A FRAMEWORK FOR QUANTIFYING TACTICAL TEAM BEHAVIOUR IN AUSTRALIAN RULES FOOTBALL

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ABSTRACT

The inception of tracking technologies has allowed for increased access to the positioning data of team sport athletes. This information assists in understanding collective team behaviour by measuring the continuous movement patterns of players. Assessing the efficacy of collective team behaviour research requires comprehension of the contextual factors that may influence movement behaviour, such as the match phase and field location of the ball. Limited studies that have analysed collective team behaviour have accounted for such contextual variables. Research on collective team behaviour in invasion sports has typically focused on football and basketball, while investigations in Australian football (AF) remain largely absent. Furthermore, collective team behaviour investigations to date have generally inferred performance through the positioning of players without directly determining the continuous influence on match play. Therefore, this thesis presents new methodologies for measuring collective team behaviour in AF. This information was used to understand the extent to which collective team behaviour influenced match play in a continuous manner. The findings provide a framework to quantify tactical team behaviour in Australian Rules football (AFL).

Global positioning systems (GPS) spatiotemporal datasets were obtained from match simulation sessions and elite-level AFL matches. This information was aligned with match event data to provide contextual information, such as match phase and ball location. Initial chapters investigated the collective behaviour of AF teams using a macroscopic approach during match simulation and a competitive match. This was undertaken using a range of spatiotemporal metrics that summarise how certain players are positioned across a field of play. These chapters identified teams that were able to obtain increased possession of the ball covered greater spatial regions. Players also repositioned deeper towards their own goal when the ball was in their defensive half and relocated higher up the field when the ball was

in their forward half. Subsequent chapters used a microscopic approach to model the position of every player to understand the spatial control of each team across a playing surface. The central findings from these chapters were that the total number of players increased based on where the ball was positioned and both teams obtained greater spatial control compared to the opposition when the ball was in their defensive half. Teams were also able to arrest spatial control when forcing a turnover in possession.

The general findings from this thesis are spatiotemporal metrics can be used to infer tactical behaviour. A method that continuously represents how players occupy sub-areas of play may provide coaches and sport science practitioners with a more precise account of how tactical team behaviour influences ensuing match play. Finally, quantifying the resistive exchange in spatial control between teams and detecting the value placed on controlling specific regions may contribute to providing a more representative understanding of tactical team behaviour.

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"I, Jeremy Peter Alexander, declare that the PhD thesis entitled 'A framework for quantifying tactical team behaviour in Australian Rules Football' is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

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LIST OF ABBREVIATIONS

AF – Australian Football

AFL – Australian Football League

ApEn – Approximate Entropy

CI – Confidence Interval

CL – Clearance

CV – Coefficient of Variation

***d* –** Cohen's Conventions for Effect Size

ES – Effect Size

F – F-test of equality of variances

GPS – Global Positioning System

Hz – Hertz

ICC – Intraclass Correlation Coefficient

KI – Kick In

km·h-1 – Kilometres per hour

LPS – Local Positioning System

MANOVA - Multivariate Analysis of Variance

m – Metres

m² – Metres squared

m·s-1 – Metres per second

m·s-2 – Metres per second squared

n – Sample Size

η_p^2 – Partial Eta Squared

r – Pearson's Correlation Coefficient

ShannEn – Shannon Entropy

SSG – Small Sided Game

TO – Turnover

LIST OF DEFINITIONS

Behind – A score valued at one point. Obtained when a team moves the ball through the outer goalposts or the ball crosses the goal line of the inner goalposts other than a kick from the attacking team

Clearance – A match event where possession of the ball is obtained from a contested situation

Contest – A match phase where players from both teams aim to obtain possession of the ball

D50 – A section on a playing field positioned within the 50 m arc located in a team's defensive half

DMID – A section on a playing field positioned between the 50 m arc and the middle of the ground within a team's defensive half

F50 – A section on a playing field positioned within the 50 m arc located in a team's attacking half

FMID – A section on a playing field positioned between the middle of the ground and the 50 m arc within a team's attacking half

Goal – A score valued at six points. Obtained when a team kicks the ball through the inner goal posts

Kick In – A match event where a team returns the ball to play after the opposition has scored a behind

Mark – A match event that is awarded when a player receives the ball on the full after a kick that has travelled at least 15 metres

Turnover – A match event where possession is gained from the opposition

LIST OF PUBLICATIONS

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2. Alexander, J. P., Spencer, B., Sweeting, A. J., Mara, J. K., & Robertson, S. (2019). The influence of match phase and field position on collective team behaviour in Australian Rules football. *Journal of sports sciences*, *37*(15), 1699-1707. (Chapter 4)
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CHAPTER 1 – INTRODUCTION

Tactical team behaviour is an integral component of success in invasion sports (Clemente, Sequeiros, Correia, Silva, & Martins, 2018). This is due to its established positive influence on both match play (Clemente, Couceiro, Martins, Mendes, & Figueiredo, 2013; Goncalves, Marcelino, Torres-Ronda, Torrents, & Sampaio, 2016; Rein & Memmert, 2016) and performance outcomes (Lamas, Barrera, Otranto, & Ugrinowitsch, 2014). Tactical team behaviour has been defined as the general patterns of collective team behaviour that are performed in similar match situations (Andrienko et al., 2019). On the other hand, collective team behaviour represents the continuous actions of players in relation to teammates and opponents (Andrienko, et al., 2019). Thus, collective behaviour has been used to describe tactical team behaviour, whereby repetitive patterns of movement are formed (Sampaio & Macas, 2012).

Recent advancements in player tracking technology has allowed for investigations into collective team behaviour to become possible (Rein & Memmert, 2016). Collective team behaviour research has generally been undertaken using a macroscopic approach, whereby the overall positioning of specific players throughout a match is condensed to represent a global overview of movement behaviour (Bialkowski, Lucey, Carr, Yue, & Matthews, 2014). This approach doesn't exclusively require every player on the field to be considered, which may induce information loss. More recently, a microscopic approach has been preferred. This uses a comparatively more detailed method where the continuous positioning of every player at each point in time is modelled, which limits information loss (Fernandez & Bornn, 2018; Lucey, Bialkowski, Carr, Foote, & Matthews, 2012; Spencer, Jackson, Bedin, & Robertson, 2019).

Studies investigating collective team behaviour via a macroscopic approach have used player positioning data to generate a range of spatiotemporal metrics or variables that summarise how certain players are positioned across a field of play (Clemente, Couceiro, Martins, & Mendes, 2013; Clemente, et al., 2013; Frencken, Lemmink, Delleman, & Visscher, 2011). The expression and interaction of these metrics in different match contexts can then be used to define and understand a global overview of a team's collective movement behaviour. Effective evaluation of this research, however, requires knowledge of the contextual factors that may influence collective behaviour, such as the match phase and field location of the ball. Despite this, limited studies that have analysed collective team behaviour in invasion sports have accounted for such contextual variables. By determining the extent to which contextual variables (such as ball position and match phase) influence movement behaviour, a more comprehensive global overview of collective team behaviour may be determined.

By modelling the position of every player at different timescales, information regarding a team's formation or structure may provide a more representative understanding of collective team behaviour (Spencer, et al., 2019). This may be achieved by understanding how the specific positioning of players provides a degree of spatial control over a playing surface (Vilar, Araújo, Davids, & Bar-Yam, 2013). Studies have used both discrete and continuous approaches when assessing the spatial control of teams. Discrete approaches have been achieved by recording player numerical advantages at different sub-areas on a field of play by comparing to the opposing team (Silva et al., 2014; Vilar, et al., 2013). Continuous approaches provide a more fluid method that isn't restricted to distinct regions but measures the degree or probability of control by considering the position of the ball, teammates and opponents (Fernandez & Bornn, 2018). However, the extent to which continuously represented team spatial control varies with respect to specific match play events as well as the influence of contextual variables is yet to be established. Therefore, this thesis determines the extent to which team spatial control impacts match play in a continuous manner, whilst incorporating contextual variables, such as ball position and match phase. This information has the potential to provide a more detailed understanding of collective team behaviour compared to macroscopic approaches, which can be used to develop both enhanced insights and context to tactical team behaviour.

Research on the collective team behaviour of invasion sports has typically focused on football (soccer) and basketball (Bourbousson, Seve, & McGarry, 2010; Clemente, et al., 2018), while investigations in Australian football (AF) remain largely absent. Therefore, this thesis will aim to provide a framework to analyse collective team behaviour in Australian football. Specifically, a general overview of collective team behaviour will be determined by assessing a range of spatiotemporal metrics whilst accounting for contextual variables, such as match phase and field position. To provide a more detailed understanding of collective team behaviour, a microscopic approach will then be used to measure the spatial control of teams and its association to match play in a continuous manner.

CHAPTER 2 – REVIEW OF LITERATURE

2.1 Performance Analysis in Sport

2.1.1 Performance Analysis Overview

The aim of performance analysis is to increase the understanding of game play, whilst aspiring to improve future outcomes (McGarry, 2009). To improve performance, tangible assessments of performance variables are essential to provide a practical evaluation to players and coaches (Bishop, 2008). There has been a wider adoption of performance analysis studies of team sports in recent years (Rein & Memmert, 2016). Typically, approaches to performance analysis investigations have been reductionist in nature by notating the actions of players and teams, whereby discrete performance variables are used to define some or all aspects of a performance (Hughes & Bartlett, 2002). More recently, studies have progressed past this notational approach to view match play as a more holistic system where patterns of coordination are continuously established as teammates and opponents constantly adjust to dynamically changing environments (Passos et al., 2009).

2.1.2 Notational Analysis

Notational analysis consists of recording discrete match events including passes, shots on goal, possession, turnovers, and tackles that are completed by players and teams over time to describe performance outcomes (Collet, 2013; Ensum, Pollard, & Taylor, 2004; Hughes & Bartlett, 2002). These events are referred to as performance indicators (Hughes & Bartlett, 2002). Numerous studies have attempted to explain successful competitive outcomes, by distinguishing causal relationships and general associations with performance indicators of winning and losing teams (Lago, 2007; Lago-Ballesteros & Lago-Peñas, 2010; Oberstone, 2009; Tenga & Sigmundstad, 2011). A key feature of this approach is the concept of reductionism (Brustad, 1997). Reductionism attempts to explain and understand the operation of the whole by the segregation and analysis of its individual parts (Brustad, 1997). However, this approach may not accurately reflect the complexity of team sport, given match outcome is inherently multifaceted and unpredictable (Vilar, Araujo, Davids, & Button, 2012). By focussing on reducing performance to single or multiple indicators, the functionality of team sports is presented in a somewhat simplistic and straightforward process (Cushion, 2007; Mackenzie & Cushion, 2013). For instance, investigations that aim to predict match outcome by associating with performance indicators, such as an increased number of passes (Harrop & Nevill, 2014). This approach describes what happened, rather than explaining how or why it occurred (Vilar, et al., 2012). Reductionism also assumes that each match event has an equal weighting on the overall performance outcome (McGarry, 2009). Furthermore, by reducing match play into convenient components by focusing on single aspects of play, it may not account for other segments of play (Mackenzie & Cushion, 2013; McGarry, 2009). Additional critiques include that retrospective analysis is only relevant under the circumstances it was performed (O'Donoghue, 2001). As such, the resultant analysis may only be valid under the conditions in which it was administered and caution should be taken when extrapolating results (Atkinson & Nevill, 2001). Therefore, the applicability of findings from this approach to inform training content or coaching regimes may not be representative of competition, due to the complex nature of factors that influence performance (Mackenzie & Cushion, 2013).

Performance indicators may also change as a result of differing contextual variables (Duarte, Araujo, Correia, & Davids, 2012). For example, the possession rates of football teams vary in relation to match status, standard of opposition, and match location (Lago, 2009). In this sense, notational analysis may lend itself to conveying learning and performance as a linear process, in which a specific action or play can be adjusted to increase or improve the future success of the team (Rein & Memmert, 2016). Whilst notational analysis investigations have contributed to determining the most important aspects of competition and provide an understanding of sporting performance, the benefit to coaches and support staff may not be fully appreciated as this approach may not take into account key features of team sports (Glazier, 2010). As such, investigations have progressed past the notation of discrete performance indicators towards a theoretical approach that understands how teams manage space and time through their movements as a result of continuous emerging interactions between individual players (Duarte, et al., 2012; Passos, et al., 2009; Travassos, Araujo, Vilar, & McGarry, 2011; Travassos et al., 2016; Vilar, et al., 2012; Vilar, Araujo, Davids, Correia, & Esteves, 2013)

2.1.3 Complex Systems

Rather than considering movement behaviour as isolated segments through a notational analysis perspective, a complex systems approach advocates that movement patterns will emerge as a result of dynamically changing environments, whereby players adapt to the positioning of opponents, teammates, and the ball during competition (Araújo & Reilly, 2005; Duarte et al., 2013). Invasion sports may be considered as complex adaptive systems where team interactions may be influenced by the relationship with the opposition (Grehaigne, Bouthier, & David, 1997). Specifically, to achieve success, teams are required to capture and transition the ball into opposition defensive territory to score a goal (Grehaigne, et al., 1997; Vilar, et al., 2013). The ability of players to manage space and time during different sub-phases of play, such as offence and defence, is critical in achieving this (Araujo & Davids, 2009). During offence, players must effectively transfer the ball despite defending players restricting space and creating impediments in an attempt to regain possession (Vilar, et al., 2013). Resulting analysis should therefore incorporate the continuous interactions between individual players that occur throughout a match (Duarte, et al., 2013; Passos, et al., 2009). This allows for the understanding of how teams dynamically position players across a field of play during various timescales (Sampaio & Macas, 2012). The reasoning behind a shift from notational analysis towards a theoretical approach that understands how teams manage space and time is in part due to the availability of reliable positioning data (Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007; Rein & Memmert, 2016). The introduction of player tracking technologies allows for information on player positions and physiological parameters to be captured during training and competition in a continuous manner (Carling, Bloomfield, Nelsen, & Reilly, 2008).

A complex systems approach uses player tracking data to advocate that individual player actions are influenced by teammates and opponents, which create a collective organisation (Duarte, et al., 2012). This approach proposes that clear team patterns and game behaviours develop across different periods of competition (Duarte, et al., 2012; Travassos, Davids, Araújo, & Esteves, 2013) and aims to understand how and why teams adjust their movement behaviour to achieve a desired outcome (Travassos, et al., 2013). Performance may therefore be derived from and defined as the continuous adaption and co-adaption of players to the emerging match events throughout competition (Travassos, et al., 2013). As such, performance should be measured by assessing the movement patterns of players during various sub-phases of play (Travassos, et al., 2011).

The movement patterns of players are constrained by the positioning of opponents, teammates, and the location of the ball (Grehaigne, et al., 1997). By investigating match analysis under this framework, performance analysts and coaches may gain a more representative understanding of the performance of players and teams (Duarte, et al., 2012). This information may allow coaches to generate more applicable training scenarios that replicate competitive situations and inform tactical team behaviour (Sampaio & Macas, 2012).

2.1.4 Tactical Analysis

The fundamental underpinning of team sports is the concept of two interconnected yet opposing forces (Grehaigne & Godbout, 1995). The nature of opposition requires players to constantly regulate their behaviour throughout a match (Grehaigne & Godbout, 1995). This resistive exchange generates a competition where players aim to gain ball possession and transition to create scoring opportunities (Grehaigne, et al., 1997). Therefore, the ensuing choices players are required to make are influenced by the position and speed of teammates and opponents (Grehaigne, et al., 1997).

Early research proposed that decisions that are made prior to a match best described the team's strategy (Grehaigne & Godbout, 1995; Grehaigne, et al., 1997; James, Mellalieu, & Hollely, 2002). Specifically, player positioning or methods to move the ball in a certain manner were examined (Grehaigne & Godbout, 1995; Taylor, Mellalieu, & James, 2005). The adaptation of players to emerging constraints occurring throughout a match was referred to as the tactics employed by the team (Grehaigne, et al., 1997; James, et al., 2002). Specifically, how players regulated their behaviour as a result of the opposition's strategy (Collet, 2013; Grehaigne, et al., 1997).

The delineation between strategy and tactics has been examined recently (Rein & Memmert, 2016). Discerning between strategy and tactics is difficult as the on-going interactions between players will be influenced by the pre-ordained strategy and vice versa (Rein & Memmert, 2016). Therefore, tactics have since been described as how a team regulates space, time, and individual actions to win a game or match (Rein & Memmert, 2016). Specifically, space identifies where on the field an action occurs and/ or how teams regulate defensive and attacking formations (Rein & Memmert, 2016). Time refers to how quickly an action occurs, such as ball movement, and individual actions identify the type of actions that are executed, such as passes, turnovers and tackles (Garganta, 2009). How teams manage time and space may therefore be used to describe tactical team behaviour (Memmert & Rein, 2018).

A principal factor in influencing performance of invasion sports is the tactics a team employs (Carling, Reilly, & Williams, 2007; Rein & Memmert, 2016; Sampaio, Lago, Goncalves, Macas, & Leite, 2014). During offence, teams may aim to create space by stretching the opposition defence by lengthening and widening the effective playing area (Vilar, et al., 2013). Conversely teams may aim to constrain the opposition by compressing the effective playing area whilst defending (Duarte, et al., 2012; Folgado, Lemmink, Frencken, & Sampaio, 2014; Frencken, et al., 2011). Tactics can then be further organised based on how many players are involved in a specified situation, including at an individual, group, team, and match level (Carling, et al., 2008; Rein & Memmert, 2016). Individual tactics describe all one-on-one events that occur during attacking and defending instances (Rein & Memmert, 2016). Group tactics involve a collection of players that cooperate as a sub-group within a team, including the defenders, while team tactics describes formations and the specific positions across the playing surface (Grunz, Memmert, & Perl, 2012). Finally, match tactics describe the game philosophy that a team employs. This may include a conservative approach through maintaining possession of the ball or a fast-paced method achieved by moving the ball as quickly as possible aiming to displace the opposition defensive formations (Rein & Memmert, 2016; Vogelbein, Nopp, & Hokelmann, 2014).

Tactics govern the structural principles that span from an individual to the entire team (Rein & Memmert, 2016). Tactics include both the predetermined strategic decisions and the adaptive behaviour from continuous exchanges occurring throughout a match (Rein & Memmert, 2016). As such, tactics should not be considered as a fixed set of decisions but a fluid adaption to the dynamic interactions between the opposing teams (Rein & Memmert, 2016). Therefore, tactics are administered by a complex system of interconnecting factors that influence each other (Kempe, Grunz, & Memmert, 2015). For instance, the removal of a player due to injury or illness, playing at home or away, the score of the match or even the weather conditions may influence tactical decision making (Rein & Memmert, 2016). Tactics at an individual level influence tactics on a larger team scale and vice versa, with the flow of information moving in both directions (Rein & Memmert, 2016). Accordingly, tactical analysis should represent this complex system of interconnecting proceedings (Rein & Memmert, 2016).

The advent of player tracking technologies now provides the capacity to undertake investigations that more accurately reflect the tactics in team sports (Fernandez & Bornn, 2018; Lucey, et al., 2012; Lucey, Oliver, Carr, Roth, & Matthews, 2013). This data can be used to understand team tactics by determining how players position themselves across a field of play (Bialkowski et al., 2013). This collective organisation may describe how teams facilitate player movement to adapt to the emerging constraints that occur throughout a match (Bialkowski, et al., 2014; Castellano & Casamichana, 2015). Such approaches should be adopted when investigating the tactical behaviour of teams.

2.2 Player Tracking Technologies

Player tracking technologies provide a method to collect the movement behaviour of teams (Carling, et al., 2008; Rein & Memmert, 2016). The commonly used player-tracking systems to profile team-sport behaviour include vision based systems, Local Positioning Systems (LPS), and Global Positioning Systems (GPS) (Carling, et al., 2008; Leser, Baca, & Ogris, 2011). These technologies record an athlete's position with respect to a playing surface at a specified timestamp (Sweeting, Cormack, Morgan, & Aughey, 2017).

2.2.1 Manual Video Analysis

Manual video analysis was an early method used to determine the time motion profile of players (Carling, et al., 2008). Cameras were stationed around the playing field and filmed players during a match and the resulting match video footage was used to record locomotor activity (Spencer et al., 2004). This was achieved post-match with human observation of footage, which provided the capacity to pause, rewind and slow down the vision (Carling, et al., 2008). These methods typically only allow single players to be viewed for a period of time (Mohr, Krustrup, & Bangsbo, 2003). As such, complete movement activities of athletes could not be captured using this type of analysis (Sweeting, et al., 2017). Reference points on a field of play, such as line markings, were used to calibrate match activities performed by athletes (Carling, et al., 2008). These generally included, estimates of total distance covered, mean velocity, and sum of distance travelled at various velocity ranges (Bangsbo, Nørregaard, & Thorsoe, 1991). However, limitations of manual video analysis include the potential for inaccurate data due to the subjective nature of human's manually coding movement events, laborious time demands in regards to video capture and ensuing analysis, difficulty in comparing between grounds of different dimensions, and inability to provide information for multiple players (Sweeting, et al., 2017).

2.2.2 Semi-automated Vision-based Tracking Systems

Alternate technologies that provide a method of filming players with limited human supervision have been utilised in elite team-sports (Castellano, Alvarez-Pastor, & Bradley, 2014). Semi-automated vision tracking systems allow players to be filmed with the use of multiple cameras, which are in fixed positions that cover all areas across a playing surface (Castellano, et al., 2014). The detection of player trajectories are then captured and extracted from the vision (Barris & Button, 2008). A player's vector is derived from the relative position on the field and is presented as an *XY* coordinate (Hoppe, Baumgart, Polglaze, & Freiwald, 2018).

The validity of semi-automated systems has been undertaken by comparing athlete displacement during various high-speed running tasks against a criterion measure (Valter, Adam, Barry, & Marco, 2006). For example, semi-automated tracking systems have been validated against infrared timing gates, whereby participants performed a sequence of running tasks at various velocities (Valter, et al., 2006). Results indicated that average velocity measured by the semi-automated vision tracking systems during paced runs of 60 m and 50 m displayed a strong (r = 0.999) correlation with the average velocity measured by the timing gates (Valter, et al., 2006). Maximal sprint efforts of 15 m also showed a strong (r = 0.970) correlation (Valter, et al., 2006).

However, the shortcomings of semi-automated vision based tracking systems include significant cost, possible occlusion between players, and the requirement of multiple cameras (Castellano, et al., 2014). In addition, these systems are fixed, which prohibits the portable use of player tracking at multiple venues, which is undesirable for competitions that require teams to train and play at different locations (Sweeting, et al., 2017).

