



The Influence of the Phases of Match-Play on the Physical, Technical and Tactical Profiles of Professional Australian Football

by

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Michael Rennie declare that this thesis, is submitted in fulfillment of the requirements for the award of Doctor of Philosophy, in the Faculty of Health at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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PREFACE

This thesis is written as per the requirements of the degree, Doctor of Philosophy and published according to the “Thesis presentation and submission” guidelines. The manuscripts included in this thesis are logically progressive in nature and form a body of work that encompasses the investigation of the phases of match-play in professional Australian Football.

The data collected during this candidature and associated research methodology has resulted in one manuscript being accepted for publication while a further three manuscripts are currently being reviewed by peer-reviewed journals. The Introduction section provides a brief background of the literature, defines the research problem and outlines the aim and purpose of each study. The Literature Review provides a synopsis of the current available literature describing the physical, technical and tactical demands of Australian Football. The next four chapters encompass the manuscripts which are presented in a logical sequence that specifically address the research problems outlined in the Introduction. The figures, tables and referencing format remains according to the peer-review journal guidelines. Each manuscript in Chapter Three to Chapter Six outlines an introduction to the specific research problem, individual methodology, results and discussion. Next, a General Discussion chapter provides a synopsis of the findings from the various manuscripts. Practical recommendations are provided to exemplify the real-world relevance for coaches, sport scientists and performance analysts. The limitations and delimitations of the current work is also discussed. The final chapter, Summary & Recommendations offers an interpretation of the collective findings resulting from the thesis. Finally, suggestions of future research are provided in light of the findings in this thesis. The APA 6th reference style has been used throughout the document and the reference list is located at the end of thesis.

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ABSTRACT

Australian Football is a team sport involving periods of ball possession, contested play (where both teams compete for possession) and stoppages of varying durations. The physical element of the game is characterised by intermittent high-speed running along with frequent collisions, tackles and changes of direction. Players also require technical skill qualities depending on specific scenarios arising during match-play along with tactical strategies designed by coaching staff that consider various contextual factors to maximise the likelihood of success. Performance is dependent on the interaction of these constructs which are closely associated to the phases of match-play. Accordingly, this thesis comprises of four progressive studies that investigated the influence of the phases of match-play on the physical, technical and tactical profiles of professional Australian Football.

Study One described the mean duration and frequencies of the phases of Australian Football match-play. Six operational definitions were created for offence, defence, contested play, umpire stoppages, set shots and goal resets. This study examined the coding methodology central to the three subsequent studies. A test-retest design assessed the precision of coding the phases of play. There were ~500 changes in the phases of play per Australian Football match, highlighting the intermittent nature of match-play. The intra-coder reliability assessment demonstrated that a trained researcher can code the phases of play with high precision. These findings permitted the use of these phases of match-play for the proceeding studies. *Study Two* analysed the distribution of physical and technical performance during the phases of Australian Football match-play. The physical and technical demands varied significantly depending on the phase of match-play. Additionally, average and 'worst-case scenario' activity and recovery cycles provided practical information for coaches to design match-specific training. *Study Three* examined the influence of player position and game quarter on running during the phases of match-play. Nomadic and key position players shared similar match-running profiles during the phases of play, however, nomadic players performed higher volumes and intensity of movement. The data demonstrated that reductions in match intensity occur

during active periods of match-play, but not during stoppages. These findings have applications for informing training practices for different positions and suggest that metabolic power estimates may be useful for analysing specific elements of competition where spatial constraints limit opportunities for high-speed running. *Study Four* examined differences in physical and technical performance measures during the phases of match-play whilst considering contextual factors including quarter success, calibre of opposition and playing away from home. The contested element of match-play increased when the quarter was lost and when competing against high calibre opposition. The findings have applications for informing training practices to increase the likelihood of match success and mitigate the effects of playing against high calibre opposition and away from home. Collectively, the series of studies showed that the phases of match-play contribute to the intense nature of competition and should be considered when interpreting match profiles. The physical and technical demands of the phases of match-play are also influenced by player position, match-induced fatigue, match success, opposition calibre and match location.

