examines fatigue in elite soccer played in hot conditions. High-profile soccer players (n=20) were studied during match play at [proportional to]31 [degrees]C. Repeated sprint and jump performances were assessed in rested state and after a game and activity profile was examined. Additionally, heart rate (HR), blood lactate, muscle temperature and body mass changes were determined. Repeated sprint and jump performances were reduced (P<0.05) by 2.6% and 8.2%, respectively, after the game. The fatigue index in the repeated sprint test was 6.0[+ or -]0.7% after the game compared with 1.7[+ or -]1.0% at rest (P<0.05). High-intensity running was 57[+ or -]4% lower (P<0.05) during the last 15-min interval of the game compared with the first 15-min period. No differences were observed in mean HR or blood lactates between halves. Muscle temperature was 40.5[+ or -]0.4 [degrees]C after the first half, which was 0.8[+ or -]0.2 [degrees]C higher (P2% of the body mass. Correlations were observed between net-fluid loss and repeated sprint test fatigue index after the game (r=0.73, P<0.05) and Yo-Yo intermittent recovery, level 1 test performance and high-intensity running during the final 15 min of the game (r=0.51, P<0.05). The study provides direct evidence of compromised repeated sprint and jump performances induced by soccer match play and pronounced reduction in high-intensity running toward the end of an elite game played in a hot environment. This fatigue could be associated training status and hyperthermia/dehydration.