2.2.3 Local Positioning Systems

Wearable technologies, which provide a portable method to measure player positioning, is a solution to track the position of team-sport athletes at multiple venues (Sweeting, et al., 2017). Wearable technologies include Local positioning systems (LPS) and Global positioning systems (GPS). Local positioning systems are able to be used in a multitude of environments, including indoors (Hedley & Humphrey, 2011). The LPS operates by assigning small tags to players, generally housed in a custom made harness between the scapula, which are monitored by anchor nodes placed in fixed locations (Hedley & Humphrey, 2011). The validity and reliability of LPS has been established through various studies (Frencken, Lemmink, & Delleman, 2010; Luteberget, Spencer, & Gilgien, 2018). Distance and speed, measured via a 1000 Hz LPS system, was compared to a measuring tape and timing gate criterion (Frencken, et al., 2010). The LPS underestimated distance (maximum mean difference of 1.6%), while the CV for speed ranged from 1.3 to 3.9% (Frencken, et al., 2010). As timing gates only measure average velocity over a set distance, the instantaneous speed and acceleration of players is unobtainable using this criterion measure. Therefore, a criterion which can capture continuous movement vectors, such as VICON motion analysis, can determine differences in instantaneous velocities (Ogris et al., 2012). The estimation of maximal velocities differed by up to 2.71 $km \cdot h_{-1}$, which indicates that the LPS is less reliable for measuring dynamic movements and instantaneous velocities (Ogris, et al., 2012). However, the authors highlighted that the LPS system provided valuable results for quantifying average velocities and player position (Ogris, et al., 2012). Complications may also arise due to the fixed installation of the system (Hoppe, et al., 2018). Anchored equipment at the location reduces the capacity to efficiently track players at different locations (Sweeting, et al., 2017). Other limitations include the potential occurrence of noise, which may appear in the presence of tall buildings, metal obstructions, and radio-based interference (Hoppe, et al., 2018).

2.2.4 Global Positioning Systems

Global positioning systems use earth-orbiting satellites that produce constant coded signals at the speed of light (Dellaserra, Gao, & Ransdell, 2014; Larsson, 2003). Units, including those worn by athletes, must receive signals from at least three satellites to locate their position (Larsson, 2003), which is subsequently transmitted to a receiver that provides information on position, time and velocity (Aughey & Falloon, 2010). The speed at which the unit transmits data is known as the sampling rate (Aughey, 2011). Through improved miniaturisation and superior battery life, GPS apparatus have become more convenient, time efficient, and popular, due to their ease of use, for quantifying player positioning (Cummins, Orr, O'Connor, & West, 2013).

The validity and reliability of GPS devices have been well established (Akenhead, French, Thompson, & Hayes, 2014; Hoppe, et al., 2018; Johnston, Watsford, Kelly, Pine, & Spurrs, 2014; Petersen, Pyne, Portus, & Dawson, 2009). Studies aimed to determine the validity of 5 Hz and 10 Hz GPS devices when measuring instantaneous velocity during acceleration deceleration, and constant motion in straight line running using a laser sampling at 50 Hz as the criterion method (Varley, Fairweather, & Aughey, 2012). Participants performed acceleration efforts at various starting velocities to offer ecological validity as team sport athletes move at a variety of different speeds during games (Varley, et al., 2012). Results indicated that the 10 Hz GPS were two to three times more accurate and up to six times more reliable than the 5 Hz GPS (Varley, et al., 2012). Both the validity and reliability decreased when the rate of change in velocity increased in both the 5 Hz and 10 Hz GPS devices although it improved when sampling at 10 Hz (Varley, et al., 2012). Overall, acceleration was underestimated and deceleration was overestimated with the CV ranging from 3.1 – 11.3% (Varley, et al., 2012), which advocates sufficient accuracy for the use of player tracking purposes (Johnston, et al., 2014). An additional investigation using a 10 Hz GPS device was undertaken to determine the acceleration dependent validity and reliability (Akenhead, et al., 2014). A subject towed a sliding platform over 10 m a total of 15 times (Akenhead, et al., 2014). Similar to the previous study (Varley, et al., 2012), a laser was employed as the criterion measure which was re-sampled to 10 Hz so it could be directly compared with the GPS output (Akenhead, et al., 2014). Findings were in agreement with the previous study as both the validity and reliability decreased with an increase in acceleration (Akenhead, et al., 2014). There was an acceleration dependent shift with acceleration being overestimated during lower accelerations (0 – 2 $m{\cdot}s^2$) and underestimated at higher accelerations (> 4 m·s^2) with accuracy being compromised at this threshold (Akenhead, et al., 2014). While studies have suggested some overestimations, 10 Hz GPS devices are generally adequate for most player tracking purposes (Johnston, et al., 2014).

2.3 Collective Team Behaviour

Success in team invasion sports is influenced from the individual actions of players within a collective framework (Duarte, et al., 2012; Rein & Memmert, 2016). The regulation of player positioning throughout a match may influence the efficacy of these actions (Rein & Memmert, 2016). The development of player tracking technologies provides a method to assess the interactions between teammates and opponents in a continuous manner that reflect the emerging nature of match play (Clemente, et al., 2018; Travassos, et al., 2013). Studies have typically relied on time motion reports to understand the movement profile of players during various activities (Aughey, 2011; Brewer, Dawson, Heasman, Stewart, & Cormack, 2010; Wisbey, Montgomery, Pyne, & Rattray, 2010). More recently, investigations have been undertaken that use player tracking data to analyse the collective behaviour of players by determining how players position themselves across a field of play (Correia, Araújo, Davids, Fernandes, & Fonseca, 2011).

Emerging contextual variables, such as match phase and field position of the ball, which occurs throughout a match, influences player's movement behaviour. These factors are inextricable to the principles of invasion sports (Bialkowski, et al., 2014; Castellano, Álvarez, Figueira, Coutinho, & Sampaio, 2013; Clemente, et al., 2013). For instance, teams will aim to transition the ball in an attempt to scoring during offensive sequences of play. Conversely, they will attempt to prevent the opposition from achieving this (Memmert, Lemmink, & Sampaio, 2017). However, as offence and defence operate as an interconnected systems, a team may find it difficult to concurrently generate attacking options whilst preserving defenders in supportive regions to maintain defensive stability (Grehaigne, et al., 1997). As such, distinct differences in player positioning may occur due to the emerging requirements throughout a match (Castellano, et al., 2013; Clemente, Couceiro, Martins, Mendes, & Figueiredo, 2013; Clemente, et al., 2013).

2.3.1 Spatiotemporal Metrics

Researchers have consequently examined the collective behaviour of teams by proposing a collection of spatiotemporal metrics that measure the organisation of players across a field of play. An example of the distinct zones on a playing surface in Australian Football with relative *x*, *y*-axes is displayed in Figure 2-1. These variables typically focus on quantifying the team center (Clemente, et al., 2013; Frencken, et al., 2011), team dispersion (Bartlett, Button, Robins, Dutt-Mazumder, & Kennedy, 2012; Castellano, et al., 2013), team synchronisation (Bourbousson, et al., 2010), and division of labour (Figueiredo, Mendes, Clemente, Couceiro, & Martins, 2014).

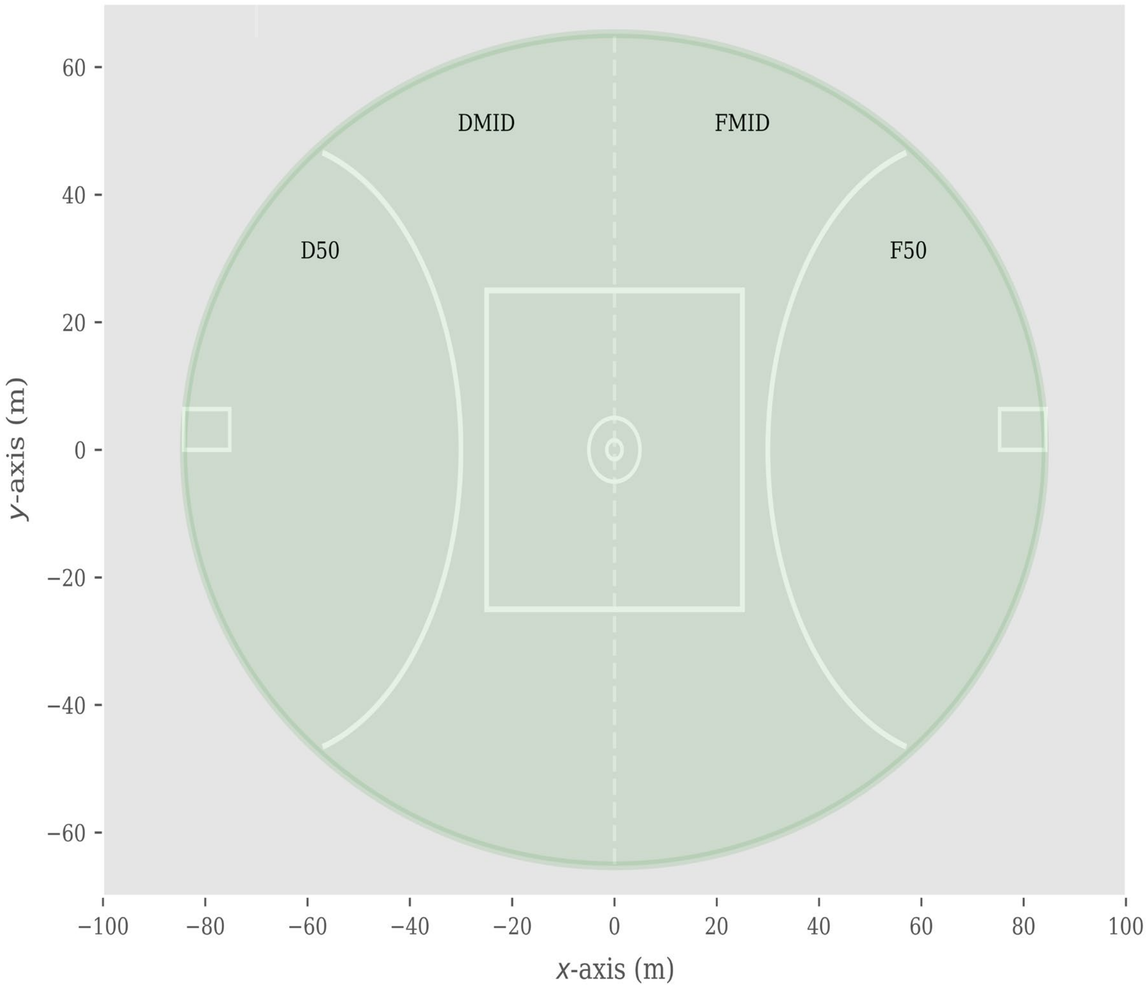

Figure 2-1. Four field positions and dimensions for an Australian football playing field

2.3.1.1 Team Center

The team center has been referenced as the geometric centre of the positions from a set of players on a field of play (Clemente, Santos-Couceiro, Lourenço-Martins, Sousa, & Figueiredo, 2014). The most common method is the team centroid (Clemente, et al., 2018), which is calculated as the mean (x, y) position of all players on the field (algorithm 2-1).

Algorithm 2-1: The geometrical center of the team (C), for each point in time i, is calculated by summing the position of every player k in the longitudinal axis (x-axis) $\boldsymbol{p_{xk}}(i)$ and the horizontal axis (y-axis) and dividing by the total amount of players in a team N for any given instant i.

$$C\ (i) = \left(\frac{\sum_{k}^{N} p_{xk}\ (i)}{N}, \frac{\sum_{k}^{N} p_{yk}\ (i)}{N} \right)$$

Two measures are derived from the team centroid, which are the distance in the x-axis centroid (m) and the distance in the y-axis centroid (m) (Frencken, et al., 2011). These have been measured with or without the goalkeeper (Frencken, et al., 2011). The team center has also been measured via a weighted centroid, which incorporates all players but assigns greater emphasis on players closer to the ball (Clemente, et al., 2014). Finally, the team centroid has been quantified as the middle point between the two farthest players on the ground (Lames, Ertmer, & Walter, 2010). Measures of team centroid that account for ball location are generally preferred as it considers the distance of all players from the ball, therefore, incorporating their relevance on match play. However, this measure requires the location of the ball at each point in time, which is not always available.

The team centroid has been used extensively to describe collective team behaviour in invasion sports (Clemente, et al., 2013; Folgado, et al., 2014; Fradua et al., 2013; Frencken, et al., 2011; Goncalves, Figueira, Macas, & Sampaio, 2014; Silva et al., 2014). Specifically, it has been used to identify the association between critical match events, for instance, a shot on goal (Frencken, et al., 2011), determine the in-phase associations between two teams and sub-groups of players (Goncalves, et al., 2014; Siegle & Lames, 2013), and understand the variation in player positioning during various contextual variables, such as pitch dimensions and match location (Bartlett, et al., 2012; Clemente, et al., 2013; Frencken, et al., 2011).

An introductory study in football using a 4-a-side match suggested that goal-scoring opportunities may emerge when the two competing teams' centroids cross over, creating a numerical advantage for the attacking team, which may increase the probability of scoring (Frencken, et al., 2011). However, subsequent research using 11-a-side competitive matches in football found no clear convergence of team centroids crossing during scoring events (Bartlett, et al., 2012). Goalkeepers were excluded when analysing the team centroid, which provided authors with enough confidence to report limited support for previous studies that suggested team centroids may converge during critical moments of play (Bartlett, et al., 2012). These findings suggest that players who are farthest from the ball who may exert minimal influence on match play, which could impact the capacity of a team's centroid to converge with the opposition team's centroid in an 11-a-side match format. Investigations using a weighted centroid are required to determine if similar results would occur.

Other research in football suggests a strong relationship between opposing teams centroids during match-play (McGarry, O'Donoghue, & Sampaio, 2013). This discovery expresses the recurrent flow of teams attacking and defending whilst moving up and down the field in a synchronised manner (Memmert, et al., 2017; Siegle & Lames, 2013). The association between centroids has been further analysed in smaller sub-groups of players including attackers, defenders, and midfielders (Goncalves, et al., 2014). Results indicate that players were more coordinated with their position specific centroid, which suggests players may be more attuned to players that are facilitating similar roles (Goncalves, et al., 2014).

Investigations that assess how the team centroid differs between various contextual variables identified a larger distance between team centroids in football when increasing 4-a-side to 5-a-side and comparing younger players to more experienced players (Aguiar, Goncalves, Botelho, Lemmink, & Sampaio, 2015; Folgado, et al., 2014). Conversely, other research has reported greater values between teams centroids in 3-a-side compared to 4-a-side SSG (Folgado, et al., 2014). Changes in pitch size have also been associated with a greater relative distance between team centroids (Frencken, Van Der Plaats, Visscher, & Lemmink, 2013).

Other research used the team centroid in football to demonstrate that teams position themselves higher up the field during home games compared to away games (Bialkowski, et al., 2014), and in the second half compared to the first half (Clemente, et al., 2013). This behaviour may result in an increased possession in the forward third and a greater number of shots on goal (Bialkowski, et al., 2014). Irrespective of match context, the majority of research assessing the team center identifies that teams tend to maintain an overall position behind the centre of the field, thereby preserving a level of defensive stability (Bialkowski, et al., 2014; Castellano, et al., 2013; Clemente, et al., 2013; Vilar, et al., 2013).

2.3.1.2 Team Dispersion

Team dispersion represents the amount of expansion and contraction teams execute on a field of play (Frencken, et al., 2013). This concept has been applied to understand how teams manage space throughout a match during different timescales (Duarte et al., 2012). Various measures of team dispersion have been assessed in research to date with some of the more commonly used metrics including; team length (algorithm 2-2) (Clemente, et al., 2013; Folgado, et al., 2014), team width (algorithm 2-3) (Castellano, et al., 2013; Clemente, et al., 2013), team stretch index (algorithm 2-4) (Clemente, et al., 2013; Duarte, Travassos, Araújo, & Richardson, 2013), and team surface area (algorithm 2-5) (Duarte, et al., 2013).

Algorithm 2-2: Team length is measured as the distance between the most forward and most backward player in the *x*-axis (m) (Frencken, et al., 2011). Where $\boldsymbol{t_l}$ is calculated by subtracting the most forward player $\boldsymbol{max(P_x)}$ by the most backward player $\boldsymbol{min(P_x)}$ in the *x*-axis at each point in time (*i*).

$$t_l\,(i) = \; max\big(P_x(i)\big) - \; min\big(P_x(i)\big)$$

Algorithm 2-3: Team width is defined as the distance between the two most lateral players on the ground in the *y*-axis (m) (Frencken, et al., 2011). Where $\boldsymbol{t_w}$ is assessed by subtracting the most lateral player $\boldsymbol{max(P_y)}$ by the least lateral player $\boldsymbol{min(P_y)}$ in the *y*-axis at each point in time (*i*).

$$t_w(i) = \; max\left(P_y(i)\right) - \; min\left(P_y(i)\right)$$

Algorithm 2-4: The stretch index considers the mean dispersion of the players in relation to the team centroid (Clemente, et al., 2013). Where *SI* is calculated by assessing the positions of all players in the *x*-axis $\boldsymbol{p_{xk}(t)}$ and *y*-axis and subtracting from the team centroid *C* at instant *t.* This is then divided by the total number of players *N* on a field of play.

$$SI_{(t)} = \frac{\sum_k^N \sqrt{(p_{xk}(t) - C_x(t))^2 + p_{yk}(t) - C_y(t))^2}}{N},$$

Algorithm 2-5: The team surface area of each team has been calculated as the total space (m) covered by a single team, referred to as a convex hull (Frencken, et al., 2011). Where *SA* is calculated as the area of the polygon measured as the area with the least number of vertices (x_i, y_i) that can encompass all players on the field.

$$SA = \frac{(x_1y_2 - y_1x_2) + (x_2y_3 - y_3x_2) + \cdots + (x_ny_1 - x_1y_n)}{2}$$

Researchers in football suggest team length, width, and surface area may be used to identify the expansion and contraction of teams during different game states (Clemente, et al., 2013; Figueiredo, et al., 2014). Teams may aim to reduce the playing area by decreasing the space between players whilst defending (Castellano, et al., 2013; Olthof, Frencken, & Lemmink, 2015). Alternatively, during attacking sequences of play, teams may aim to generate increased space between players to allow easier passage of the ball (Castellano & Casamichana, 2015). Studies support this proposition with higher values of length, width, and surface area recorded during offence when compared to defence (Castellano, et al., 2013; Clemente, et al., 2013; Clemente, et al., 2013). However, greater possession rates may explain why teams display greater values in total length, width, and surface area as these teams are spending increased time in offence (Castellano, et al., 2013; Clemente, et al., 2013). Research supports this proposition as stronger teams recorded higher values of length, width, and surface area during offence when compared to defence when playing against weaker counterparts (Castellano, et al., 2013). Other studies in football have found that team length, width, and surface area for less experienced teams displayed a greater spread along the ground but a shorter dispersion across the ground when compared to more experienced teams (Folgado, et al., 2014; Olthof, et al., 2015). While teams covered larger areas in defensive situations prior to critical moments, such as, the opposition producing a shot on goal (Moura, Martins, Anido, De Barros, & Cunha, 2012). Conversely, teams generally occupied greater regions in drawn matches compared to winning or losing matches (Figueiredo, et al., 2014). Midfielders in football also cover larger areas than defenders and attacking players (Clemente, Silva, Martins, Kalamaras, & Mendes, 2016).

An initial study using the team stretch index identified the emerging nature of match play in football by showing the alternating expansion and contraction of players during offensive and defensive sequences of play (Yue, Broich, Seifriz, & Mester, 2008). Similar findings were observed in basketball with the team stretch index expanding during offensive phases and compressing during defensive phases (Bourbousson, et al., 2010). Team stretch index was also reported to be greater during home matches compared to away matches (Duarte, et al., 2013). Finally, investigations in under 13's football found a negative relationship between the weighted teams' stretch index of both teams without possession of the ball compared to being in possession of the ball, which indicates teams create space by expanding in offence and contracting in defence (Clemente, Couceiro, Martins, & Korgaokar, 2012).

2.3.1.3 Team Synchronisation

Team synchrony has generally been assessed via relative phase to describe the movement coordination between teammates and opponents (Travassos, et al., 2013). This is typically processed using a Hilbert transform method to determine the coordination between two oscillating signals, such as each player's velocity or spatial displacement (McGarry, Anderson, Wallace, Hughes, & Franks, 2002; Palut & Zanone, 2005). The output values are generally expressed in angles (Memmert, et al., 2017). Values closer to 0° represent patterns of synchronisation, which are referred to as in-phase, while values closer to 180° refer to patterns of less coordination, which are described as anti-phase (Folgado, Duarte, Fernandes, & Sampaio, 2014).

Studies in football found that a pattern of coordination between attacking players who had possession of the ball and the closest defending player (Travassos, et al., 2013). From a practical perspective, this finding suggests that defender positioning may constrain how players on the attacking team regulated their movement in order to create new tactical options for the player with possession of the ball (Travassos, et al., 2013). Other research in football found successful outcomes in relation to the attacking team, such as manoeuvring past a defender, were associated a greater level of synchronisation with opposition defenders (Duarte et al., 2012). Conversely, defensive success in football was associated with the defending player's ability to create an anti-phase state that disrupted or created a new coordinated system between opponents (Duarte, et al., 2012). More recent research indicated that football players were highly synchronised throughout the first half in elite level competition (Memmert, et al., 2017), which be due to players closely following opponents (Spencer, Robertson, & Morgan, 2017). However, the coordination between players decreased in the second half, especially between midfield opponents, which authors suggested might have been due to fatigue (Memmert, et al., 2017; Spencer, et al., 2017).

2.3.1.4 Division of labour

The division of labour is a concept that infers the tactical behaviour of teams by measuring how players interact with teammates and opponents by recording their movements throughout a match (Duarte, et al., 2012; Silva, et al., 2014). This has been assessed by measuring the dominant region of players and teams to emphasise a greater influence over a specific area (Clemente, et al., 2018). Essentially, a dominant region measures the total discrete area where a player can arrive earlier than others (Taki & Hasegawa, 2000). Research to date has measured the dominant regions of players and teams via Voronoi diagrams (Taki & Hasegawa, 2000), major ranges (Duarte, et al., 2012; Yue, et al., 2008), heat maps or spatial distribution maps (Couceiro, Clemente, Martins, & Machado, 2014; Silva, et al., 2014), and team separateness (Silva, Vilar, Davids, Araújo, & Garganta, 2016).