CHAPTER ONE

INTRODUCTION

1.1 RESEARCH BACKGROUND

Australian Football is an invasion-based team sport played on a large, oval-shaped field with the match separated into four 30-minute quarters. The primary aim is to outscore an opposition team by kicking more goals and by using a combination of physical, technical and tactical strategies. Match-play is characterised by periods of ball possession, when the ball is contested (i.e. both teams compete for possession) and stoppages of varying durations which underpin the prolonged, intermittent, high-speed running demands. Players are involved in frequent collisions, tackles, and often perform change of direction movements to evade opposing players. In addition, players require a myriad of technical skill qualities that are relevant to different periods throughout the match. Teams employ tactical strategies designed by the coaching staff that consider various contextual factors to maximise the likelihood of success. As such, applied research in Australian Football has aimed to assess the physical, technical and tactical performance profiles of match-play by measuring various parameters that relate to these performance constructs. However, the influence of the time spent in the various phases of match-play on measures of physical and technical performance are yet to be elucidated.

The relevance of assessing physical and technical constructs in Australian Football is based on the assumption that they relate to individual or team performance (Impellizzeri & Marcora, 2009). Indeed, performance has been assessed at an individual or team level using either coach subjective rating of performance (Johnston, Watsford, Austin, Pine, & Spurrs, 2016; Johnston et al., 2012; Sullivan et al., 2014b) or team success (i.e. win or loss) (Gronow, Dawson, Heasman, Rogalski, & Peeling, 2014; Ryan, Coutts, Hocking, & Kempton, 2017). The measures that most relate to performance have been adopted as causal factors relating to performance (Figure 1.1).

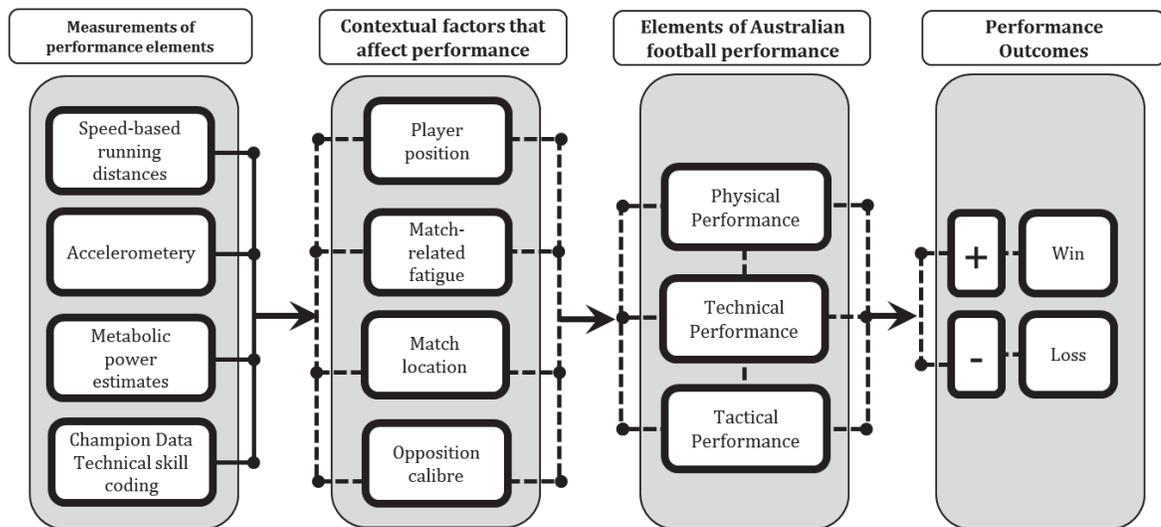


Figure 1.1: Conceptual model of Australian football performance. Adapted from Impellizzeri & Marcora (2009). The contextual factors included in this figure are only examples.