A Voronoi diagram is calculated by dividing the length and width of the field to create 1 m^2 squares (Clemente, et al., 2018). Each square is then assigned to the player with the shortest euclidean distance from it (Clemente, et al., 2018). The total number of squares attributed to each player highlights their dominant region (Clemente, et al., 2018). This approach classifies the exchange between teams by observing the interrelating spatial occupation throughout a match (Fonseca, Milho, Travassos, Araújo, & Lopes, 2013; Fujimura & Sugihara, 2005; Passos, et al., 2009). Studies using Voronoi diagrams in futsal observed the spatial dominance of teams during offence and defence and recorded a greater dominant region during offensive phases compared to defensive phases (Fonseca, et al., 2013). Other research in football found that higher ranked teams controlled more space, particularly in their forward half, in crucial regions, such as 30 m out from the opponent goal, and in dominant victories, including winning by 2 or more goals (Memmert & Rein, 2018).

Analysing the major range a player can cover has also contributed to the analysis of dominant regions of players (Yue, et al., 2008). This has been measured by centring an ellipse around each player with the axes quantifying the standard deviation in the x- and y-directions (Yue, et al., 2008). Fundamentally, it measures a player's range of spatial displacement throughout a match to infer the coordination between teammates (Clemente, et al., 2018). By assigning the spread of movement to identify the role of players, a translation to the team can be made to propose different playing styles (Clemente, et al., 2018). Studies in football have found the major range of players were stretched in the x-axis during attacking phases of play, which may indicate a more direct style of play (Clemente, et al., 2018). Conversely, a greater spread in the y-axis during the attacking phase may indicate a more possession-based approach that observes a team aiming to retain control of the ball (Clemente, et al., 2018).

Further approaches to quantifying dominant regions include heat maps or spatial distribution maps (Couceiro, et al., 2014). Movement behaviour of players can be measured by considering the total time spent in specific regions across a field of play (Clemente, Couceiro, Martins, Dias, & Mendes, 2012; Couceiro, et al., 2014). Practically, increased time spent at specific locations will indicate a greater density on the field. Recent work has aimed to identify a teams playing style by assessing ball occupancy through heat maps (Bialkowski et al., 2014; Lucey, et al., 2012). This type of analysis may provide a quantitative and visual method that assesses the variability of a team's ball movement in football (Bialkowski, et al., 2014). Results indicate that when teams play away from home they adopt a more conservative approach by occupying the ball closer to their own goal (Bialkowski, et al., 2014). Conversely, teams may be more attacking when playing at home as they occupy the ball farther up the field towards the oppositions goal (Bialkowski, et al., 2014). Heat maps have also been used in under 15's football teams during SSG (Silva et al., 2015). The findings indicated that more proficient players displayed a greater spread across a field of play compared to less skilful players when playing on a smaller sized ground but found no difference when playing on a larger sized ground (Silva, et al., 2015). However, some considerations have to be accounted for when using heat maps to quantify the movement variability of players (Couceiro, et al., 2014). Specifically, player's position is recorded without accounting for trajectory, which means the notion of time is ignored (Couceiro, et al., 2014; Silva, et al., 2015).

Finally, team separateness has been used to assess the division of labour by providing a measure of the degree of free space available to each team (Silva, et al., 2016). This has been achieved by calculating the area between players of both teams (Silva, et al., 2016).

Typically, this is measured by averaging the distance between all players to their nearest opponent (Silva, et al., 2016). Researchers proposed that team separateness could be used to understand the amount of relative space a player may have, which could describe the amount of 'pressure' a player may encounter (Silva, et al., 2016). However, an introductory study in football using this metric found no changes in team separateness using various SSG formats (3v3, 4v4, 5v5) (Silva, et al., 2016).

2.3.2 Entropy

The emerging nature and underlying complexity of team sports implies continuous variation in the spatial displacement of players throughout a match (Araújo & Reilly, 2005; Davids, Araújo, & Shuttleworth, 2005). Researchers have proposed this intrinsic variation in player movement may be used to describe the tactical behaviour of players (Vilar, et al., 2013). Specifically, players are generally consigned to a specific role and therefore occupy a certain region on the ground (Frencken, Poel, Visscher, & Lemmink, 2012). The regularity of a player's movement may provide an indication of how teams regulate player positioning during various contextual variables, such as, game score, match location, and quality of opposition (Bialkowski, et al., 2014; Lucey, et al., 2013).

Studies in team sports have used non-linear methods to measure variability to understand the inherent deviation of a system (Harbourne & Stergiou, 2009). This has been implemented through various measures of entropy in an attempt to measure the uncertainty of a variable (Cover & Thomas, 2012). For instance, multiscale entropy has been used to assess the complexity inherent to the biological signals (Costa, Goldberger, & Peng, 2002) and to understand how manipulations of resistance training influence the amount of complexity of physical outcomes in team sports (Moras et al., 2018). Entropy-based measures used in collective team behaviour investigations are generally understood in regards to movement variation (Couceiro, et al., 2014). A reduction in entropy signifies less variation as the minimum amount of information required is also reduced (Silva, Duarte, Esteves, Travassos, & Vilar, 2016). Conversely, an increase in entropy denotes greater variation as the minimum information required to describe the system is increased (Silva, et al., 2016). Research into collective team behaviour has typically used two measures of entropy when describing variation in invasion sports. These being Shannon's Entropy or information Entropy and Approximate Entropy (Couceiro, et al., 2014).

Claude Shannon first developed Information Entropy as a method to quantify the lost information in phone-line signals during World War II (Gleick, 2012). Information Entropy or Shannon Entropy (ShannEn) is now used in a multitude of disciplines including human movement, sports performance analysis, linguistics, and neurobiology (Silva, et al., 2016). Studies have used ShannEn to measure the variability of information content, which is projected from the average amount of information comprised in a specific communication (Silva, et al., 2016). The ShannEn has been used in football to infer player movement variation by analysing the movement trajectories of players and teams (algorithm 2-6) (Silva, et al., 2014).

Algorithm 2-6: The probability mass function $p_{(i)}$ is provided by the following formula (Shannon, 1948). Where *hi* displays the histogram entries of the density value *i* and N_c is the number of total cells of the field (typically measured in m^2).

$$p\ (i) = \frac{h(i)}{Nc}$$

$$S\ =\ -\sum_{i=0}^{n-1} p\ (i) \log p\ (i)$$

Further studies have normalised ShannEn to provide a relative number between 0 and 1 (Couceiro, et al., 2014). A low ShannEn (near 0) suggests the variability of a given variable is low (Couceiro, et al., 2014), while a high ShannEn (near 1) indicates the variability of a given variable is high (Couceiro, et al., 2014).

The ShannEn has been used in football to infer player movement variation by analysing the movement trajectories in the form of heat maps during SSG and conditioning formats (Silva, et al., 2014). Research highlighted differences in player's spatial displacement between games played on altered ground dimensions and players of different skill levels in football (Silva, et al., 2014). Authors observed more skilful players recorded greater entropy values on smaller grounds compared to less experienced players, while both groups displayed similar values on larger sized fields (Silva, et al., 2014). Higher entropy values were used to imply greater variability or uncertainty in locating a player within a specific region (Silva, et al., 2014). In this regard, player's that obtained a broader tactical role may be required to perform more varied movement across a field of play (Silva, et al., 2014). Conversely, lower entropy values were associated with tactical roles that were more structured and therefore required less varied movement (Silva, et al., 2015).

Other research has used ShannEn to observe the variation in player numerical advantage during a football match (Vilar, et al., 2013). The effective playing area of all players on the field was divided into seven sub-areas of play (Vilar, et al., 2013). Numerical advantage was expressed as the difference between players of both teams in each one of these sections recorded throughout the match (Vilar, et al., 2013). Greater variation in numerical dominance during the middle sections on a field was also reported, which may represent that these sub-areas of play are of critical importance in fostering stability and instability (Vilar, et al., 2013).

Despite being useful for quantifying the spatial displacement of players, ShannEn does not include a time-dependent feature that accounts for variation evolving throughout a match (Silva, et al., 2016). Therefore, the underlying variation of player movement may not be captured as it occurs in real-time (Couceiro, et al., 2014). For this reason, researchers have used approximate entropy (ApEn) to quantify the amount of regularity of systems composed of interacting components (Silva, et al., 2016). This non-linear method analyses the extent of regularity within a time series (Pincus, Gladstone, & Ehrenkranz, 1991). This is quantified by calculating the logarithmic probability that a group of data points a certain distance apart will display comparable features on the subsequent comparison within the same space (Pincus, et al., 1991). Put simply, a sequence of data points is more regular if the following data points expand in a similar manner (Pincus, et al., 1991). A time series with an increased prospect of continuing the same distance apart will exhibit reduced ApEn values (Silva, et al., 2016). Conversely, a time series that displays large differences between data points will exhibit greater ApEn values (Silva, et al., 2016). Calculating ApEn is provided by algorithm 2-7 (Pincus, et al., 1991).

Algorithm 2-7: A time series is divided into vector lengths (*m*) and *m + 1* points to count the quantity of similar vectors that are within a threshold of $\pm r$. The provisional probabilities ($\boldsymbol{\phi}$) of each vector (*m* and *m + 1*) are calculated by dividing the amount of matches by the total amount of vectors. Each probability (*m* and *m + 1*) is totalled and averaged with the difference defining the ApEn value:

$$ApEn\ (m, r, \mathrm{N}) = \phi^{m}(r) - \phi^{m+1}(r)$$

Typical analysis set the *m* input parameter at 2 and *r*-value between 0.1 and 0.25 of the standard deviation (Silva, et al., 2016). Length of time-series (*N*) could be as long as 1000 data points or as short as 75 (Pincus, et al., 1991). ApEn values generally vary between 0 and 2, with values closer to 2 indicating time series with less regular or more variable patterns (Fonseca, et al., 2013). Values closer to 0 imply a more regular or less variable time series (Fonseca, et al., 2013).

Variation in football during 5-a-side SSG has been measured using ApEn to suggest the distance of players to their team centroid became more regular after tactical training in novice players (Duarte, et al., 2012; Sampaio & Macas, 2012). This may suggest that expansion and contraction of players became more stable over time and could indicate the expertise of a team (Sampaio & Macas, 2012). Similar findings in the regularity of team dispersion were reported when measuring the variation in movement behaviour throughout a match in football with reduced ApEn values during each half of the match (Duarte, et al., 2013). This may have been a combination of increased coordination and fatigue by players (Duarte, et al., 2013). Football players separated into groups containing midfielders, forwards, and defenders were also used to identify that coordination of group centroid was more regular within their respective groups compared to other groups (Goncalves, et al., 2014).

Investigations into a team numerical disadvantage in 5-a-side SSG formats produced an increase in regularity in regards to the distance to the team centroid (Sampaio, et al., 2014). A team numerical advantage found that more skilful players displayed an increase in regularity with respect to the opponents when facing a numerical disadvantage (Goncalves, et al., 2016). Finally, variation of spatial dominance using Voronoi cells in futsal revealed defending teams displayed decreased coordination between players (Fonseca, et al., 2013).

2.3.3 Limitations

It may be somewhat superficial to associate certain spatiotemporal metrics with a particular tactic or strategy as collective team behaviour is influenced by contextual variables throughout a match (Rein & Memmert, 2016). For example, a team that records greater length, width, and surface may be identified as having an expansive strategy that aims to maintain possession of the ball and spread the opposition defenders. However, increased ball possession will also generally result in the same outcome due to increased time in the attacking phase. As such, players could be innately adapting to the context of the match, rather than undertaking a predetermined strategy to be expanding the playing space. Other predetermined strategies inferred from spatiotemporal metrics could include a team centroid being positioned in a team's defensive half, which may suggest conservative behaviour with an aim to restrict the opposition from scoring. However, a team that is unable to transition the ball out of its defensive half may indicate why the team centroid is behind the centre of the field, instead of a defensive strategy to preserve players closer to their own goal. In this sense, spatiotemporal metrics used to infer collective team behaviour may not necessarily represent a preconceived tactical behaviour or game style but rather an adaption to the general state of play (Rein & Memmert, 2016). Despite contextual factors providing a more informed understanding of collective behaviour, macroscopic approaches don't exclusively model each individual player at each point in time (Bialkowski, et al., 2014). As such, inferring tactical team behaviour via this method may result in information loss (Bialkowski, et al., 2014). Therefore, a more microscopic approach (see Section 2.4.4 below) is preferred as it considers all players constantly throughout a match. Determining the collective behaviour of all players in a continuous manner may provide a more representative understanding of collecive team behaviour.

2.3.4 Microscopic Approach

Recently, investigations into tactical team behaviour have modelled all players in a team to understand how they occupy different regions on a playing field at different timescales (Bialkowski, et al., 2014; Fernandez & Bornn, 2018; Spencer, et al., 2019). This information provides a comprehension of how player positioning can provide teams with a certain amount of spatial control over specific areas of play (Fernandez & Bornn, 2018; Spencer, et al., 2019). Teams may regulate player positioning to adjust this control to increase attacking potency by fostering instability in opposition defensive formations or to provide a greater amount of defensive stability (Vilar, et al., 2013).

Initially, research into team spatial control focused on discrete approaches that included how teams generated a player numerical advantage at different sub-areas on a field of play by outnumbering the opposing team (Silva, et al., 2014; Vilar, et al., 2013). Studies in football proposed that match success is associated with a team’s ability to generate a numerical advantage during offensive sequences of play (Vilar, et al., 2013) and to preserve defensive stability by allocating a greater number of players closer to their goal when compared to the opposition (Clemente, Couceiro, Martins, Mendes, & Figueiredo, 2015; Vilar, et al., 2013). However, contextual variables, such as, phase of match play and ball location are yet to be reported when assessing how teams generate a numerical advantage throughout a match. Furthermore, investigations that associate a team numerical advantage with the impact on match play in a continuous manner remain absent. Despite modelling each player when assessing a teams dominant region, studies presume that a team numerical advantage is associated with the exclusive control over a discrete sub-area of play, which may be somewhat simplistic (Fernandez & Bornn, 2018). This approach disregards the notion that spatial control over a specific region is uncertain. Constant movement of teammates and opponents generates a system where players have a degree or probability of control (Spencer, et al., 2019). Studies have since taken a continuous approach to assess the spatial control of teams (Fernandez & Bornn, 2018). Researchers in football have recorded how players generate and occupy space in the overall dynamics of a match (Fernandez & Bornn, 2018) and assessed the risk and reward of passing decisions in AF (Spencer, et al., 2019). However, studies are yet to investigate the extent to which continuously represented spatial control varies with respect to specific match play events. In addition, investigations determining how continuous team spatial control is influenced by contextual variables, such as match phase and ball position are yet to be reported.

2.4 Australian Rules Football

2.4.1 Game Characteristics

Australian Rules football (AF) is an invasion team-sport that is the most popular football code in Australia (Gray & Jenkins, 2010). The premier competition, the Australian Football League (AFL), consists of 18 teams played on an oval shaped (length = ~160 m, width = ~130 m) field (Johnston, Black, Harrison, Murray, & Austin, 2018). A team is comprised of 22 players, with 18 players allowed on the field at any one time (Gray & Jenkins, 2010). Match play has been described as a primarily aerobic running game combined with speed that requires a high level of skillful foot and hand passing (Gray & Jenkins, 2010). The game is divided into 20 min quarters with extra time added to account for any stoppages in play (Johnston, et al., 2018). Players are typically considered in positions as forwards, defenders or backs, and nomadic or midfielders (Gray & Jenkins, 2010). The overall objective of the game is to obtain or maintain possession of the ball and advance it into the opposition's defensive area to attempt a scoring opportunity (Gray & Jenkins, 2010). A goal is scored when a player kicks the ball through the two large goalposts and equates to 6 points (Woods, 2016). If a player misses the large goalposts but the ball passes through the small goalposts on either side, a single point is registered (Woods, 2016). If neither team has possession of the ball it is considered to be in contest (Gray & Jenkins, 2010). These periods occur after a goal is scored, the umpire officiates a stoppage in play or the ball goes out of bounds (Gray & Jenkins, 2010).

2.4.2 Performance Analysis Research in the AFL

Performance in AF has been linked through time motion analysis investigations (Boyd, Ball, & Aughey, 2013; Brewer, et al., 2010). Studies indicate AF is an intermittent sport containing low intensity activities interspersed with high intensity activities (Brewer, et al., 2010). Match play also involves contact including tackling, blocking, and collisions (Boyd, et al., 2013). Successful match outcomes have been associated with increased total distance but a reduction in high-speed running (Ryan, Coutts, Hocking, & Kempton, 2017). This may indicate that teams were able to possess the ball more effectively and undertook fewer high-speed movements whilst defending (Gronow, Dawson, Heasman, Rogalski, & Peeling, 2014). Although, other research has shown that successful teams complete increased higher-speed running whilst defending (Sullivan et al., 2014). This may suggest that these teams may have been more evenly matched and the outcome could have been influenced by an increased work-rate without possession (Johnston, et al., 2018). Notwithstanding, it appears that the overall movement behaviour or players has little impact on the match outcome when observed in isolation without considering other contextual factors.

Other investigations in AF have explained the match outcome using team performance indicators (Robertson, Back, & Bartlett, 2016; Robertson, Gupta, & McIntosh, 2016). Successful kicks and goal conversion rates appear to be the most important indicators when describing team performance (Robertson, et al., 2016). The technical nature of the game has undergone evolution in recent time with skill involvements increasing in kicks, handballs, and tackles, which has been associated with teams potentially adopting a higher possession based strategy (Woods, Robertson, & Collier, 2017). Game styles may have also evolved, with defensive coaching strategies potentially implemented to increase the emphasis on preventing the amount of scoring by opposing teams (Norton, 2013). This may be achieved by increasing the number of players within the vicinity of the ball, which may result in more congestion (Norton, 2013). Coaches may appear to advocate for a defence first mentality and then attack with speed and spread once gaining possession of the ball (Norton, 2013). These defensive strategies may include 'zonal defensive' where defending players occupy space rather than aim to gain possession of the ball and 'tagging' where a player's main responsibility is to minimise the influence of an opposition player, instead of contributing to attacking sequences (Norton, 2013). In light of this, overall match play in AF has observed lower scoring, increased number of stoppages, and a decrease in the amount of time the ball is play (Gray & Jenkins, 2010; Woods, et al., 2017).

Notwithstanding this, limited investigations exist that use spatiotemporal data in Australian Rules football to understand the collective organisation of players throughout a match. This may be due to the access of reliable player tracking data. The availability of this information may be used to describe tactical team behaviour, whereby repetitive patterns of movement are formed (Sampaio & Macas, 2012). These types of investigations also have the capability to provide a greater context to match events and discrete team and player performance indicators. Macroscopic and microscopic approaches have been used for assessing collective team behaviour. Macroscopic approaches assess the collective organisation of teams via spatiotemporal metrics (Clemente, et al., 2013; Folgado, et al., 2014; Frencken, et al., 2011). However, limited studies using spatiotemporal metrics to investigate the collective behaviour in AF teams have included various contextual variables, such as match phase and ball position. Microscopic approaches enable the modelling of all players, which may provide a more representative understanding of collective team behaviour. Specifically, a discrete method measures a player numerical advantage in specific sub-areas on a field of play, while a more continuous model measures team spatial control that isn't restricted by distinct zones but instead determines the probability of control by considering the position of the ball, teammates and opponents. However, the continuous balance of spatial control between two competing teams and its association to match play is yet to be investigated in AF. This information has the potential to provide a complementary assessment to add to existing tactical behavior investigations common in invasion sports.

AIMS OF THE THESIS

The overarching objective of this thesis was to provide a framework to assess tactical team behaviour in Australian Rules football. The specific aims were to:

- Measure whether differences in collective team behaviour exist in Australian Rules football during different phases of match play and to determine the extent to which collective team behaviour differed between competing teams and match half (Study One).
- Investigate the influence of match phase and field position of the ball on collective team behaviour in Australian Rules football during a competitive match (Study Two).
- Determine the relationship between a team numerical advantage and match play in Australian football in a continuous manner and quantify how players occupy different sub-areas of play, while accounting for match phase field position of the ball (Study Three).
- Determine the extent to which continuously represented team spatial control varies with respect to specific match play events in Australian football and identify whether differences in team spatial control exist during different match phases and field position of the ball (Study Four).

CHAPTER 3. STUDY 1 – COLLECTIVE TEAM BEHAVIOUR OF AUSTRALIAN RULES FOOTBALL DURING PHASES OF MATCH PLAY

This chapter is presented in pre-publication format of a recent publication titled:

Alexander, J. P., Spencer, B., Mara, J. K., & Robertson, S. (2019). Collective team behaviour of Australian Rules football during phases of match play. *Journal of sports sciences*, *37*(3), 237-243.

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Jeremy P. Alexander, Bartholomew Spencer, Jocelyn. K. Mara & Sam. Robertson (2019) Collective team behaviour of Australian Rules football during phases of match play, Journal of Sports Sciences, 37:3, 237-243, DOI: 10.1080/02640414.2018.1491113

3.1 Abstract

Using the spatiotemporal characteristics of players, the primary aim of this study was to determine whether differences in collective team behaviour exist in Australian Rules football during different phases of match play. The secondary aim was to determine the extent to which collective team behaviour differed between competing teams and match half. Data was collected via 10 Hz global positioning system devices from a professional club during a 2 x 20 min, 15-v-15-match simulation drill. Five spatiotemporal variables from each team (*x* centroid, *y* centroid, length, width, and surface area) were collected and analysed during offensive, defensive, and contested phases. A multivariate analysis of variance comparing phase of match play (offensive, defensive, contested), Team (A & B), and Half (1 & 2) revealed that *x*-axis centroid and *y*-axis centroid showed considerable variation during all phases of match play. Length, width, and surface area were typically greater during the offensive phase comparative to defensive and contested phases. Clear differences were observed between teams with large differences recorded for length, width, and surface area during all phases of match play. Spatiotemporal variables that describe collective team behaviour may be used to understand team tactics and styles of play.

3.2 Introduction

Research into the tactics or playing styles of invasion sport teams has typically been undertaken using notational analysis. This method involves the recording of discrete actions by players and teams (i.e., number of passes, possession, turnovers) in a sequential order (Hughes & Franks, 2005; Lago, 2009; Liu, Gomez, Lago-Penas, & Sampaio, 2015; Vogelbein, et al., 2014). Whilst useful in determining subsequent features of team tactics or styles of play, this approach potentially underestimates the complexity of invasion sports by disregarding broader contextual information, such as player positioning in relation to teammates and opponents (Duarte, et al., 2012; Travassos, et al., 2013; Vilar, et al., 2012).

One reason behind a lack of progress in using such contextual information may be in part due to the absence of accessible and reliable data (Memmert, et al., 2017). The advent of player tracking technologies has allowed for increased access to spatiotemporal data in training and matches. More recently, researchers have used this data to generate a range of variables that determine how teams position themselves across a field of play (Clemente, et al., 2013; Clemente, et al., 2013; Frencken, et al., 2011). Common examples include: team centroid, which has been measured longitudinally, laterally, or radially (Clemente, et al., 2013), team surface area (Castellano, et al., 2013; Clemente, et al., 2013; Clemente, et al., 2013; Frencken, et al., 2011), and team length and width (Castellano, et al., 2013; Castellano & Casamichana, 2015; Clemente, et al., 2013; Clemente, et al., 2013; Folgado, et al., 2014). The expression and interaction of these variables in different match contexts can then be used to define and understand collective team behaviour.

Such information has been used to inform team tactics or styles of play (Clemente, et al., 2013; Clemente, et al., 2013; Folgado, et al., 2014). In football, the team *x*-axis (longitudinal) centroid has been used to determine that teams are positioned higher up the field during home games when compared to away games (Bialkowski, et al., 2014) and in the second half compared to the first half (Clemente, et al., 2013). Irrespective of match context, teams tend to maintain an overall position behind the centre of the field, thereby preserving a level of 'defensive stability' (Castellano, et al., 2013; Clemente, et al., 2013; Clemente, et al., 2013; Vilar, et al., 2013). Other football research has revealed that the surface area of experienced teams was greater compared to less experienced teams (Olthof, et al., 2015) and values decreased throughout the match when comparing the first and second half (Clemente, et al., 2013). Further, comparative to lower ranked counterparts, higher ranking teams generally use more width than length by having more supporting players across the field than along it (Castellano & Casamichana, 2015).

Invasion sports have been separated into different phases of match play, such as offence and defence, which are typically dictated by ball possession (Clemente, et al., 2013). Simply, the aim in offence is to advance the ball along a playing surface to score a goal, whilst the aim of defence is to prevent the opposition from achieving this same aim (Memmert, et al., 2017). However, as offence and defence are concomitant a team cannot position players to create more attacking options whilst maintaining players in supportive regions to preserve defensive stability (Grehaigne, et al., 1997). As such, distinct differences in player positioning may occur between phases due to the emerging requirements throughout a match (Castellano, et al., 2013; Clemente, et al., 2013; Clemente, et al., 2013). It has been suggested that during offence, teams generally aim to spread to opposition's defending players to create space (Vilar, et al., 2013). While during defence, players will generally aim to restrict the area in which the opposition can attack in (Vilar, et al., 2013). Studies support this proposition with higher values of length, width, and surface area recorded during offence when compared to defence (Castellano, et al., 2013; Clemente, et al., 2013; Clemente, et al., 2013). Therefore, the amount of possession may influence the overall collective behaviour of teams (Castellano, et al., 2013; Clemente, et al., 2013). Despite this, limited studies that have analysed collective team behaviour in invasion sports have compared between phases of match play (Castellano, et al., 2013; Clemente, et al., 2013; Clemente, et al., 2013). Those that have done so are limited to utilising junior players in a 7-a-side playing format (Clemente, et al., 2013) or have not quantified the total amount of possession (Castellano, et al., 2013; Clemente, et al., 2013). Furthermore, despite a body of research examining collective team behaviour in football, investigations into Australian Rules football remain largely absent. Australian Rules football is a sport where teams compete on an oval shaped field (length = ~160 m, width = ~130 m) with 22 players in total, with 18 on the field and 4 on an interchange (Gray & Jenkins, 2010).

Determining collective team behaviour has become a central component of match analysis due to its relationship with performance outcomes (Memmert, et al., 2017). Researchers have used this information to describe team tactics or game style and compare between different phases of play (Clemente, et al., 2013; Figueiredo, et al., 2014). However investigations in Australian Football (AF) have yet to be reported. Therefore, using the spatiotemporal characteristics of players, the primary aim of this study was to determine whether differences in collective team behaviour exist in Australian Rules football during different phases of match play. The secondary aim was to determine the extent to which collective team behaviour differed between competing teams and match half.

3.3 Methods

Data were collected from one training session with 30 male professional AF players (age 23.9 ± 4.3; height 188.0 ± 7.9; body mass 86.0 ± 9.4) recruited from a single team in the Australian Football League (AFL) competition. Participants took part in a match simulation drill as part of preseason training. All participants received information about the requirements of the study via verbal and written communication, and provided their written consent to participate. The Victoria University Ethics Committee approved the study.

Participants were separated into two teams of 15 each at the coach's discretion to ensure a relatively even competition. The teams were labeled Team A and Team B for analysis purposes. The match simulation took place on an oval shaped ground using dimensions 163.7 m x 129.8 m (length x width) with two 20-min halves and a 10-min break between periods. Data for all participants were collected using 10 Hz GPS devices (Catapult Optimeye S5, Catapult Innovations, Melbourne, Australia). The devices were housed in a fitted harness on the upper back. Previous investigations have assessed the validity and reliability of these devices (Johnston, et al., 2014; Varley, et al., 2012).

Possession of the ball was determined via video observation and analysed to the nearest decisecond by the first author. The offensive phase was recorded when a team first gained possession of the ball and maintained it for at least a second and ended when the opposing team gained possession of the ball for at least a second or there was a stoppage in play (i.e., the team scored or the ball went out of bounds) (Yue, et al., 2008). Using the same conditions, the defensive phase was recorded when the opposing team had possession of the ball (Yue, et al., 2008). If neither team had possession of the ball (i.e., when the officiating umpire returned the ball to play) the phase was considered to be in 'contest' until a team gained possession of the ball for at least a second. All periods where the ball was out of play (e.g. break between periods of play, ball out of play, celebration after goals) were excluded from the analyses.

Spatiotemporal characteristics of participants recorded from the GPS units were exported in raw 10 Hz format. Each file contained a global time stamp and calibrated location (*x*- and *y*- location). The centre of the ground was signified as 0, 0. Each participant's file consisted of approximately 33,000 data points including time and location. Spatiotemporal data were then synchronised with ball possession using the respective global time stamps. This was established using the initial point when the two widest players on the field converged from a stationary position prior to start of each quarter. Five variables (Figure 3-1) were derived from the data to describe collective team behaviour. First, team centroid was calculated as the mean (*x*, *y*) position of all players on the field of one team (Frencken, et al., 2011). Two measures were derived from the centroid position. These were the distance in the *x*-axis centroid (m) and the distance in the *y*-axis centroid (m) (Frencken, et al., 2011). The team surface area of each team was calculated as the total space (m) covered by a single team, referred to as a convex hull (Frencken, et al., 2011). Team length was measured as the distance between the most forward and most backward player in the *x*-axis (m) and team width was defined as the distance between the two most lateral players on the ground in the *y*-axis (m) (Frencken, et al., 2011). These variables were assessed during offence, defence, and contested phases of match play and during first and second halves. This was processed using the computational package Python version 3.2 with *Spyder*, which is part of the Anaconda software suite (www.python.org).

Statistical Analyses

Comparison of team *x*-axis centroid, *y*-axis centroid, length, width, and surface area were assessed between phase of match play (3 levels: Offence, Defence, Contest) and position (D50, DMID, FMID, F50), via a multivariate analysis or variance (MANOVA). Homogeneity was analysed using the Levene Test, which resulted in a lack of uniformity between phases of match play. The *F* test was used to combat homogeneity violations due to the fact the total number of samples is in each group was essentially equal (Vincent, 1999). Due to the non-homogeneity of the time series data, the Central Limit Theorem was considered, which allowed the assumption of normality to be made (Akritas, 2004). Cohen's conventions for effect size (*d*) with 95% confidence intervals were obtained, where 0.2, 0.5, and 0.8 are considered as small, medium and large, respectively (Cohen, 1988). Statistical calculations were determined using StatPlus™ (AnalystSoft, Alexandria, VA, USA) with significance set at $p < 0.05$.

3.4 Results

Between-phase comparisons for each team for the first and second half are displayed in Figure 3-2. Between-team comparisons for the first and second half are presented in Figure 3-3. The *x*-axis centroid for Team B displaying possession throughout the match is displayed in Figure 3-4. The amount of possession for the first and second half is shown in Table 3-1.

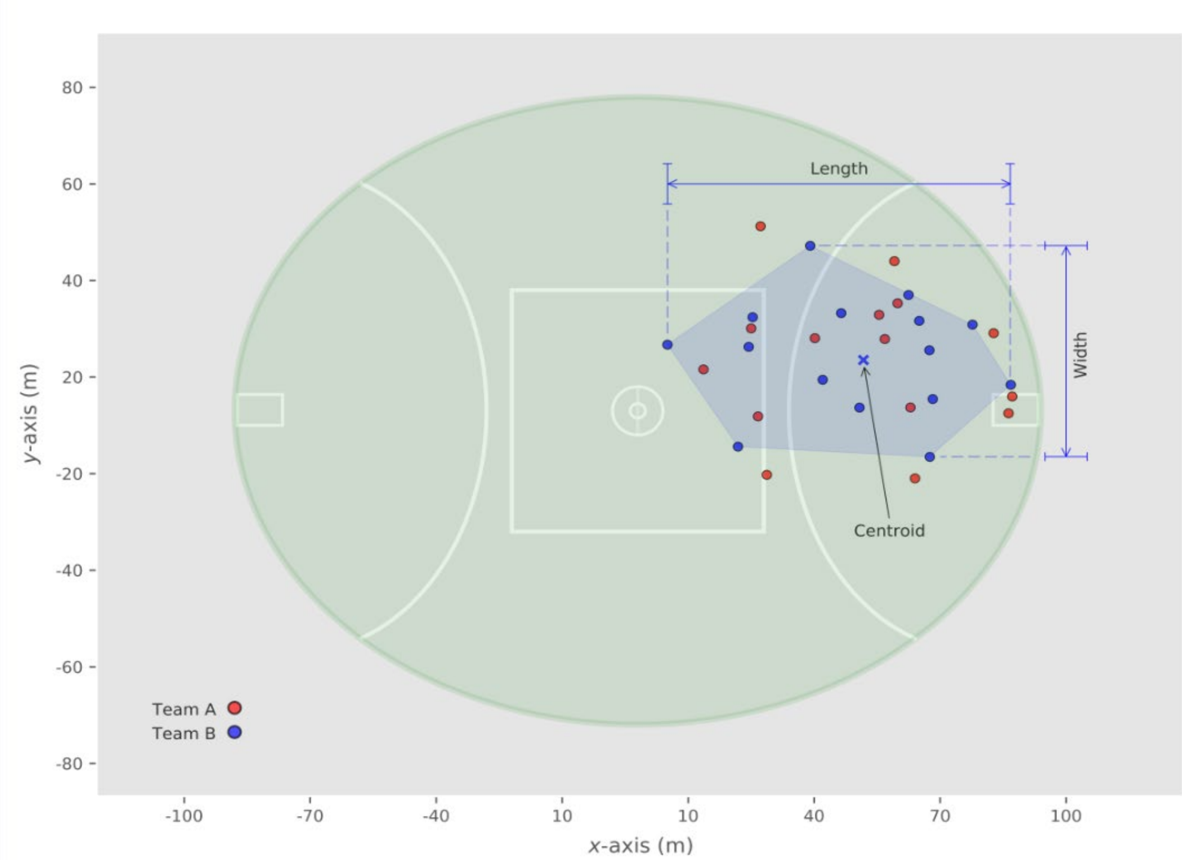

Figure 3-1: Centroid, length, width, and surface area for Team B at the 15 min mark of the first half.

Between-phase analysis for the *x*-axis centroid was mixed, as Team B was positioned higher up the field during offence when compared to defence. Although, Team A was closer to their defensive end when comparing offence to defensive and contested phases in the first half. The *y*-axis centroid displayed both teams were situated on the right hand side of the field in the first half during offence. Length was greater during offence compared to defence for both teams. Although, length during the contested phase was greater than offensive and defensive phases for both teams. Width was greater during offence compared to defence for both teams. Although Team B's width during contest was smaller during defence compared to the contested phase. Surface area was greater for both teams when comparing offence to defensive and contested phases of play and comparing defence to the contested phase.

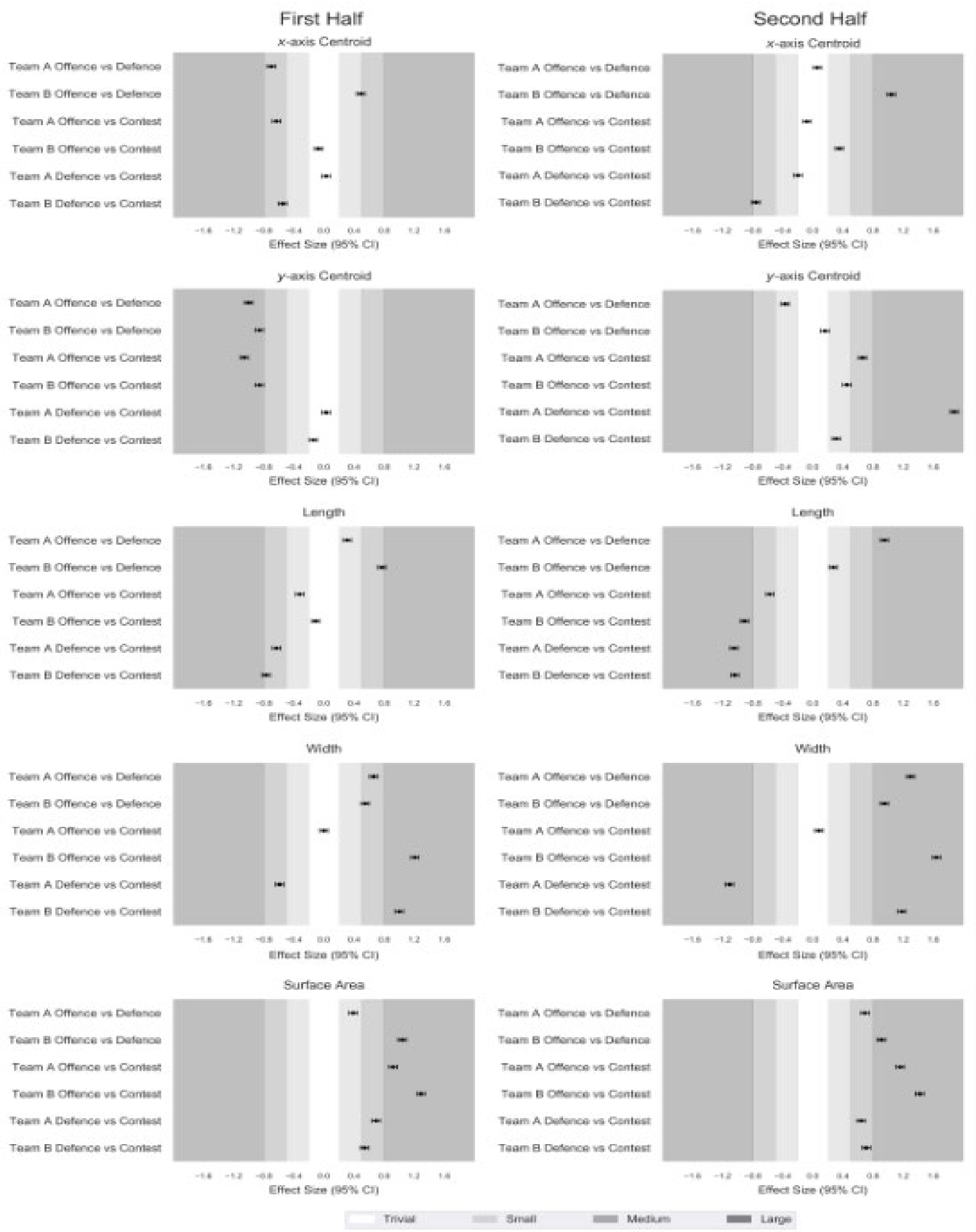

Figure 3-2: Between phase comparison of spatiotemporal variables for the first half and second half for Team A and Team B. Lighter-to-darker shaded areas indicate small, medium and large differences, respectively.

Between-team analysis (Figure 3-3) displayed the *x*-axis centroid of Team B as higher up the field in all phases of match play for the first half when compared to Team A. Contrastingly, in the second half, Team A was higher up the field in all phases of play when compared to Team B. Except for width during the contested phase, Team B had greater values in length, width, and surface area during all phases of play.

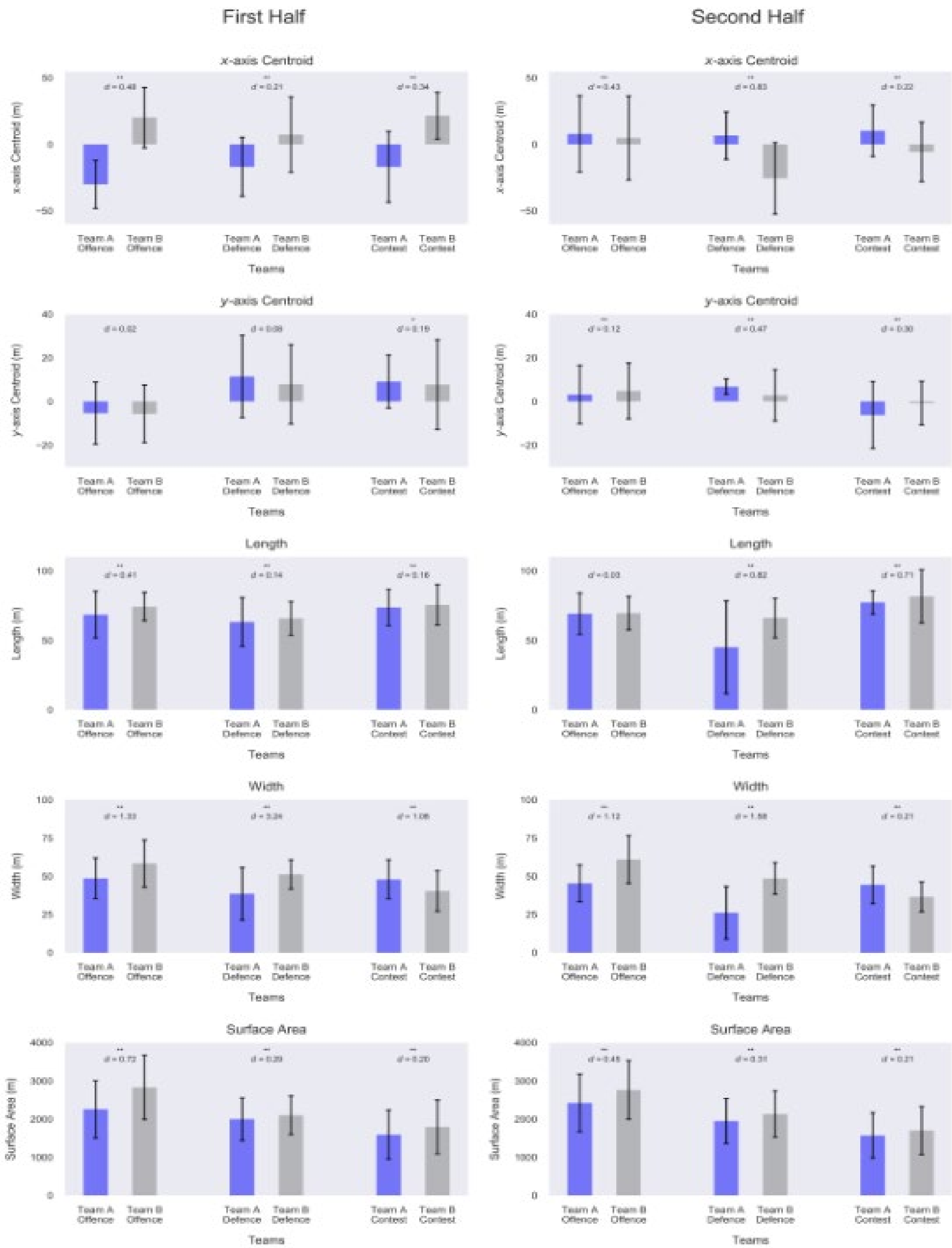

Figure 3-3: Between team comparison of spatiotemporal variables for the first half and second half.

p-value ≤ 0.05, ** p-value ≤ 0.001, *d*: Cohen's d

Possession data displayed that Team B had greater possession of the ball in the first half, while Team A had greater possession of the ball in the second half.

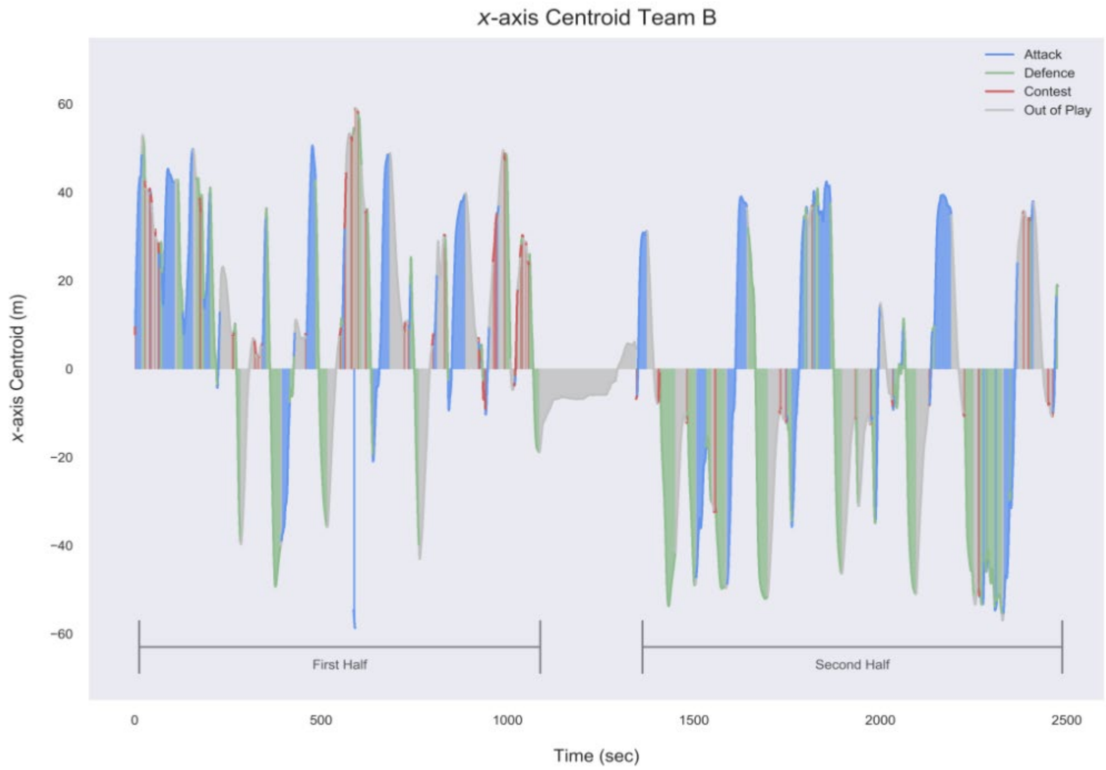

Figure 3-4: Variation in Team B *x*-axis centroid throughout both match halves. A positive value represents closer to the opponent goal.