Currently, the physical and technical performance constructs of Australian Football are most commonly measured using global positioning satellite (GPS) technology (Kempton, Sullivan, Bilsborough, Cordy, & Coutts, 2015b; Ryan et al., 2017) and manual notation methods (Johnston et al., 2016; O'Shaughnessy, 2006), respectively. Presently, every Australian Football League (AFL) club utilises micro-technology to analyse the physical performance of their players for the purposes of match analysis, training load quantification and rehabilitation. Modern GPS devices can provide speed-based running distances, accelerometry data and estimates of metabolic power and as a result, several publications have quantified the physical demands of Australian Football using a combination of these variables (Coutts et al., 2015; Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Wisbey, Montgomery, Pyne, & Rattray, 2010). Additionally, several studies have assessed the validity and reliability of these individual measures of physical performance and have been valuable for guiding the use of specific variables in current physical performance research (Coutts & Duffield, 2010; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010; Johnston, Watsford, Kelly, Pine, & Spurrs, 2014). Technical skill counts are provided by methods of manual notation analysis. In Australian Football, ChampionData® code all AFL matches for a myriad of technical skills. Several other skill

counts are also available. However, the most commonly reported technical skills utilised in Australian Football research include the frequency of kicks, handballs, possessions and tackles. The combination of GPS and technical skill data present the most common methods and causal indicators of physical and technical performance constructs in Australian Football.

Currently, there is an increasing body of research integrating the physical and technical parameters in Australian Football. Indeed, the physical, technical and tactical elements are rarely performed in isolation during match-play and thus, coaching and conditioning staff aim to develop training programs where these performance elements are trained simultaneously. Data of this kind has been deemed by many authors to have more practical significance compared to research studies where these constructs are assessed in isolation. Moreover, converting match performance data into transferrable training recommendations are more probable when recommendations involve the integration of various factors relating to performance (Bishop, 2008).

It is important to account for contextual factors that are known to influence performance profiles including match location, the calibre of the opposition and the time spent in the difference phases of match-play (Carling, 2013; Carling, Wright, Nelson, & Bradley, 2014). Indeed, several Australian Football studies have analysed measures related to physical and technical performance, along with several contextual factors either independently or using mixed model approaches. These include, but are not limited to, the influence of player position (Coutts et al., 2015; Coutts et al., 2010), level of competition (Brewer, Dawson, Heasman, Stewart, & Cormack, 2010), match-related fatigue (Aughey, 2010; Kempton, Sirotic, Rampinini, & Coutts, 2015a), match location (Ryan et al., 2017), point differential (Sullivan et al., 2014a), physical capacity (Mooney et al., 2011), previous training loads (Aughey, Elias, Esmacili, Lazarus, & Stewart, 2016) and player calibre (Johnston et al., 2016; Johnston et al., 2012). However, one area that has received a great deal of attention in professional soccer, but not Australian Football, is the influence of the time spent with and without possession of the ball (Bradley, Lago-Penas, Rey, & Gomez Diaz, 2013; Castellano, Casamichana, & Lago, 2012;

Collet, 2013; Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009; Jones, James, & Mellalieu, 2004; Lago, 2009; Lago & Martin, 2007). Overall, the recent literature indicates that the investigation of the physical and technical demands of competition should be performed in conjunction with the time that the ball is in play. Furthermore, several physical and technical measures during different phases of possession have been shown to differentiate high and low calibre teams (Hoppe, Slomka, Baumgart, Weber, & Freiwald, 2015; Rampinini, Impellizzeri, Castagna, Coutts, & Wisloff, 2009).

The influence of the time spent in the various phases of play (offence, defence, contested play and stoppages) are yet to be considered as a contextual factor that influences the physical and technical profile of teams during competition (Gronow et al., 2014). Several studies in professional soccer have shown that time in possession influences both physical and technical profiles (Lago, Casais, Dominguez, & Sampaio, 2010; Rampinini et al., 2009). The time spent in the various phases of match-play during the game likely underpins opportunity for players to perform technical skills and thus, skill counts may be more relevant to time in possession (Bradley et al., 2013). Additionally, the phase of match-play may influence the temporal physical demands throughout the match and contribute to the intermittent demands that are so often reported in team sport research (Gabbett, Polley, Dwyer, Kearney, & Corvo, 2014)

Furthermore, several studies in team sports have shown that technical and tactical constructs are more closely related to successful match outcomes when compared to physical performance measures (Kempton, Sirotic, & Coutts, 2016; Sullivan et al., 2014a). However, these constructs have not been assessed with respect to the time spent in the various phases of match-play. Researchers have encouraged the adoption of an integrated approach to the reporting of physical and technical construct data (Carling, 2013; Kempton et al., 2016). Rather than considering these constructs in isolation, it may be beneficial to examine these constructs during specific elements of play. As the individual constructs of match performance are closely linked and do not occur in isolation, continued efforts to integrate these measures of performance and interpret outcomes in relation to the context in which

they occur will yield further important insights into overall match performance in professional Australian Football.