Table 3-1: Possession rate for both teams in the first and second half

		1st Half		2nd Half	
Team	**Phase**	**Time (data points 10 Hz)**	**Portion (%)**	**Time (data points 10 Hz)**	**Portion (%)**
Team A	Offence	3741	39.75	4908	47.99
	Defence	4080	43.35	4450	43.51
	Contest	1590	16.90	870	8.51
Team B	Offence	4080	43.35	4450	43.51
	Defence	3741	39.75	4908	47.99
	Contest	1590	16.90	870	8.51

3.5 Discussion

This is the first study to describe collective team behaviour in AF teams during different phases of match play. The central finding was that collective team behaviour was influenced by match phase. The *x*-axis centroid and *y*-axis centroid recorded large variations during all phases of match play. Length, width, and surface area were typically greater during offence when compared to defence and contest. Between-team analysis established differences in collective team behaviour with Team B recording greater values in length, width, and surface area during all phases of match play.

In the first half, Team A's *x*-axis centroid recorded the team in their defensive half during all phases of match play. This may suggest that they were displaying more conservative team behaviour by preserving players to defend their goal. However, the *x*-axis centroid during offence was further behind their *x*-axis centroid in defence. This would indicate that the players moved towards their defensive end during attacking sequences, which would be counterintuitive. Therefore, this finding may be associated with where possession of the ball was gained or lost. If possession were gained in the defensive half, it would mean attacking sequences commenced further away from the opposition's goal. As subsequent attacking sequences moved towards their scoring end a turnover of possession would mean their centroid in defence is higher up the field of play. This may be associated with the possession rate as Team B had more possession of the ball in the first half, which would require Team A to defend more often and more than likely in their defensive end. In the second half, Team A had greater possession of the ball and their *x*-axis centroid was considerably closer to their goal in all phases of match play. As a result, Team B's *x*-axis centroid signified that they defended closer to their goal in both contested and defensive phases. However, Team B did maintain a positive *x*-axis centroid during offence throughout the whole match. The *y*-axis centroid indicated that both teams attacked from the right hand side of the field in the first half. Throughout the match, Team B displayed more expansive behaviour compared to Team A regardless of match. Specifically, Team B recorded consistently greater values in length, width, and surface area during all phases of match play, apart from width during the contested phase. This type of behaviour may be associated with players aiming to spread the opposition defending players to create a greater effective playing space, which allows for an easier passage of the ball (Vilar, et al., 2013).

Research undertaken in football suggests that overall teams employ more conservative team behaviour by positioning players closer to their own goal (Clemente, et al., 2013; Clemente, et al., 2013; Vilar, et al., 2013). Results from this study indicate that AF teams display large variations in both positive and negative overall positioning. Whilst a formal comparison between sports has not been made here, AF teams may be more willing to collectively move higher up the field if the ball is in their attacking end and conversely, reposition deeper towards their defensive end when the opposition has possession of the ball. Investigations in soccer have found that teams play with more length, width, and surface area in offence compared to defence (Clemente, et al., 2013). Correspondingly, this study suggests AF teams have typically greater values in offence compared to defence. Furthermore, both teams had a greater surface area in both offence and defence when compared to contest. This may indicate that both teams tried to constrict space when the ball was in dispute or be a defensive mechanism to close down space quickly if the opposition gained possession of the ball.

Whilst invasion sport teams will engage certain behaviours in order to achieve success, resulting player movement is constantly influenced by athletes adapting to contextual variables (i.e., match status, opposition team tactics, time, and where ball possession takes place) (Castellano, et al., 2013; Rein & Memmert, 2016). Therefore, it is difficult to differentiate if collective team behaviour is a result of a preconceived team tactic, due to emerging contextual variables, or a combination of both (Rein & Memmert, 2016). This conundrum is highlighted through research in football which established that when playing against lower ranked teams within the same league, higher values of length, width, and surface area were found during offence when compared to defence (Castellano, et al., 2013). However, this finding was reversed when playing against higher ranked teams, with smaller values of length, width, and surface area during offence compared to defence (Castellano, et al., 2013). Nonetheless, researchers analysing an entire season of first and second division Spanish soccer found that length in top ranking teams in first division was different to length in top ranking teams in the second division league (Castellano & Casamichana, 2015). This finding indicates a different strategy to play with more length when comparing first division and second division teams. Furthermore, longitudinal investigations in soccer also found that teams in the English Premier League may employ more conservative team behaviour by positioning players closer to their own goal during away games when compared to home games (Bialkowski, et al., 2014).

Limitations surrounding sample size and match reproducibility in this study should be considered. This study analysed collective team behavior from one out-of-season match. Additional data from multiple matches during a competitive season are required to determine the generalisability of these findings. Future studies should also look to incorporate contextual variables such as field position of the ball.

Quantifying collective team behaviour on a longitudinal basis, whilst considering contextual variables, will assist in uncovering repeated patterns in player movement. This information can provide sporting organisations with an enhanced understanding of teams tactics or styles of play, which may assist in improving performance. Practically, this information may be used to assist in developing specific training regimes. Coaches can promote desired tactical structures by reinforcing how players should position themselves across the field during various phases of play. It may also be used to gain a competitive advantage by better understanding opposing team tactics or game style. Specifically, determining if teams may be predisposed to a more offensive or defensive style of play may influence internal decision making in how to best combat those tactics.

3.6 Conclusion

The results from this study describe the collective team behaviour of AF teams during various phases of match play. The main findings advocate that collective team behaviour is influenced by match phase. The *x*-axis centroid and *y*-axis centroid recorded large variations during all phases of match play. Length, width, and surface area were typically greater during offence when compared to defensive and contested phases. Clear differences were observed between teams with large differences recorded for length, width, and surface area during all phases of match play. Spatiotemporal variables that describe collective team behaviour may be used to understand team tactics and styles of play.

CHAPTER 4. STUDY 2 – THE INFLUENCE OF MATCH PHASE AND FIELD POSITION ON COLLECTIVE TEAM BEHAVIOUR IN AUSTRALIAN RULES FOOTBALL

This chapter is presented in pre-publication format of a recent publication titled:

Alexander, J. P., Spencer, B., Sweeting, A. J., Mara, J. K., & Robertson, S. (2019). The influence of match phase and field position on collective team behaviour in Australian Rules football. *Journal of sports sciences*, *37*(15), 1699-1707.

Jeremy. P. Alexander, Bartholomew Spencer, Alice J. Sweeting, Jocelyn. K. Mara & Sam Robertson (2019) The influence of match phase and field position on collective team behaviour in Australian Rules football, Journal of Sports Sciences, 37:15, 1699-1707, DOI: 10.1080/02640414.2019.1586077

4.1 Abstract

This study investigated the influence of match phase and field position on collective team behaviour in Australian Rules football (AF). Data from professional male athletes (years 24.4 ± 3.7; cm 185.9 ± 7.1; kg 85.4 ± 7.1), were collected via 10 Hz global positioning system (GPS) during a competitive AFL match. Five spatiotemporal metrics (*x*-axis centroid, *y*–axis centroid, length, width, and surface area), occupancy maps, and Shannon Entropy (ShannEn) were analysed by match phase (offensive, defensive, and contested) and field position (defensive 50, defensive midfield, forward midfield, and forward 50). A multivariate analysis of variance (MANOVA) revealed that field position had a greater influence on the *x*-axis centroid comparative to match phase. Conversely, match phase had a greater influence on length, width, and surface area comparative to field position. Occupancy maps revealed that players repositioned behind centre when the ball was in their defensive half and moved forward of centre when the ball was in their forward half. Shannon Entropy revealed that player movement was more variable during offence and defence (ShannEn = 0.82 – 0.93) compared to contest (ShannEn = 0.68 – 0.79). Spatiotemporal metrics, occupancy maps, and Shannon Entropy may assist in understanding the game style of AF teams.

4.2 Introduction

Collective team behaviour in invasion sports refers to how individual players position themselves across a field of play to form an overall group organisation (Rein & Memmert, 2016). This behaviour has been used to describe team tactics or game style, whereby repetitive patterns of movement are formed (Sampaio & Macas, 2012). Collective team behaviour has become a central component of match analysis (Clemente, et al., 2018) due to its established relationship with performance outcomes (Clemente, et al., 2013; Goncalves, et al., 2016; Rein & Memmert, 2016) and the capability to provide greater context to match events (Lamas, et al., 2014).

Collective team behaviour has typically been defined via spatiotemporal metrics including *x*-axis centroid, *y*-axis centroid, length, width, and surface area (Clemente, et al., 2013; Folgado, et al., 2014; Frencken, et al., 2011). The team centroid represents the geometric centre of all players on the field, which can be assessed in both the *x*-axis and *y*-axis, team length and width describes the distance between the two players furthest apart along the pitch and across the pitch respectively, and the team surface area signifies the region that encompasses all players across a field of play (Bartlett, et al., 2012). More recently, studies have visualised occupancy maps or heat maps and combined them with a measure of entropy to determine the variability of player movement (Clemente, et al., 2018; Couceiro, et al., 2014; Silva et al., 2014). To provide additional context to the understanding of collective behaviour, investigations have been separated into various phases of match play, such as offence and defence (Bialkowski, et al., 2014; Castellano, et al., 2013; Clemente, et al., 2013).

Research in football has considered the *x*-axis centroid and occupancy maps to suggest teams may be more attacking by positioning players higher up the field in both offence and defence during home matches compared to away matches (Bialkowski, et al., 2014; Lucey, et al., 2013). This behaviour may be associated with an increased possession in the forward third and a greater number of shots on goal (Bialkowski, et al., 2014; Lucey, et al., 2013). Irrespective of match location, a conservative approach is generally taken, with the team *x*-axis centroid located in their defensive half (Clemente, et al., 2013). Investigations in football have used the length, width, and surface area to propose that whilst defending, teams will aim to compress the field of play by decreasing the area in which attacking players can operate (Vilar, et al., 2013). Increasing the number of defensive players surrounding an attacking team taking a shot at goal is associated with a concomitant decrease in successful scoring attempts (Ensum, et al., 2004; Wright, Atkins, Polman, Jones, & Sargeson, 2011).

Conversely, when teams are in offence they will attempt to spread the opposing defence to create more space (Castellano & Casamichana, 2015). Defending players are then compelled to either restrict the impact of these players or hold their position to protect space closer towards their goal (Vilar, et al., 2013). Higher-ranking teams in football may therefore be more effective at accomplishing this as they commonly produce greater values of length, width, and playing space compared to their lower-ranked counterparts (Castellano, et al., 2013).

Due to the continuous nature of invasion sports, it is difficult to associate discrete parts of collective team behaviour with a certain type of play (Lucey, et al., 2013). Specifically, it may be somewhat simplistic to assign specific movement behaviour to a particular tactic or game style, as a team's movement behaviour is constantly influenced by emerging aspects of match play (Rein & Memmert, 2016). Therefore, collective team behaviour may not necessarily be a preconceived team tactic or game style but rather an adaption to the general state of play (Rein & Memmert, 2016). Thus, to gain a more comprehensive representation of team tactics or game style, researchers should account for contextual variables, such as match phase and field position of the ball (Alexander, Spencer, Mara, & Robertson, 2019; Castellano, et al., 2013; Clemente, et al., 2013). Research into collective team behaviour in Australian Football (AF) also remains largely absent, with only one study reported to date (Alexander, et al., 2019).

Australian Football is an invasion sport where teams compete on an oval shaped field (length = ~160 m, width = ~130 m). The match is separated into four quarters, contested by 22 players per team, with 18 on the field and 4 on an interchange bench (Gray & Jenkins, 2010). Initial research in AF identified that teams display large variations in overall positioning throughout a match that may be influenced by the position of the ball (Alexander, et al., 2019). Therefore, field position of the ball may influence collective team behaviour

(Alexander, et al., 2019). However, the extent to which collective team behaviour is influenced by match phase in relation to field position of the ball is yet to be investigated.

Determining collective team behaviour whilst accounting for contextual variables may provide a greater understanding of team tactics or game style. Therefore, this study investigated the influence of match phase and field position of the ball on collective team behaviour in AF.

4.3 Methods

Data were collected from 22 male professional AF players (years 24.4 ± 3.7; cm 185.9 ± 7.1; kg 85.4 ± 7.1), recruited from a single team in the Australian Football League (AFL) competition. Participants took part in a match as part of the regular premiership season. All participants received information about the requirements of the study via verbal and written communication, and provided their written consent to participate. The University Ethics Committee approved the study.

The match took place on an oval shaped ground using dimensions 159.5 m x 128.8 m (length x width) with four 20-min quarters. Spatiotemporal data for all participants were collected using 10 Hz GPS devices (Catapult Optimeye S5, Catapult Innovations, Melbourne, Australia). The devices were housed in a sewn pocket in the jersey that is located on the upper back. The number of GPS satellites were greater than 8 packets per second, which ensured adequate signal quality (Corbett, Sweeting, & Robertson, 2017).

Spatiotemporal data was exported in raw 10 Hz format. Each file contained a global time stamp and calibrated location (x- and y- location). Match phase was determined via which team had possession of the ball (offensive, defensive or contest). The offensive phase was recorded when a team first gained possession of the ball and maintained it for at least a second and ended when the opposing team gained possession of the ball for at least a second or there was a stoppage in play. For example, the team scored or the ball went out of bounds

(Yue, et al., 2008). Using the same conditions, the defensive phase was recorded when the opposing team had possession of the ball (Yue, et al., 2008). If neither team had possession of the ball, for example, when the officiating umpire returned the ball to play, the phase was considered to be in contest until a team gained possession of the ball for at least one second. All periods where the ball was out of play, for example, when there was a break between periods of play, celebration after goals, were excluded from the investigation. Field position of the ball was separated into four zones (defensive 50; D50, defensive mid; DMID, forward mid; FMID, forward 50; F50) by the two 50 m arcs and the centre of the ground (see Figure 4-1). The centre of the ground was signified as 0, 0. Match phase and field position were analysed via video observation and recorded to the nearest second by a commercial statistical provider (Champion Data Pty Ltd, Melbourne, Australia). Previous investigations have assessed the validity and reliability of similar match events (Robertson, et al., 2016). Positional data was then synchronised with match phase and field position data using the respective global timestamps. This was established using the initial point when the two widest players on the field converged from a stationary position prior to start of each quarter.

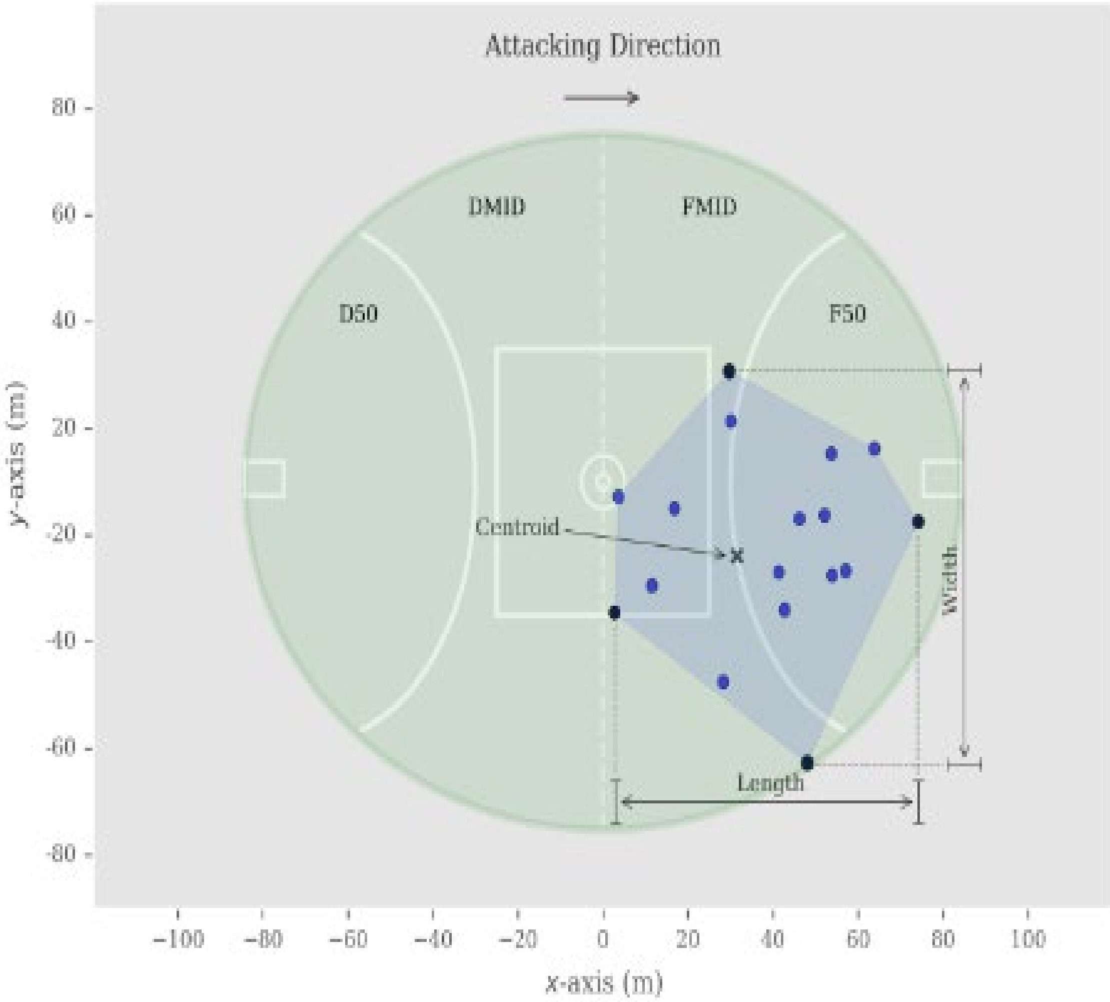

Figure 4-1: Four field position zones and spatiotemporal metrics including centroid, length, width, and surface area.

Five spatiotemporal metrics (Figure 4-1) were derived from the data to describe collective team behaviour. Team centroid was calculated as the mean (*x*, *y*) position of all players on the field (Frencken, et al., 2011). Two measures were derived from the centroid position. These were the distance in the *x*-axis centroid (m) and the distance in the *y*-axis centroid (m) (Frencken, et al., 2011). The team surface area was calculated as the total space (m) covered by a single team (Frencken, et al., 2011). Team length was measured as the distance between the most forward and most backward player in the *x*-axis (m) and team width was defined as the distance between the two most lateral players on the ground in the *y*-axis (m) (Frencken, et al., 2011). Variability of player movement was visualised via occupancy maps (Couceiro, et al., 2014; Silva, et al., 2014), which represent the density of players across a given area (Silva, et al., 2014). The occupancy maps were combined with Shannon Entropy (ShannEn) to provide an enhanced understanding of team movement variability. To calculate ShannEn, the field of play was quantised into bins of equal size (1 m^2) to provide adequate spatial resolution (Couceiro, et al., 2014). The total count from each bin was used to determine the total time spent in each bin. A probability distribution of the total time spent in each bin was then used to determine the variability of a player being located in a specific bin. Both the heat maps and ShannEn values were normalised to total time spent in each position on the field for each match phase. Synchronisation and analysis were undertaken using the computational package Python version 3.2 with *Spyder*, which is part of the Anaconda software suite (www.python.org).

Statistical Analyses

Comparison of team *x*-axis centroid, *y*-axis centroid, length, width, and surface area were assessed between match phase (3 levels: Offence, Defence, Contest) and field position (4 levels: D50, DMID, FMID, F50), via a multivariate analysis of variance (MANOVA). Homogeneity was analysed using the Levene Test, which resulted in a lack of uniformity between match phase and field position. The *F* test was used to combat homogeneity violations due to the fact the total number of samples is in each group was essentially equal (Vincent, 1999). Due to the non-homogeneity of the time series data, the Central Limit Theorem was considered, which allowed the assumption of normality to be made (Akritas, 2004). Effect sizes were determined by calculating partial eta-squared (η_p^2) and was considered as small ($\eta_p^2 < .06$), moderate ($\eta_p^2 > .06$ $\eta_p^2 < .15$) or large ($\eta_p^2 \geq .15$) (Cohen, 1988). Significant p values reported are < .001 unless otherwise stated. These calculations were determined using SPSS, v21.0; Inc., Armonk, NY, USA). Using Shannon Entropy *S*, the probability $p_{(i)}$ of finding a player in bin i was measured via quantising the field into n bins. Entropy was then normalised N to total match time spent in each position on the field for each phase of play to return a relative number between 0 and 1.

$$S\,(\%) = -\sum_{i=0}^{n-1} p\,(i)\log p\,(i)\log N$$

A low ShannEn (near 0) suggests the variability of player movement is low (Couceiro, et al., 2014). A high ShannEn (near 1) indicates the variability of player movement is high (Couceiro, et al., 2014). These calculations were completed using the computational package Python version 3.2 with *Spyder*, which is part of the Anaconda software suite (www.python.org).

4.4 Results

Total differences between match phase and field position of the ball for each spatiotemporal metric are displayed in Figure 4-2. Individual playing sequences exhibited over time for field position and match phase are represented in Figure 4-3, while the distribution of these sequences are displayed in Figure 4-4. Heat maps and ShannEn values displaying player movement variability between match phase and field position are presented in Figure 4-5. The team observed in this study won the game 109 – 38.

Overall, field position of the ball had a greater influence on the *x*-axis centroid (η_p^2 = .41) when compared to match phase. Although, match phase had a greater influence on length (η_p^2 = .06), width (η_p^2 = .27), and surface area (η_p^2 = .14) when compared to field position of the ball. The *x*-axis centroid in the D50 was further behind centre when compared to the DMID (-10.7; 95% CI -11.2 – -10.2), FMID (-35.3; 95% CI -35.7 – -34.9) and the F50 (-48.1; 95% CI -48.6 – -47.7). The *x*-axis centroid in the DMID was also recorded further behind the FMID (-24.6; 95% CI -25.0 – -24.1) and F50 (-37.4; 95% CI -37.9 – -37.0), while the *x*-axis centroid in the FMID was recorded forward of centre it was still behind the F50 (-12.9; 95% CI -13.3 – -12.5). Length was greater during the DMID when compared to the D50 (22.9; 95% CI 22.3 – 23.6) and F50 (22.9; 95% CI 22.3 – 23.6). Length in the FMID was also greater than the D50 (8.1; 95% CI 7.6 – 8.7). Width was reduced in the D50 when compared to the DMID (-16.7; 95% CI -17.2 – -16.2), FMID (-10.6; 95% CI -11.0 – -10.2), and F50 (-14.5; 95% CI -14.9 – -14.0). The surface area in the DMID was larger when compared to the D50 (1900.3; 95% CI 1857.9 – 1942.8), FMID (976.4; 95% CI 934.4 – 1018.3), and F50 (1054.0; 95% CI 1012.3 – 1095.7). Surface area in the FMID was also larger when compared to the D50 (923.9; 95% CI 885.1 – 962.8) and F50 (77.6; 95% CI 39.6 – 115.7).