A phasic approach to the analysis of competition could account for teams who use different ball possession tactics (i.e. high possession team compared to a counter-attacking team) and the combination of a team's physical and technical profile during the phases of match-play may provide indirect information about a team's tactical approach to the game. For example, one soccer-based study showed that high-intensity running distance is no different between players of more successful teams (ranked in the first five positions) with the players of less successful teams (ranked in the last 5 positions) of the same league (Rampinini et al., 2009). However, differences were found for high-intensity activities with the ball. As such, the interaction of physical performance and technical indicators within different phases of play may provide better indicators of performance. Nevertheless, it is currently unknown whether these phases of Australian Football match-play can be coded with an acceptable level of precision. If deemed to be reliable, the methodology may permit physical and technical research during these phases. Clearly, the analysis of the physical and technical demands of the phases of play would be hazardous without first assuring the coding procedures are reliable. To enhance current understanding about performance in Australian Football, it appears important to assess these performance factors in relationship to the time spent in each phase of match-play. This analytical methodology may provide more robust detail relating to the different performance constructs by revealing factors relating to match performance.

1.2 RESEARCH AIM

While a number Australian Football studies have contributed to current understanding of the physical, technical and tactical performance constructs associated with match performance, no empirical research exists that has considered the influence of the time spent in the phases of match-play. The elucidation of the phases of match-play has applications for determining match demands and

intensities, developing activity and recovery cycles, identifying differences in positional demands, determining the presence of match-related fatigue, and examining other contextual factors related to match success. A large body of literature in soccer demonstrates the importance of considering phases of possession due to relationships to measures of individual and team performance (Bradley et al., 2013; Castellano et al., 2012; Collet, 2013; Di Salvo et al., 2009; Jones et al., 2004; Lago, 2009; Lago & Martin, 2007). However, few studies have applied this methodology in professional Australian Football (Gronow et al., 2014). Anecdotally, stoppages during Australian Football involve low intensity activity, while active elements of match-play involve high-intensity activity. However, no studies have empirically assessed the effects of phases of match-play on the intermittent demands of competition. Performance is dependent on the interaction of these constructs (physical, technical and tactical) which are closely associated to the phases of match-play, but this relationship is yet to be examined in detail. From a practical perspective, further information that describes the context of match-running and technical skills during the phases of match-play would have numerous applications in training, talent identification and player development.

1.3 RESEARCH OBJECTIVES

Four separate research studies were designed to specifically investigate the influence of the phases of match-play in professional Australian Football and as such, contribute new knowledge to a conceptual model that aims to identify factors that relate to performance (Figure 1.2). The first study was imperative to develop a set of operational definitions and determine the intra-assessor reliability associated with coding these phases of play (*study one*). The second objective of this research (*study two*) was to determine the distribution of match-running performance (measured via GPS) and technical skills within the phases of match-play, effectively contextualising the nature of running and skill performance in professional Australian Football. The elucidation of these phases of play will also permit the design of common activity and recovery cycles associated with competition. The following two studies (*studies three and four*) investigated the influence of player position, match

quarter, match location, opposition calibre and match success on physical and technical performance during the phases of match-play.

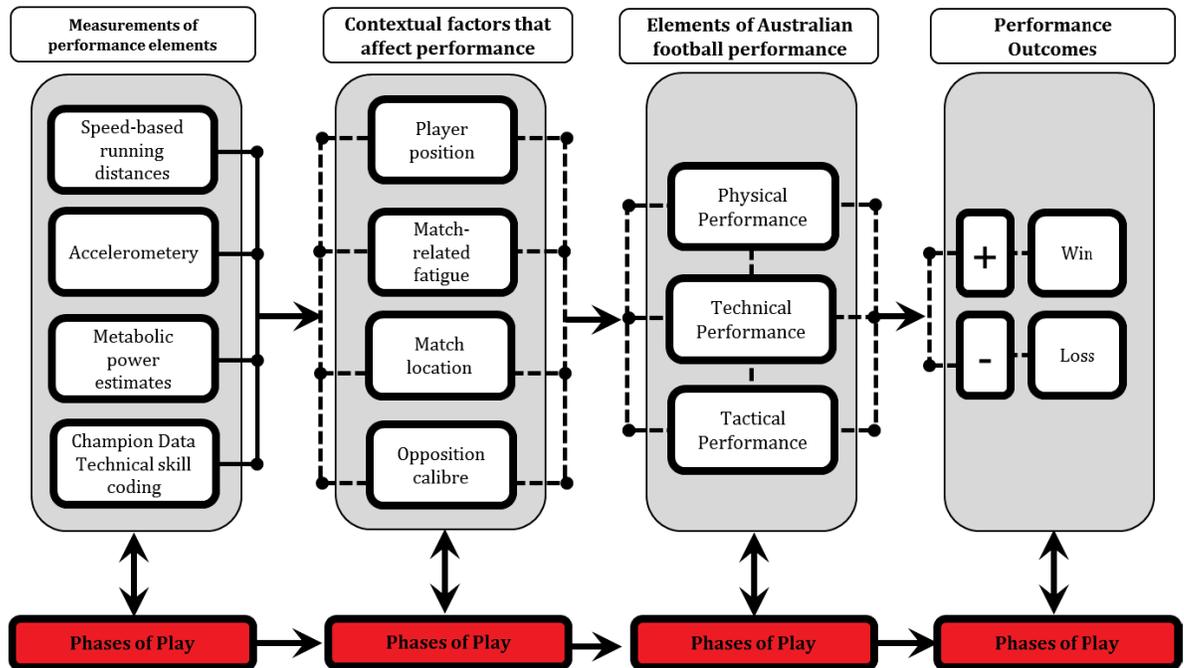


Figure 2.2: Objectives of the research studies and how the phases of play could contribute to new information regarding performance in professional Australian Football.

Effectively, these studies aimed to investigate the phases of match-play that underpin the intermittent demands of Australian Football, examine the influence of contextual factors on performance during the phases of play and develop further knowledge pertaining to the relevant performance constructs of Australian Football that influence the likelihood of match success.

STUDY ONE: PHASES OF MATCH-PLAY IN PROFESSIONAL AUSTRALIAN FOOTBALL: DESCRIPTIVE ANALYSIS & RELIABILITY ASSESSMENT

Aim

The aims of this study were to a) assess the intra-assessor reliability of coding the phases of professional Australian Football match-play (offence, defence, contested play, umpire stoppage, set

shot and goal reset); and, b) to describe the average duration and frequency of the phases of match-play.

Significance

When developing notational methods, it is of primary importance to determine the repeatability and typical error associated with the methodology. The findings of this study are important to determine whether the phases of match-play can be coded with an acceptable degree of reliability and repeatability, describe the intermittent nature of match-play according to changes in match context and create a clear set of operational definitions of the phases of match-play for applications in match analysis.

STUDY TWO: PHASES OF MATCH-PLAY IN PROFESSIONAL AUSTRALIAN FOOTBALL: DISTRIBUTION OF PHYSICAL AND TECHNICAL PERFORMANCE

Aim

The aims of this study were to a) describe the physical and technical profiles of the various phases of match-play and b) describe the physical and technical elements of activity and recovery cycles associated with professional Australian Football match-play.

Significance

This study investigated the context of match-running demands and technical skills during the different phases of match-play, enabling a greater understanding of the factors that underpin fluctuations in match-intensity in professional Australian Football. Additionally, activity and recovery cycles can be developed from this information, which are highly useful for coaches and sport science practitioners in a training context.