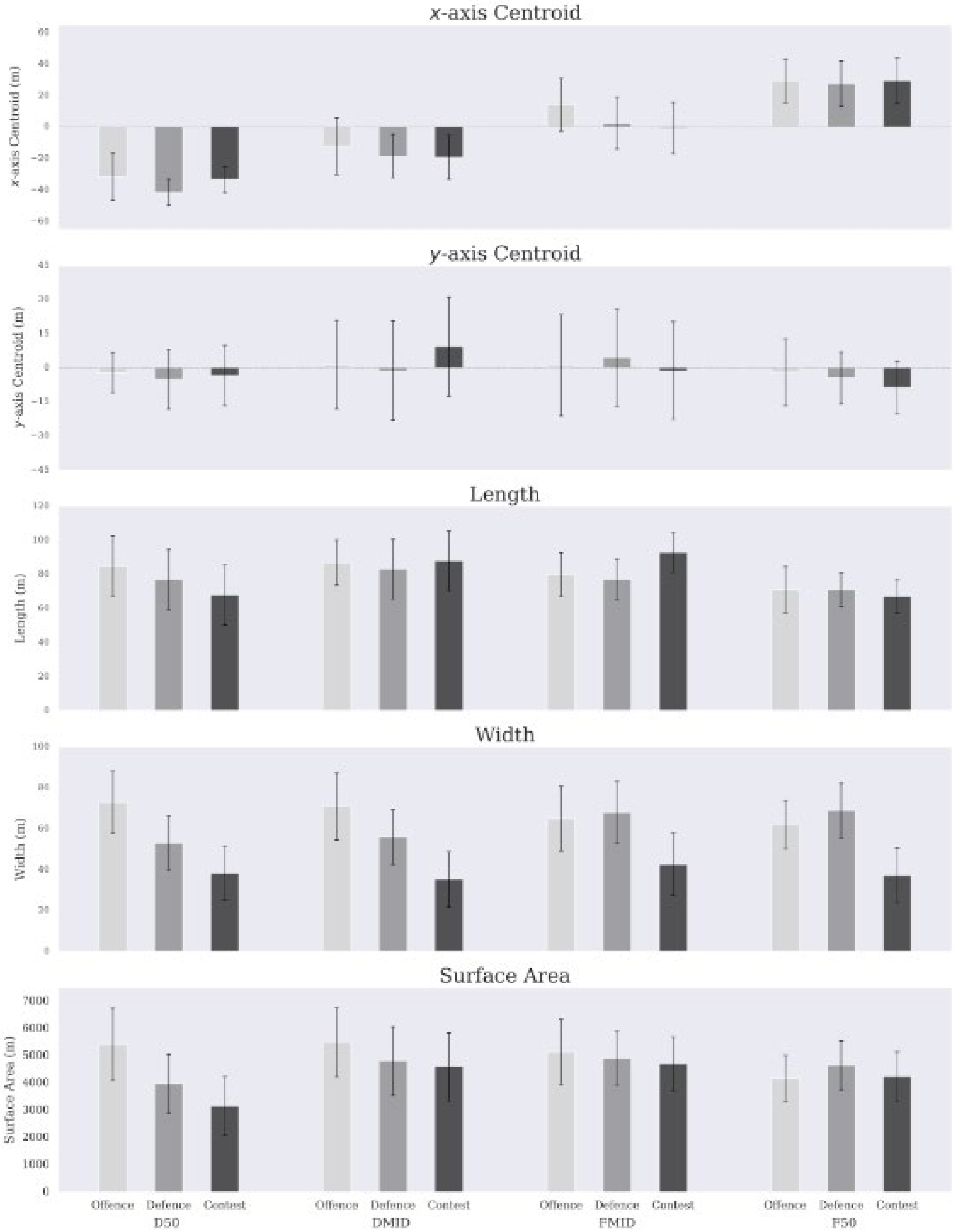

Figure 4-2: Comparison of mean ± standard deviation between match phase and field position of spatiotemporal metrics.

Between-phase analysis recorded the *x*-axis centroid higher up the ground during offence when compared to defence (3.6; 95% CI 3.1 – 4.0) and contest (3.3; 95% CI 2.6 – 4.0). Length was greater during offence compared to defence (4.7; 95% CI 4.2 – 5.3), while contest was greater than offence (3.5; 95% CI 2.5 – 4.5) and defence (8.2; 95% CI 7.2 – 9.3). Width was greater during offence when compared to defence (3.3; 95% CI 2.9 – 3.8) and contest (27.9; 95% CI 27.2 – 28.7). Width was also greater during defence compared to contest (24.6; 95% CI 23.8 – 25.4). Surface area was greater during offence compared defence (397.5; 95% CI 359.8 – 435.2) and contest (794.2; 95% CI 727.4 – 861.0). Surface area during defence was also greater than contest (396.8; 95% CI 327.8 – 465.8).

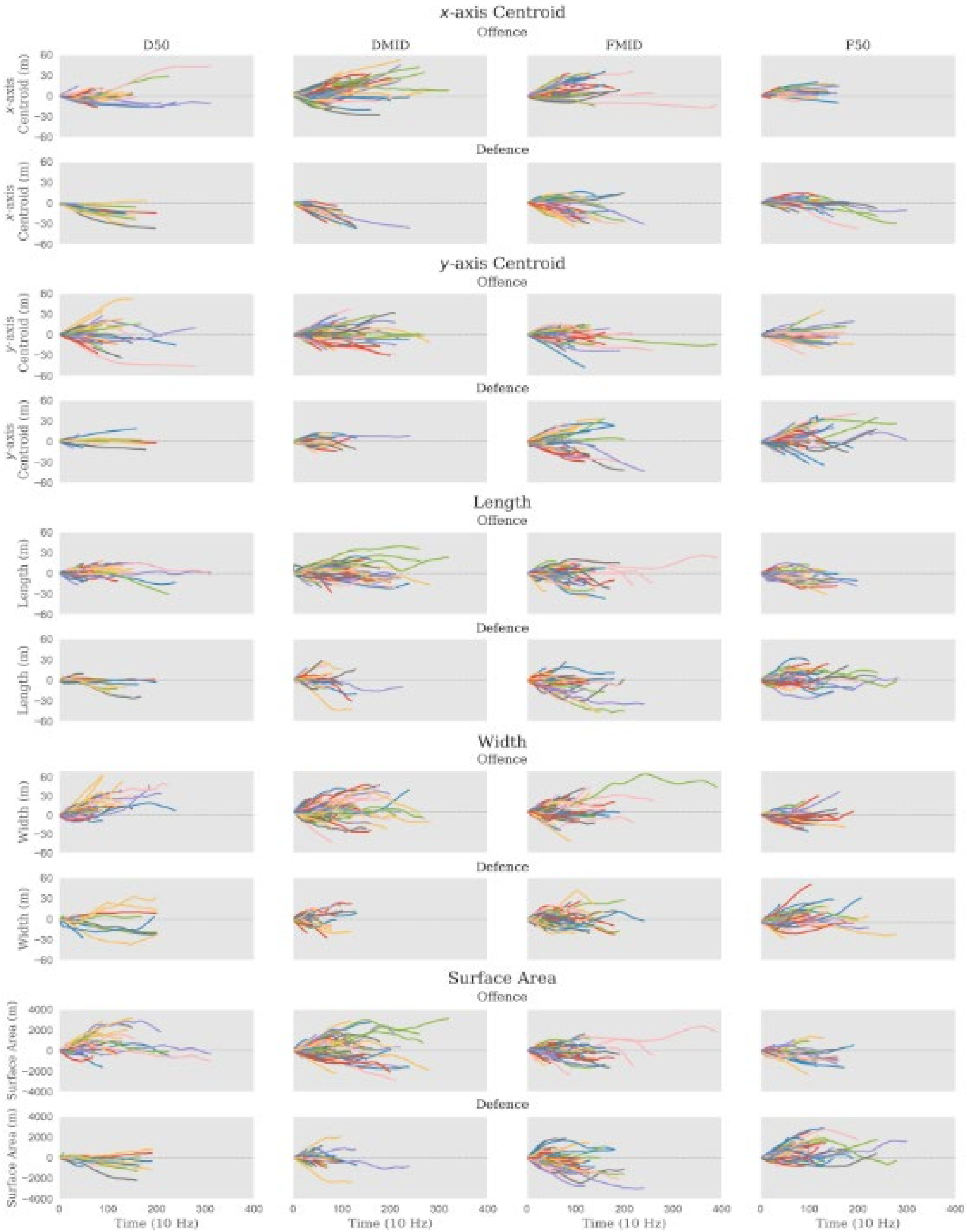

Figure 4-3: Comparison of individual instances of spatiotemporal metrics in relation to the duration of time for match phase and field position.

Visual inspection of the distribution plots (Figure 4-4) displayed similar time duration for offensive and defensive sequences with the majority of playing sequences between 0 – 20 seconds. Total time during contest was reduced with the majority of sequences measuring between 0 – 10 seconds.

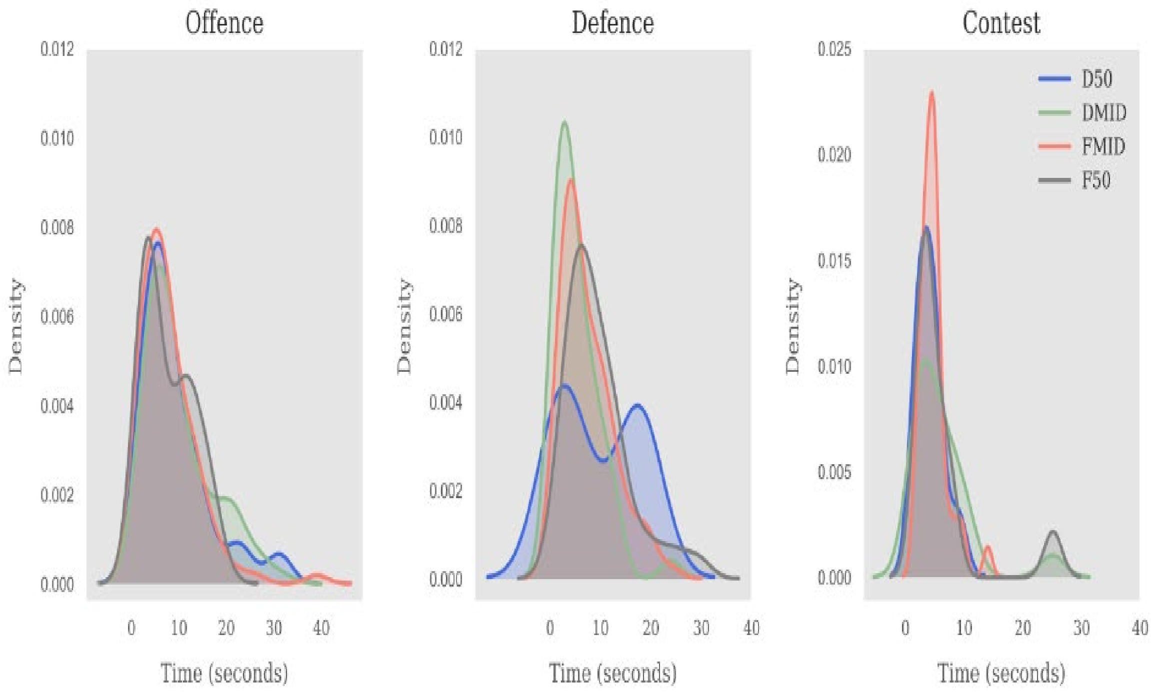

Figure 4-4: Between match phase comparison of the distribution of total time for field position.

ShannEn values (Figure 4-5) were greater during offence and defence compared to contest. Between field position analysis indicated that variability of team movement decreased during defence when in the D50 and in offence when in the F50. ShannEn values were greater during contest when the ball was in the middle of the ground compared to D50 and F50.

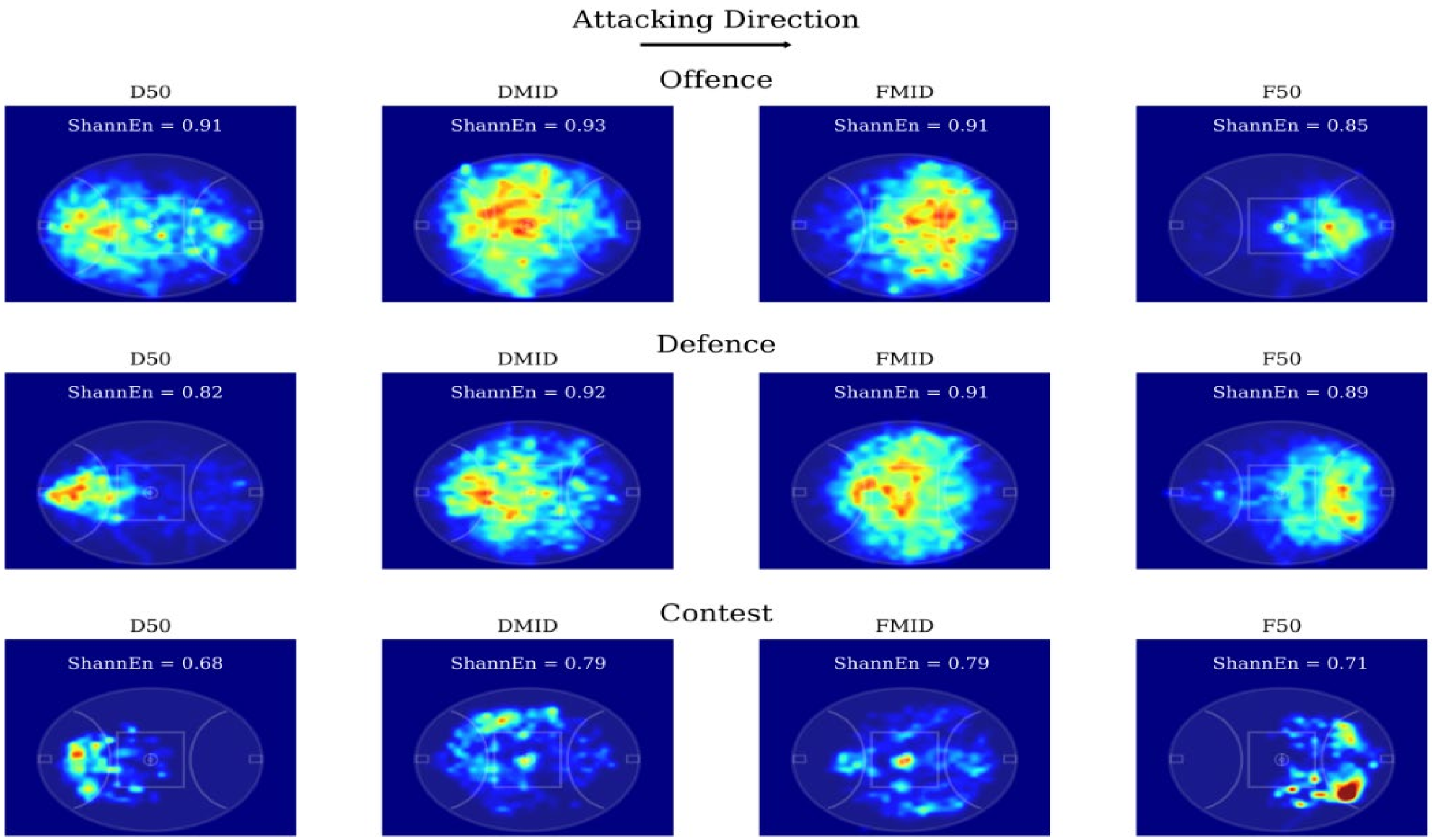

Figure 4-5: Comparison of occupancy maps and ShannEn values for match phase and field position.

4.5 Discussion

This is the first study to investigate the influence of match phase and field position of the ball on collective team behaviour in AF. This proof of concept study may be used to provide a complementary framework to add to existing match analyses common in AF. Specifically, the addition of spatiotemporally-derived metrics relating to collective team behaviour has the potential to provide both enhanced insights and context to existing consideration of discrete team and player performance indicators.

A predominant finding was field position of the ball had a greater influence on the *x*-axis centroid when compared to phase of play. Conversely, phase of play had a greater influence on length, width, and surface area when compared with field position of he ball. Players collectively transitioned closer to their goal when the ball was in their defensive half and pressed higher up the field when the ball was in their forward half. Variation in player movement, as signified by ShannEn, increased through FMID and DMID compared to F50 and D50 and during offence and defence when compared to contest.

Overall, the majority of players were positioned close to where the ball was situated. The density of players was more pronounced when the ball was in the D50 or F50 and further amplified when in the contested phase. Length, width, and surface area were also reduced under these circumstances. This type of behaviour may be associated with players trying to reduce the amount of space an opposition can operate in (Vilar, et al., 2013) and is also representative of AFL rules, whereby no movement restrictions are imparted on players. This behaviour could be beneficial when defending in the D50 as it may be more difficult for the opposing team to achieve an effective shot on goal if an increased number of players are located within this area (Ensum, et al., 2004; Wright, et al., 2011). Alternatively, when the ball is located in the F50 it may be more difficult for the opposing team to successfully move the ball out of this area if players have setup an effective ‘barrier’ behind the ball. Increased width and variation in player movement throughout the middle of the ground comparative to the F50 and D50 areas may also be somewhat attributed to the oval shaped field dimensions of an AF ground. However, reduced entropy in these areas during the contested phase suggests movement variability may differ between field position and match phase. Increased variability during offence in the D50, DMID, and FMID could indicate players may be utilising various movement patterns to disrupt opposing defensive structures (Garganta, 2009). Reduced movement variation during the contested phase may reflect the inactive period, prior to a change in match phase. The duration of playing sequences during the contested phase was also reduced when compared to offensive and defensive phases. In the present study, while players may produce less movement variation during contest, they are required to be prepared to react when either team gains possession of the ball.

Studies investigating the physical movement output of team sport athletes through the duration of time are ubiquitous (Brewer, et al., 2010; Dwyer & Gabbett, 2012; Wisbey, et al., 2010). However, there is limited research on the duration of time with respect to collective team behaviour. Findings from the present study indicate the time duration of playing sequences before a change in field position are generally between 0 and 20 seconds for offensive and defensive phases and 0 to 10 seconds for the contested phase.

The combination of spatiotemporal metrics, heat maps, and entropy measures may assist in measuring particular collective team behaviour, which can be used to design more representative training regimes. For instance, if the ball is in the forward half, players may be instructed to press higher up the field in a certain period of time to generate enough pressure to keep the opposition from moving outside this zone. Alternatively, an aim to maintain possession of the ball may be more attainable if surface area is being created when initially gaining possession of the ball. Opposition analysis may also be benefit from a greater understanding of rival collective team behaviour. For example, an opposing team that quickly transitions players deep in their defensive end after losing possession of the ball defence could cause increased space through the middle of the ground. This could be exploited by employing a higher possession style of play with a slower build-up that reduces the risk of losing possession.

Collective team behaviour investigations in football have revealed that a more defensive game style is generally employed by preserving players behind the centre of the field (Clemente, et al., 2013). However, teams may be inclined to engage in a more offensive game style during home matches compared to away matches by positioning players higher up the field (Bialkowski, et al., 2014; Lucey, et al., 2013). Higher ranked football teams may also display a more expansive game style with greater values of length, width, and surface area during the offensive phase of play (Castellano, et al., 2013; Castellano & Casamichana, 2015). Results from the present study suggest AF teams may undertake a more circumstantial approach in allocating players to achieve certain tasks. Teams may aim to restrict space if the ball is in their D50 and press higher up the field to hold the play in their forward half when the ball is in their F50. Increased variation in player movement also exists during the middle of the ground. However, it is difficult to discern if these types of behaviour are a predetermined game style or if its players adapting to the emergent state of the game. For instance, length, width, and surface area appear to be influenced by match phase, while the *x*-axis centroid is influenced by field position. As such, an increased time spent in offence may be the cause of a team's increased surface area and not necessarily a premeditated approach to commit to a more expansive game style. In addition, a team's inability to move the ball out of its defensive half may represent why the *x*-axis centroid is behind centre, instead of a defensive strategy to preserve players closer to their own goal.

Whilst contextual factors provide a more informed understanding of how collective behaviour changes during different game states, it is misleading to solely associate collective behaviour with specific team tactics or game style. The current macroscopic approach determines player positioning during a specific match phase or field position to infer game style or team tactics. A more granular approach is required that better reflects the different strategies a team might employ during different situations. Specifically, a microscopic method that determines group structures or formations at each point of time will provide a more representative comprehension of game style. This information should be combined with match events or performance outcomes to better understand the efficacy of various playing styles.

Some limitations relating to sample size and amount of teams included in this study should be recognised. The present study analysed the collective team behaviour of one club during a single competitive match. Thus additional research should include multiple clubs throughout several matches to construct a more accurate representation of collective behaviour of AF teams and if any variances between teams exist. Future investigations may also analyse the player movement during various contextual variables to gain a more comprehensive understanding of AF collective team behaviour. Relationships between the observed collective team behaviour from this team and specific strategy or team tactics are not yet known. Future work may also incorporate a more granular approach that includes how collective team behaviour form specific structures in real time. In addition, this analysis should incorporate match events (Corbett et al., 2018) or performance outcomes to provide a more representative understanding of team tactics or game style.

4.6 Conclusion

This study investigated the influence of match phase and field position of the ball on collective team behaviour in AF, thereby providing a proof of concept for future work in this area. When considering field position of the ball and match phase, the variation in the *x*-axis centroid could be attributed to the change in field position, while match phase had a greater influence on length, width, and surface area. Players were more inclined to re-position closer to their defensive end to restrict space when the ball was closer to their goal and conversely, press higher up the field when the ball was in their forward half. Future investigations of collective team behaviour in AF should look to measure specific formations and structures continuously. This information, with the combination of match events, may provide a more representative understanding of game style or team tactics.