STUDY THREE: PHASES OF MATCH-PLAY IN PROFESSIONAL AUSTRALIAN FOOTBALL: POSITIONAL DEMANDS AND MATCH-RELATED FATIGUE

Aim

The overall aim of this study was to investigate the influence of the player position and game quarter on match-running performance during phases of play. The objectives were to a) identify if positional running demands differ depending on the phase of match-play and b) determine whether reductions in match-running performance are global or isolated to specific phases of match-play.

Significance

Many studies in Australian Football have demonstrated that nomadic players have the highest physical demands when compared to other positions. However, it is currently unknown whether positional demands are dependent on the phases of play. Secondly, recent research in rugby league has illustrated the importance of considering stoppage time when assessing match-related fatigue as it is unknown whether reductions in physical output are due to fatigue or the phase context of match-play. This research is valuable for conditioning and coaching staff to determine the distribution match running between the different phases of play for various positions to appropriately guide training processes. Furthermore, the elucidation of the phases of play in this context would assist in identifying whether reductions in match-running performance are global (i.e. occur in all aspects of play) or are isolated to specific elements of match-play.

STUDY FOUR: FACTORS AFFECTING PHYSICAL AND TECHNICAL PERFORMANCE DURING THE PHASES OF PROFESSIONAL AUSTRALIAN FOOTBALL MATCH-PLAY

Aim

The aim of this study was to compare the time spent in the various phases of match-play, along with the physical and technical profiles during: a) successful and unsuccessful quarters, b) against high and low calibre opposition, and c) when playing home or away.

Significance

While the important physical and technical performance measures have been identified in professional Australian Football, no study has considered performance outcomes during the various phases of match-play. This study would provide useful information about the physical and technical performance during the different elements of match-play and how they relate to quarter success. These findings will provide insight into the differences between successful and unsuccessful matches. The calibre of the opposition and match location have also been shown to influence performance, however these contextual factors have not been investigated in Australian Football in relation to the phases of match-play. These findings may help guide training approaches and prepare for matches against high calibre opposition and alleviate the deleterious effects of playing away home.

1.4 LIMITATIONS OF THE RESEARCH

There are inherent limitations associated with the research studies. These include:

- The use of S5 GPS units (Catapult Sports, Melbourne, Australia) and associated resolution of the GPS sampling rate (10 Hz).
- The number of available satellites, horizontal dilution of precision and current software and firmware versions associated with the data production.
- Processing error associated with firmware and software.

- Player motivation, calibre and performance during matches.
- Injuries during match-play that could lead to reductions in available match samples, and within match intensity changes due to player rotations.
- Coaching influence on the physical, technical and tactical performance of players throughout the data collection period.
- Results from the matches analysed thus implicating the samples associated with successful and unsuccessful quarters.

1.5 DELIMITATIONS OF THE RESEARCH

The following delimitations were evident in this research:

- The definitions of the phases of Australian Football match-play used to categorise phase context. Furthermore, the use of SportsCode as a coding tool to assess the video footage.
- Sample size utilised in the research. The results of this project were based on 34 professional Australian Football players. Therefore, the suggested implications may only apply to this population group and may not be representative of athletes from teams or level of competition (e.g. applicable to players from sub-elite Australian Football competitions).
- Matches played under a variety of environment conditions and differences in field size which can influence physical and technical profiles.
- Within match changes in player position that relate to coaching tactics.
- The use of key, nomadic and ruck position descriptors to characterise player position.
- The use of a GPS system to measure physical performance.
- The use of Champion Data statistics to measure the technical elements of match-play.
- The use of specific physical and technical variables to assess performance.

CHAPTER TWO

LITERATURE REVIEW

INTRODUCTION

Professional Australian Football involves a dynamic and complex interaction of the physical, technical and tactical constructs that are inherent to the rules and structure of the game. The physical demands of Australian Football have been well documented, and collectively suggest that match-play involves the highest running volumes compared to any other team sport (Varley, Gabbett, & Aughey, 2014). Players perform frequent, intermittent bouts of high-speed running, accelerations, decelerations, change of direction and are also involved in frequent collisions with opposition player. Technical performance involves a myriad of hand and foot skills that are important for passing and gaining possession of the ball. Teams also employ an array of tactics depending on their own personnel, coaching philosophies, the opposition team, field dimensions and environmental conditions during the match. Given that the physical, technical and tactical performance elements are rarely performed in isolation during match-play, research studies that integrate this information are most likely to transcend into useful training applications. Several studies have assessed the causal factors related to these performance constructs and more recently, others have investigated contextual factors that contribute to changes in performance.