CHAPTER 5. STUDY 3 – THE IMPACT OF A NUMERICAL ADVANTAGE ON MATCH PLAY IN AUSTRALIAN RULES FOOTBALL

This chapter is presented in pre-publication format of a recent international conference titled: Alexander, J. P., Spencer, B., Sweeting, A. J., Mara, J. K., & Robertson, S. (2019). The impact of a team numerical advantage on match in Australian Rules football. Presented at the *MathSport International 2019,* Athens, Greece

The impact of a team numerical advantage on match play in Australian Rules football by *Alexander, J.P., Spencer, B., Sweeting, A.J., Mara, J.K., Robertson, S.*, was published in *Proceedings of the MathSport 2019 Conference*, *2019*, *pp. 1-9*.

CHAPTER 6. STUDY 4 – A CONTINUOUS APPROACH TO ASSESSING TEAM SPATIAL CONTROL IN AUSTRALIAN RULES FOOTBALL

6.1 Abstract

The primary aim of this study was to determine the extent to which continuously represented team spatial control varies with respect to specific match play events in Australian football. The secondary aim was to determine whether differences in team spatial control exist during different match phases and ball location. Data from Australian football athletes were collected via 10 Hz global positioning system (GPS) during match simulation. Team spatial control and Approximate Entropy (ApEn) were analysed during three match phases (offensive, defensive, and contested) and four field positions (defensive 50, defensive midfield, forward midfield, and forward 50). Results revealed that teams obtained greater spatial control during offence, but experienced reduced control during defence. Notwithstanding, both teams were able to seize spatial control when forcing a turnover in possession. A trade-off scenario may apply as specific formations may generate a competitive advantage in particular aspects of match play, whilst concurrently triggering a disadvantage in other facets of match play. Continuously quantifying the resistive exchange in spatial control between teams and detecting the value placed on controlling specific regions may contribute to providing a more representative understanding of tactical team behaviour.

6.2 Introduction

Team performance in invasion sports is dependent on outcomes of continual interactions between teammates and opponents (Balagué, Torrents, Hristovski, & Kelso, 2017; Duarte, et al., 2012). In this system with multiple interacting parts, players are required to regulate their movement to either generate offensive opportunities in an attempt to score or to preserve defensive stability (Vilar, et al., 2013). The specific organisation of players across a field of play may enhance the effectiveness of these interactions (Clemente, et al., 2015). Specifically, by creating local numerical advantages or installing disorder in opposition structures, teams may promote a greater spatial control over a given region or sub-area of play (Fernandez & Bornn, 2018). Fundamentally, spatial control has been understood as the amount of dominance or influence a player or team contains over a specific region on a playing surface (Fernandez & Bornn, 2018). Studies have typically measured spatial control through a discrete approach by isolating specific sub-areas of play to players or teams. These methods include Voronoi diagrams (Taki & Hasegawa, 2000), heat maps (Couceiro, et al., 2014; Silva, et al., 2014), and team numerical advantages (Vilar, et al., 2013).

Voronoi diagrams attribute discrete sub-areas on a field to players by calculating the space they could occupy before any other player (Taki & Hasegawa, 2000). Studies in Futsal have indicated these sub-areas provide teams with greater control during offensive phases compared to defensive phases (Fonseca, et al., 2013). Heat maps determine spatial control by considering the total time spent in discrete sub-areas across a field of play (Clemente, et al., 2012; Couceiro, et al., 2014). Investigations in football revealed that more proficient players displayed increased control across a field of play compared to less skilful players (Silva, et al., 2015). Other research in football has associated advantageous outcomes with increased spatial control through team numerical advantages (Vilar, et al., 2013). Teams are able to both create offensive opportunities to score and to preserve defensive stability by outnumbering the opposing team at discrete sub-areas on a field of play (Silva, et al., 2014; Vilar, et al., 2013).

Notwithstanding the benefits of the above approaches in assessing team spatial control, the underlying concept relies on the presupposition that a given player exclusively dominates a specific region on a field of play (Fernandez & Bornn, 2018; Spencer, et al., 2019). This discrete approach neglects the concept that a player's control of space is imprecise with uncertainty as to who controls particular regions (Fernandez & Bornn, 2018; Spencer, et al., 2019). Players are frequently regulating their positioning into an area of perceived higher value. This may involve providing greater attacking opportunities during offensive sequences or to impede or restrict opposition players whilst defending. This emerging nature witnesses fluctuating player velocities, greater densities in specific regions, and occupation into previously vacant areas. Thus, team spatial control should be understood as the degree or probability of control that a player or team has on a specific region (Fernandez & Bornn, 2018; Spencer, et al., 2019). This advocates that ownership of space is continuous, with uncertainty in who controls areas between players (Fernandez & Bornn, 2018). Therefore, team spatial control may be considered as a more probabilistic system that oscillates between limited control and complete control (Fernandez & Bornn, 2018).

Continuous approaches to spatial control should also consider contextual variables that influence match play, such as match phase, ball positioning, and teammates positioning relative to that of opponents (Fernandez & Bornn, 2018). Research of this manner has been undertaken in football to quantify the off-ball dynamics to identify how players occupy and generate space for teammates (Fernandez & Bornn, 2018) and to assess the risk and reward of passing decisions in Australian Rules football (AF) (Spencer, et al., 2019). However, the continuous dynamic balance of space control between two competing teams and its association to match play is yet to be investigated in AF. Therefore, the primary aim of this study was to determine the extent to which continuously represented spatial control varies with respect to specific match play events in AF. The secondary aim was to determine the extent to which team spatial control differs during various match phases and ball location.

6.3 Methods

Data were collected from one training session with 30 male professional AF players (years 23.9 ± 4.3; cm 188.0 ± 7.9; kg 86.0 ± 9.4) recruited from a single team in the Australian Football League (AFL) competition. Participants took part in a match simulation drill as part of preseason training. All participants received information about the requirements of the study via verbal and written communication, and provided their written consent to participate. The University Ethics Committee approved the study.

Participants were separated into two teams of 15 each at the coach's discretion to ensure a relatively even competition and were labeled Home team and Away team for analysis purposes. The match simulation took place on an oval shaped ground of 163.7 m x 129.8 m (length x width) with two 20-min halves and a 10-min break between periods. Data for all participants were collected using 10 Hz GPS devices (Catapult Optimeye S5, Catapult Innovations, Melbourne, Australia). The devices were housed in a sewn pocket in the jersey that is located on the upper back. The number of GPS satellites was greater than 8 per second, which ensured adequate signal quality (Corbett, et al., 2017).

Player positioning data was exported in raw 10 Hz format. Each file contained a global time stamp and calibrated location (*x*- and *y*- location). Match event data notated the action of the player who had possession of the ball and was recorded to the nearest second. Match phase was determined via which team had possession of the ball (offensive, defensive or contest). If possession was gained via the opposition it was considered to be a turnover, while possession gained from a contested situation was recorded as a clearance (Woods, et al., 2017). Previous investigations have assessed the validity and reliability of similar match events and reported very high levels (ICC range = 0.947 – 1.000) of agreement (Robertson, et al., 2016). All periods where the ball was out of play were excluded from the investigation (for example, when there was a break between periods of play, the ball went out of the field of play, celebrations after goals). Field position of the ball was separated into four zones (defensive 50; D50, defensive mid; DMID, forward mid; FMID, forward 50; F50) by the two 50 m arcs and the centre of the ground (see Figure 6-1). Positional data was synchronised with match event data using the respective global timestamps. This was established using the initial point when the two widest players on the field converged from a stationary position prior to start of each quarter.

Team spatial control was quantified using a bivariate Gaussian distribution that was adjusted for a player's location, velocity, and relative distance to the ball (Fernandez & Bornn, 2018). For a provided location in time, a degree or probability of control can be determined through the distribution's probability density function (Fernandez & Bornn, 2018). Specifically, a player's influence I at a provided location p at time t is defined by a bivariate Gaussian distribution with mean μ_i (t) and covariance matrix $\sum_i$ (t), given the player's velocity $\vec{s}$ and angle θ (Fernandez & Bornn, 2018). For a specified position in space p at t, the probability density function of player i influence area is measured by a standard multivariate Gaussian distribution (Fernandez & Bornn, 2018).

$$f_i(p,t) = \frac{1}{\sqrt{(2\pi)^2 detCOV_i(t)}} exp(-\frac{1}{2}(p - \mu_i(\vec{s}_i(t)))^T COV_i(t)^{-1}(p - \mu_i(t)))$$

The player's influence likelihood is referred to as the normalisation of f by the value of f at a player's current location p_i (t) (Fernandez & Bornn, 2018).

$$I_i(p,t) = \frac{f_i(p,t)}{f_i(p_i(t),t)}$$

The influence of each player I is then used to determine team spatial control SC at location p

at time t, where H and A refer to the index of the player in each opposing team.

$$SC_{(p,t)} = \frac{(\sum_H I_{(p,t)} - \sum_A I_{(p,t)})}{\max\ (\sum_H I_{\max(p,t)}, \sum_A I_{\max(p,t)})}$$

This provides a normalised degree of spatial control within a range of -1 to 1 for any given location on a playing surface, with values between 0 and 1 indicating the Home team has greater spatial control and values between 0 and -1 signifying the Away team has greater spatial control. The player control distribution can account for location and velocity by adjusting the mean and covariance matrix (Fernandez & Bornn, 2018). This value of team spatial control was mapped at the location of the ball at each point in time.

Statistical Analyses

The variability of team spatial control within the four field positions and match phase was calculated using the Approximate Entropy (ApEn) (Pincus, et al., 1991). Provided with a given time series of N points (x_1, x_2, ..., x_N), ApEn (m, r, N) can be used to measure the logarithmic probability that lengths of patterns with m points that are close, continue to be close within a tolerance factor r for the subsequent assessments (Pincus, et al., 1991). To calculate ApEn (m, r, N), the parameters m, the length of compared runs, and r, the tolerance factor, need to be consistent for all assessments to ensure reliable analysis (Pincus & Goldberger, 1994).

$$ApEn\ (m, r, \mathrm{N}) = \phi^{m}(r) - \phi^{m+1}(r)$$

ApEn values vary between 0 and 2, with values closer to 2 indicating time series with less regular or more variable patterns (Fonseca, et al., 2013). Values closer to 0 imply a more regular or less variable time series (Fonseca, et al., 2013). These calculations were completed using the computational package Python version 3.2 with *Spyder*, which is part of the Anaconda software suite (www.python.org).

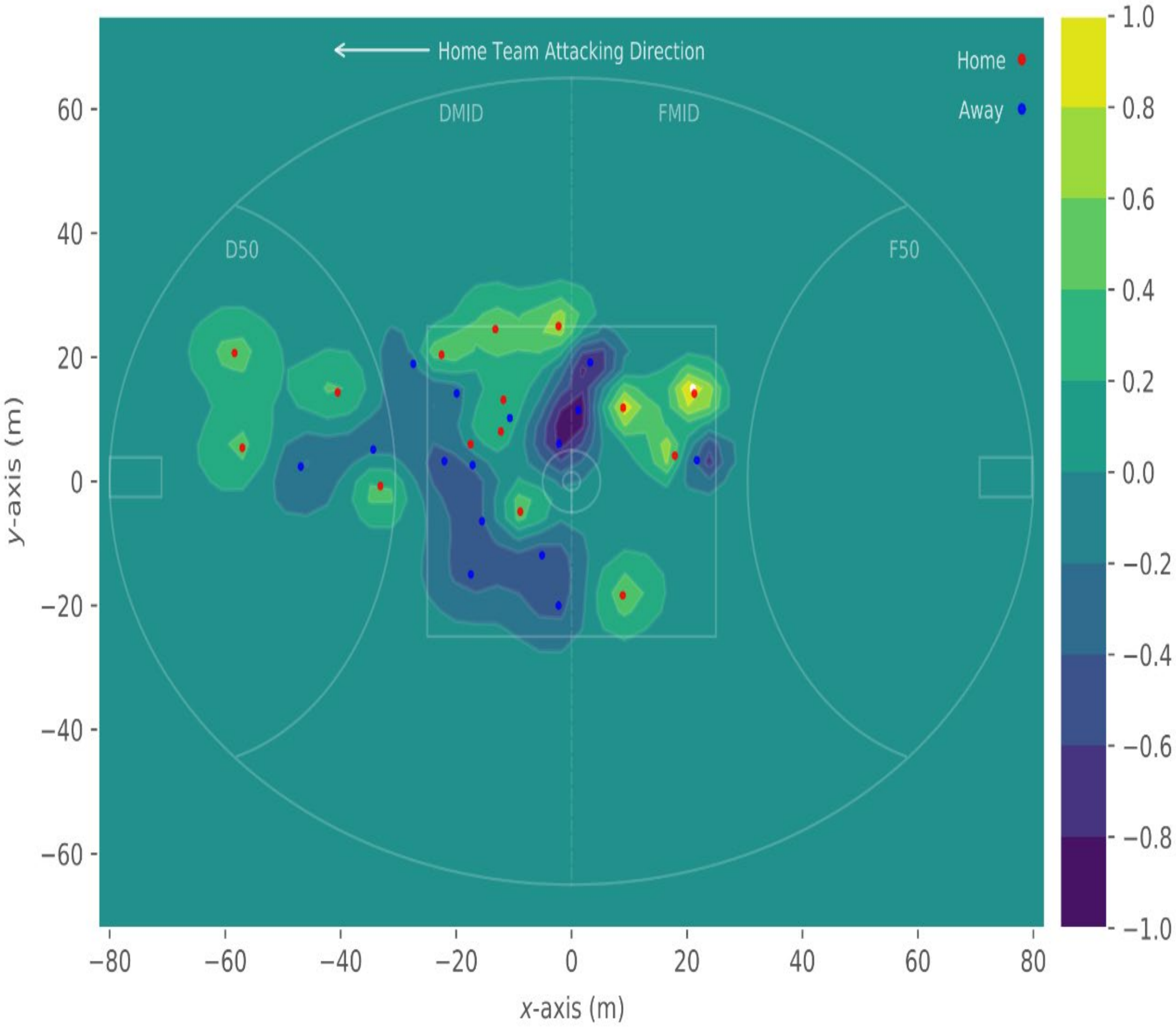

Figure 6-1: Areas of spatial control for the Home team and Away team at the 10-minute mark of the match. Values between 0 and 1 indicate Home team control and values between 0 and -1 indicate the Away team control. Ball location (21, 14) indicates the Home team has greater control of the ball.

6.4 Results

The distribution of team spatial control during each match phase and field position for the Home team and Away team are displayed in Figure 6-2. Both teams had a greater control of space when in possession of the ball and endured reduced control whilst defending. However, the Away team was able to obtain greater control during the contested phase. This finding was more distinct when the ball was in the D50 and F50.

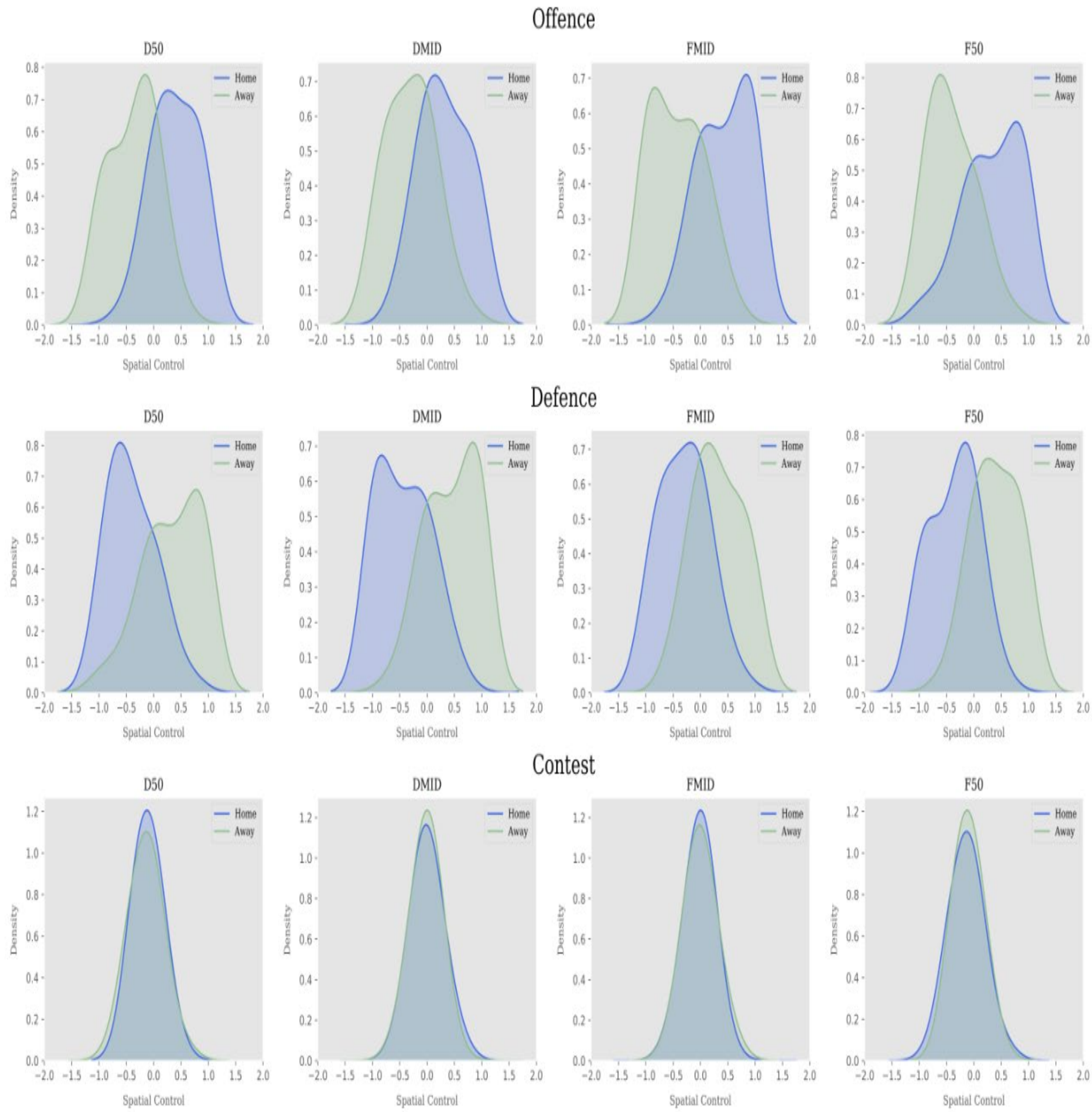

Figure 6-2: Distribution of team spatial control for the Home team and Away team in each field position for each phase of play.

Variability in team spatial control represented by ApEn is expressed in Figure 6-3. ApEn values in team spatial control were greater during offence and defence compared to the contested phase.

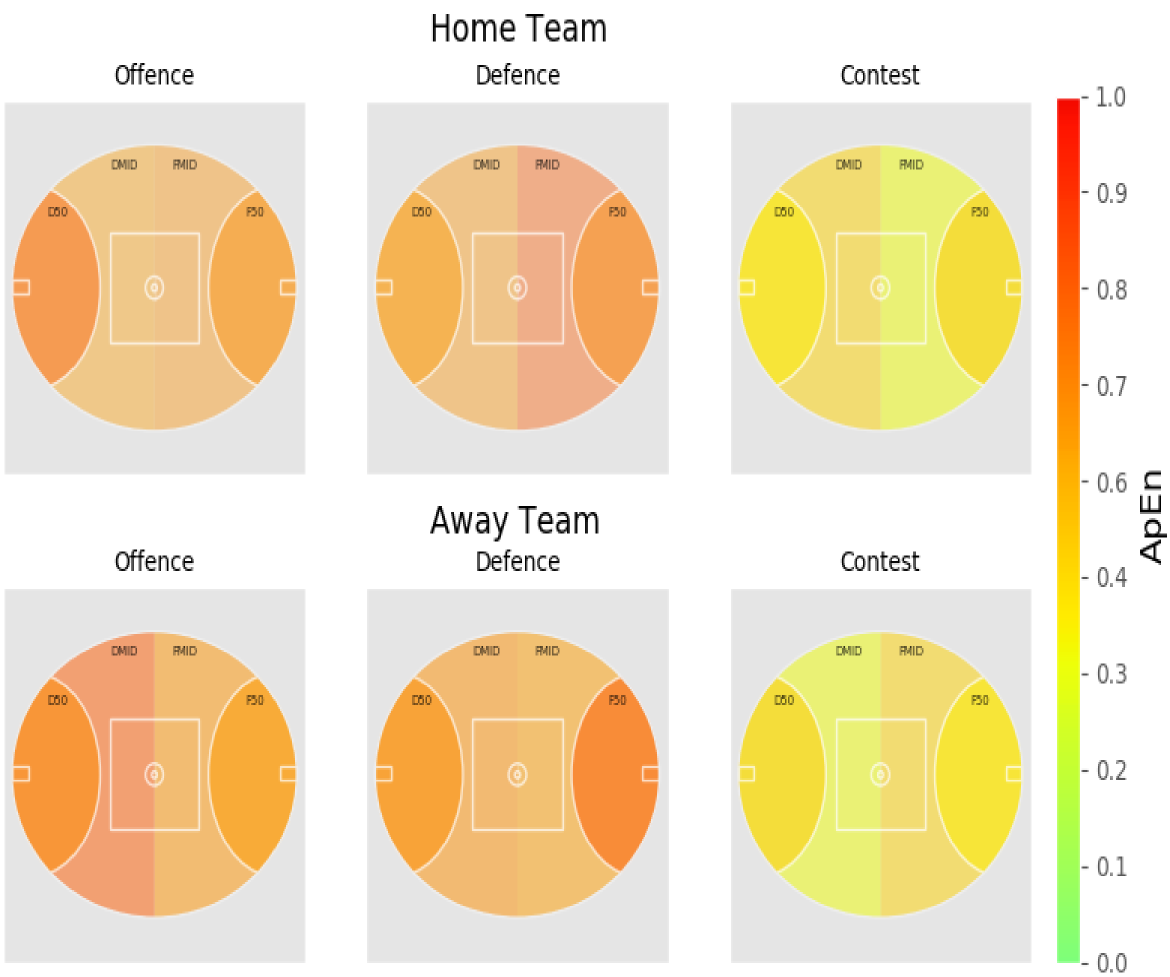

Figure 6-3: ApEn values for team spatial control in each field position for each phase of match play. Values closer to 0 indicate less variability, with values closer to 1 indicating greater variability.

The extent to which continuously represented spatial control varies with respect to specific match play events is represented in Figure 6-4 and the individual instances of spatial control in relation to the duration of time for match phase is displayed in Figure 6-5. The Away team won the match 51 – 39. A total of 44 turnovers were recorded throughout the match with the Home team gathering 20 and the Away team obtaining 24. The Home team obtained 16 clearances, while the Away team gathered 14. Visual inspection of the distribution plots identified that both teams were able to generate greater spatial control when generating a turnover.

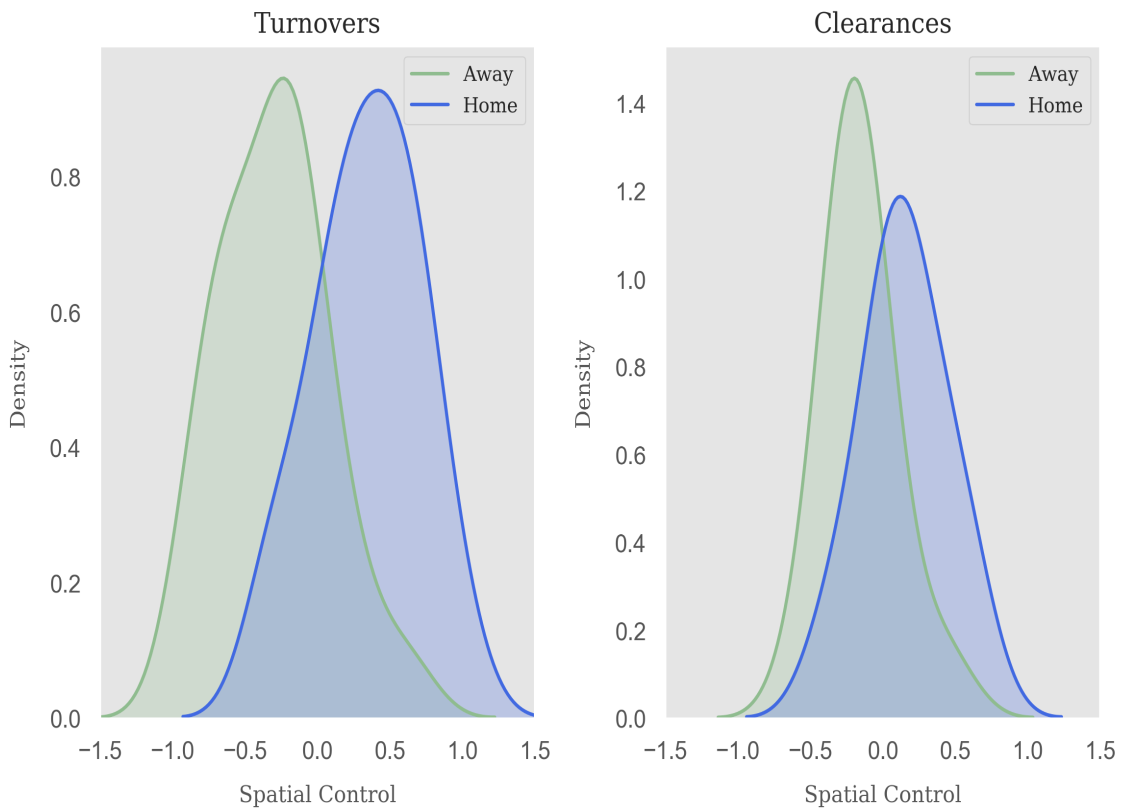

Figure 6-4: Distribution of team spatial control during clearances and turnovers for the Home team and Away team.

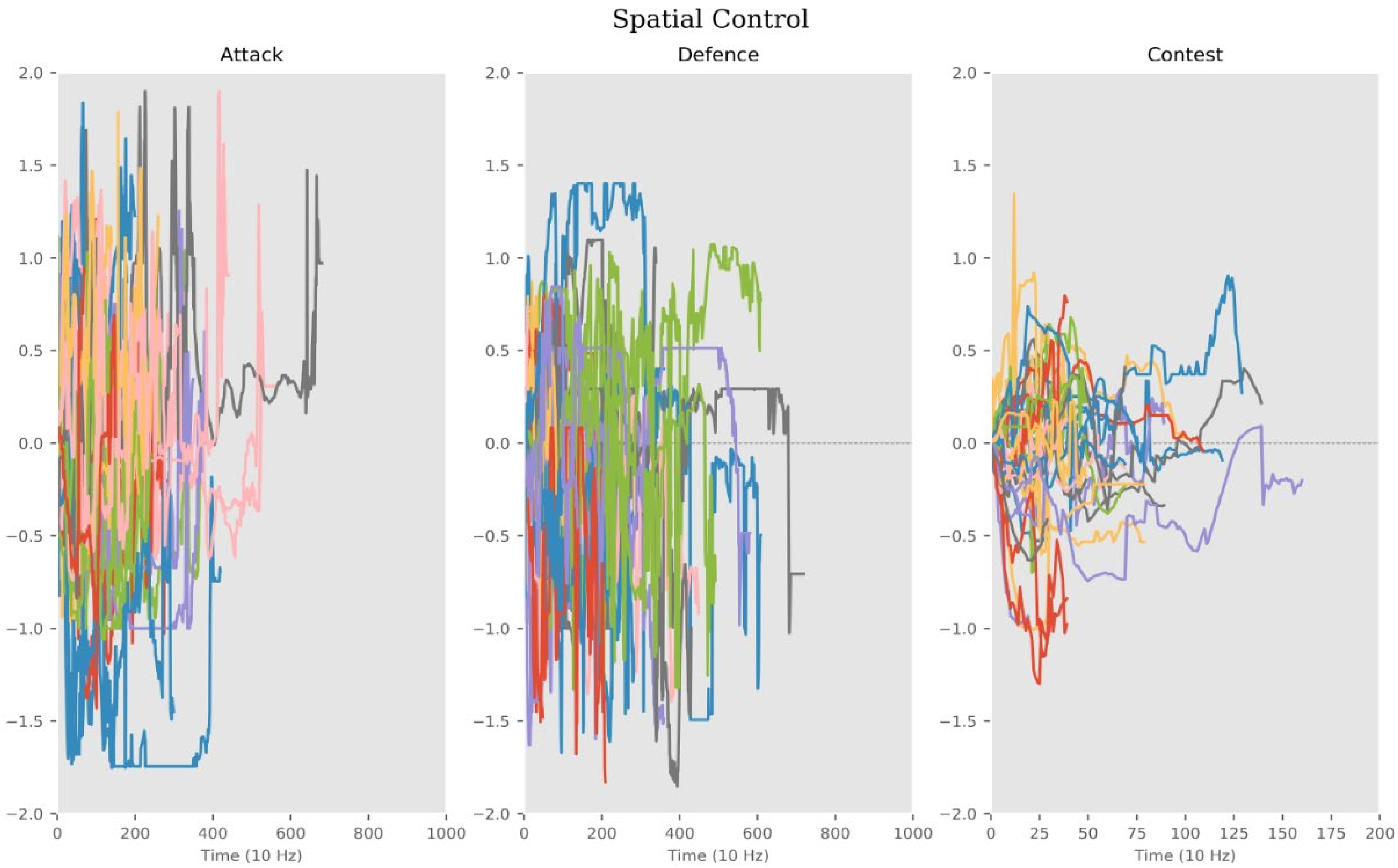

Figure 6-5: Comparison of individual instances of spatial control in relation to the duration of time for match phase.

6.5 Discussion

This proof of concept study is the first to investigate the extent to which continuously represented team spatial control varies with respect to specific match play events in Australian football. This research also advances a novel approach in using player-tracking data to measure the spatial control of teams in a continuous manner.

The present findings support the observations of previous research that advocate emergent patterns of coordination transpire between attackers and defenders during specific contextual variables (Alexander, et al., 2019; Lucey, et al., 2013; Travassos, et al., 2016; Vilar, Araujo, Davids, & Travassos, 2012). Relative to ball position, teams maintained greater spatial control when in possession during offensive sequences of play and experienced reduced control whilst defending. This outcome was observed regardless of field position of the ball, which is in contrast to previous research (Aguiar, et al., 2015; Clemente, et al., 2015; Vilar, et al., 2013). Whilst studies are yet to report on spatial control in reference to the ball, teams have generally recorded conservative movement behaviour by maintaining greater spatial control in their defensive half (Clemente, et al., 2015; Vilar, et al., 2013). However, findings from the current study may be influenced by AF rules, whereby teams spent extended periods of time in complete spatial control due to marking the ball. In AF, a mark is awarded where a player cleanly catches the ball that has travelled at least 15 m from a kick without being touched or hitting the ground (Appleby & Dawson, 2002). The player is allowed to advance the ball from the spot where the ball was marked unimpeded, which prevents any opposing player from aiming to regain possession of the ball (Appleby & Dawson, 2002). This rule may result in players having complete spatial control relative to the ball during these instances, which may skew the overall distribution of spatial control. In general play however, the Away team was able to generate greater spatial control when the ball was in the contested phase, which may have assisted in obtaining possession of the ball during these instances. Furthermore, both teams were able to arrest spatial control when forcing a turnover. Variability in spatial control, measured through ApEn, was reduced during the contested phase when compared to offence and defence, which is supported by previous research as increased movement may exist during these phases as players are required to create attacking opportunities for their teammates during offensive sequences, whilst transitioning to defend their own goal when the opposition gains possession of the ball (Clemente, et al., 2015).

Analysing the relationship of player positioning between teams and the resulting continuous exchange of spatial control is central in determining tactical team behaviour. The fundamental underpinning of team sports is the concept of two interconnected yet opposing forces (Grehaigne & Godbout, 1995). Teams must manage risk in relation to creating offensive opportunities to score, whilst maintaining defensive security (Vilar, et al., 2013). This emergent system suggests a trade-off scenario may apply, when referencing how teams position players during these game states. Specifically, teams may strategically position players across a field of play in an attempt to gain a competitive advantage, whilst concurrently absorbing a disadvantage in other aspects of match play. For example, results from the current investigation identified teams obtained greater spatial control when forcing a turnover in possession. During defence, teams may employ a 'pressing' strategy, which requires defenders to be positioned higher up the ground to attempt to regain possession closer to the opponent's goal. This strategy may generate increased turnovers closer to their attacking end, however, it may lessen the capacity to protect space closer their own goal if the opposition is able to transition the ball through the defensive structure, which may inflict greater scoring opportunities from the opposing team. Specific tactical considerations to AF include how to position players during contested phases of play. Teams may allocate more players around the ball to provide a greater chance of gaining possession during these match events. However, this may create a spatial control shortfall elsewhere on the field that has the potential to influence other aspects of match play. For example, if a forward is used to achieve greater control around contested situations, the opposition may obtain greater control in their defensive half. This may provide the opposition with the opportunity to create more turnovers in this area of the field, which may limit a team's ability to score once entering their forward half.

Determining the continuous spatial control of teams has the potential to provide a more comprehensive framework for measuring tactical team behaviour by quantifying more representative models that assess risk and reward probabilities of individual passes and expected goals (Spencer, et al., 2019). Furthermore, these models could be combined with a teams formation (Bialkowski, et al., 2014) to understand which game style or structure may potentially assist in increasing the capacity of completing successful passes or increase expected goal values. For instance, defenders may employ set formations that aim to impede or restrict the oppositions attacking sequences, potentially constraining a team's capacity to transition the ball effectively. Determining the set positioning of defenders may provide the attacking team with information to quantify valuable space, such as passages toward goal, which may produce greater scoring opportunities.

Some limitations relating to sample size and the number of teams included in this study should be recognised. Additional research should include multiple clubs throughout several matches to construct a more accurate representation of how players generate and sustain spatial control and if any variations exist between various contextual variables. Future investigations may also determine the level of association between a team spatial control and performance in AF.

6.6 Conclusion

This study investigated the extent to which continuously represented spatial control varies with respect to specific match play events in AF, thereby advancing a novel approach in using player positioning data to measure the spatial control of invasion sports teams in a continuous manner. When in possession, teams maintained greater spatial control and endured reduced control whilst defending. However, both teams were able to arrest spatial control when forcing a turnover. Future investigations should include a greater sample size of matches that measure specific formations and structures in combination with a continuous spatial control technique. This approach has the potential to provide a more representative understanding of tactical team behaviour.

CHAPTER 7 – GENERAL DISCUSSION, PRACTICAL APPLICATIONS, FUTURE DIRECTIONS & CONCLUSIONS

7.1 Overview

The aim of this thesis was to provide a framework to quantify tactical team behaviour in Australian Rules football. The uptake of player tracking technologies in invasion sports has provided a method to describe tactical team behaviour by measuring the general patterns of collective behaviour undertaken throughout a match (Andrienko, et al., 2019). Generally, research measuring collective team behaviour has taken a more macroscopic approach, whereby the positioning of certain players is summarised to represent global team behaviour. A more microscopic approach has also been used as it accounts for all players in a continuous manner, which may provide a more detailed analysis of collective team behaviour.

In this thesis, macroscopic and microscopic approaches were used for assessing collective team behaviour. Specifically, a macroscopic approach was undertaken by using a range of spatiotemporal metrics during match simulation (chapter 3) and a competitive match (chapter 4) to provide a global overview of collective team behaviour during various contextual variables, such as match phase and ball position. A microscopic approach enabled the modelling of all players, which may provide a more representative understanding of collective team behaviour. This was achieved through a discrete method that measures a player numerical advantage in specific sub-areas on a field of play (chapter 5). In addition, a more continuous model was employed where spatial control isn't restricted by distinct zones but instead determines the probability of control by considering the position of the ball, teammates and opponents (chapter 6). To further enhance the application of the framework developed in this thesis, a larger dataset would be required to find reoccurring structures or formations in collective team behaviour and to determine the level of association between team spatial control and match play in a continuous manner. This would contribute to a greater understanding of tactical team behaviour by determining the importance teams place on controlling specific regions of space during different aspects of match play.

7.2 General Discussion

Information of sport competition is gathered and disseminated within teams to prepare for future contests (McGarry, et al., 2002). The capacity to gather information regarding the performance of teams has improved, largely due to technological advancements (Travassos, et al., 2013). To enhance performance however, effective evaluation of collected information is required to deliver useful feedback to players and coaches (Bishop, 2008).

Analysing sporting performance has generally been outcome focused where a notation system is used to record discrete player or team actions in isolated categories during a match (Mackenzie & Cushion, 2013). This process involves limited reference to the wider performance environment and the contextual variables that may influence player behaviour (Duarte, et al., 2012; Travassos, et al., 2013). The underlying framework of performance analysis has since evolved past the discrete notation of isolated events towards a more theoretical process based understanding where performance is observed as the product of continuous interactions between teammates and opponents (McGarry, 2009; Travassos, Araujo, Duarte, & McGarry, 2012). In this sense, teammates exhibit patterns of coordination as they manage relations with opposing players in space and time, which may provide a more representative understanding of how and why a performance occurs (Travassos, Araújo, Correia, & Esteves, 2010). A key feature of sport teams as complex systems is the evolving patterns of coordination that emerge between players presented in a dynamic environment (Rein & Memmert, 2016; Ric et al., 2016). How teams regulate their positioning in respect to specific contextual variables that emerge throughout a match may describe their tactical team behaviour (Duarte, et al., 2012). Whilst studies have investigated how collective team behaviour develops throughout a match, considering specific contextual variables that may influence movement behaviour has been largely ignored. In this respect, variability in movement patterns may be determined by understanding the factors that influence player behaviour (Davids, Glazier, Araujo, & Bartlett, 2003). A central component influencing the variability of invasion sport teams is the opposition relationship (Gréhaigne, Godbout, & Zerai, 2011). Teams may regulate their positioning to impose their tactical behaviour or strategy, while limiting that of the opposition (Davids, et al., 2005). Fundamentally, teams cannot take risks in an attempt to score, whilst concurrently maintaining defensive stability (Gréhaigne, et al., 2011). Thus, the positioning of players during different match contexts may partially describe the tactical behaviour of teams.

Studies to date suggest that during attacking sequences, teams in football may aim to increase the playing space by stretching and expanding distances between players, while conversely, restrict or close down the playing space by reducing the distance between players during defence (Clemente, et al., 2013; Vilar, et al., 2013). This strategy may allow easier passage of the ball during attacking phases, while impede or constrain ball movement whilst defending (Travassos, et al., 2012). Other research proposes that football teams typically display more conservative behaviour by positioning players closer to their own goal (Clemente, et al., 2013). By building on this research through incorporating contextual variables when measuring collective team behaviour, further investigations have identified that teams in football may employ a more attacking strategy during home matches by positioning higher up the ground, which may produce increased possession of the ball in their attacking half and generate a greater amount of scoring opportunities (Bialkowski, et al., 2014).

The findings from this thesis also advocate that collective movement behaviour of AF teams is influenced by contextual variables, including match phase and ball position. Specifically, chapter 3 identified teams that obtained greater possession of the ball displayed increased length, width and surface area, and were positioned higher up the ground. Chapter 4 included ball position to record players repositioned behind centre when the ball was in their defensive half and moved forward of centre when the ball was in their forward half. This finding is further supported in Chapter 5, which recorded the total number of players increased based on where the ball was positioned and teams were outnumbered when the ball was in their forward half. Furthermore, Chapter 6 recorded that both teams were able to arrest spatial control when forcing a turnover in possession.

7.3 Practical Applications

7.3.1 Strategic Decision Making

The framework quantifying tactical behaviour developed in this thesis may be used to support decision-making by determining the effectiveness of a team's game style. This concept may also be extended to gain a competitive advantage by better understanding opposing team tactics or game style. These findings could be applicable to various invasion sports. Specifically, the combination of spatiotemporal variables (chapter 3 - 4) and methodologies that measure team spatial control (chapter 5 - 6) may assist in measuring particular collective team behaviour. Assessing the interaction of different collective behaviour between teams during multiple matches will assist in determining the validity of this framework. This could be further extended to better understand how different strategies influence spatiotemporal metrics and spatial control of teams. For instance, teams that may want to employ a 'pressing strategy' in an attempt to retain the ball in their forward half, may position higher up the ground to generate enough pressure to keep the opposition from moving the ball outside this zone. By assessing the team centroid and spatial control during defensive phases, coaches and sport science practitioners can provide practical feedback on the positioning of players. Alternatively, an aim to maintain possession of the ball may be more attainable if surface area is being created when initially gaining possession of the ball. Specific considerations to

AF include how player positioning is managed during contested phases of play. Increased players in the vicinity of contested situations may provide a greater capacity to obtain possession of the ball. However, reallocating players from other areas of the field to achieve this may generate a spatial control deficit that may influence other aspects of match play. For example, if a forward is used to achieve greater control around contested situations, the opposition may obtain greater control in their defensive half. This may provide the opposition with the opportunity to create more turnovers in this area of the field, which may limit a team's ability to score once entering their forward half. Opposition analysis may also be benefit from a greater understanding of rival collective team behaviour. For example, an opposing team that quickly relocates players deep in their defensive end after losing possession of the ball could produce increased space through the middle of the ground. This may be exploited by employing a higher possession style of play with a slower build-up that reduces the risk of losing possession.

7.3.2 Designing Representative Training Regimes

The association between tactical team behaviour and the physical output of players requires attention from all staff within a sporting organisation. In an attempt to obtain successful performance outcomes, coaches may aim to instill certain tactical behaviour or styles of play, which may influence the physical output of players. As such, monitoring athlete movement profiles in relation to differences in collective team behaviour may assist in designing training regimes that more effectively represent match play movement profiles (Larsson, 2003). Understanding how spatiotemporal metrics may be influenced by specific collective behaviour in training and matches may provide important information when benchmarking movement expectations. For instance, observing how the manipulation of various training modalities, such as including extra defenders or attackers in a training drill, influences these movement expectations. More specifically, teams employing counter attacking behaviour by maintaining defensive stability until the opposition has positioned higher up the ground during offensive sequences, may produce exposed space in the opposition's defensive half, which may be exploited upon regained possession. This collective team behaviour may exhibit extended periods of moderate running demands interspersed with high intensity sprints. By incorporating tactical team behaviour and physical output datasets, coaches and sport science staff may obtain a more representative understanding of athlete movement profiles. This may assist in generating a synergistic environment that grasps how predetermined roles and responsibilities of players may influence physical output. Such information may be considered when providing feedback to players, rather that solely using physical output data to determine their performance. More effective interpretation of these datasets may assist in developing desired adaptive behaviour during training and matches.

7.4 Future Directions

Current research proposes that invasion sports are highly complex, multifaceted, and dynamic in nature. Players are constantly regulating their positioning in an attempt to balance attacking opportunities and maintain defensive stability. Thus collective team behaviour is continually being influenced by various contextual variables. Preliminary investigations have incorporated certain contextual variables, such as match location, level of competition, etc. The findings from this thesis emphasise the demand for performance analysts and sport science practitioners to consider match phase and ball location when assessing the tactical behaviour of teams. Future investigations may also employ a continuous model that represents spatial control to assess expected goals values and reoccurring formations and structures. The findings generated from this thesis provide a preliminary framework to quantify tactical team behaviour in Australian Rules football. Specifically, the methods developed in the individual chapters may be combined to determine the collective team behaviour in Australian Rules football. However, while future studies may incorporate the spatiotemporal metrics used in this thesis, researchers should be mindful that additional metrics might be added to further expand upon the framework. Research should also include a microscopic approach that considers every player to provide a more representative understanding of tactical behaviour.

7.5 Summary

This thesis aimed to provide a framework to quantify tactical team behaviour in Australian Rules football. Player positioning data was used to measure collective team behaviour during various contextual variables, thereby providing a method to analyse tactical team behaviour when repetitive patterns of movement were formed. A macroscopic approach using spatiotemporal metrics was used in match simulation (chapter 3), which were further combined with heat maps and ShannEn entropy in a competitive match (chapter 4) to provide a global overview of collective team behaviour of AF teams. A microscopic approach was then used to provide a more representative measure of collective team behaviour by modelling the positioning of every player to understand how this provided a degree of team spatial control. This approach was used to understand the extent to which team spatial control influences match play in a continuous manner. A discrete method of team spatial control was developed in chapter 5 by determining the team numerical advantage in specific sub-areas of play. A continuous approach (chapter 6) enabled a more representative understanding of team spatial control. As this framework is a starting point for quantifying tactical team behaviour, future applications require larger datasets to determine specific player formations and structures to determine the association with performance outcomes.

7.6 Conclusions

The specific conclusions of this thesis are:

1. Collective team behaviour was influenced by match phase with teams positioning higher up the ground during offence and relocating closer to their own goal during defence.
2. Field position of the ball had a greater influence on the *x*-axis centroid. Conversely, match phase had a greater influence on length, width, and surface area.
3. The total number of players increased based on where the ball was positioned and both teams outnumbered the opposition when the ball was in their defensive half.
4. Teams maintained greater spatial control during offence and endured reduced control whilst defending. Both teams were able to arrest spatial control when forcing a turnover.

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