There is an emerging body of research in professional soccer and rugby league that together, describes the importance of considering the time that either team is in possession of the ball. In addition, the amount of stoppage time during a competitive match can also influence player opportunity to perform locomotor activity and technical skills. While the physical and technical demands of professional Australian Football have been thoroughly investigated, the influence of the time spent in the different phases of match-play on the physical and technical demands has yet to be empirically assessed.

Subsequently, the purpose of this literature review was to examine the physical, technical and tactical constructs of Australian Football performance with specific consideration to the phases of match-play. The initial component of the review considers methods of quantifying performance in Australian

Football and discusses the main parameters typically reported in the literature. Furthermore, the main factors currently known to affect the physical and technical profiles are discussed. A brief overview of Australian Football match-play is provided to describe the objectives and structure of the game, while the methods used to analyse the physical and technical demands of match-play are also examined. The physical performance metrics are discussed alongside the variability associated with these measures. Finally, the second section of the literature review discusses common factors that are known to influence the physical and technical demands of Australian Football match-play.

The articles included in this review were sourced via an online search using PubMed, SportDiscus and Google Scholar electronic databases and by examining reference lists of relevant publications. Various combinations of the following keywords were used in the electronic database searches: The following keywords and various combinations were used: 'Australian Football', 'performance analysis', 'running performance', 'technical performance', 'physical performance', 'motion analysis', 'match demands' and 'possession'. Further research was obtained via examining the references lists of papers found using the key words identified above. Match analysis studies examining professional, semi-professional and elite amateur Australian Football match play was considered for review. Other studies in team sports that have considered ball possession as a factor influencing performance were also considered due to the limited comparative literature in Australian Football. The final number of references included in this literature review included 144 original investigations, 16 review articles, 1 conference presentations and 2 books.

2.1 OVERVIEW AUSTRALIAN FOOTBALL MATCH-PLAY

Australian Football match-play can be described as a combination of soccer, rugby league, rugby union and basketball whereby a number of different skillsets are required to effectively compete in various aspects of the game (Gray & Jenkins, 2010). The sport involves elements of foot and hand skills that are integral to passing, speed of ball movement and obtaining possession. Players are frequently involved in collisions that are either related to tackling, competing for ball possession and blocking opposition players to increase the difficulty of gaining possession (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004). An Australian Football team is comprised of 22 players, with 18 players permitted on the field at one time during the match, with the remaining four players on the interchange bench. Players who are on the interchange bench are rotated with on-field players at any time throughout the match (Gray et al., 2010). The rules of the game are reviewed each year and as a consequence, the number of permissible interchanges per team has gradually reduced from unlimited to the current interchange limit of 90 that was introduced prior to the 2016 AFL season. An AFL match is composed of four, 20 minutes quarters of ‘in-play’ game time. The clock is stopped in the event of a goal being kicked, injury on the field or the ball travelling out of bounds (Ebert, 2000; Gray & Jenkins, 2010). Although there are frequent ‘stoppages’ throughout a match, it is imperative to recognise that important performance elements still exist even when the ball is out of play (Dillon, Kempton, Ryan, Hocking, & Coutts, 2017). Interchanges, on-field directions from players, set-up of tactical structures marking opposition players can all occur during stoppage periods. Quarter duration varies between 25 to 30 minutes, resulting in a total game time of approximately 120 minutes (Coutts et al., 2010; Johnston et al., 2012). Furthermore, matches are played on large, oval shaped grounds that vary in length (149 – 175 m) and width (122 – 136 m) (Figure 2.1) (Gray & Jenkins, 2010). Consequently, the duration and complexity of an Australian Football match, along with the speed of

the game, size of the field, requires players to develop a highly efficient physical, technical and tactical qualities in order to succeed.

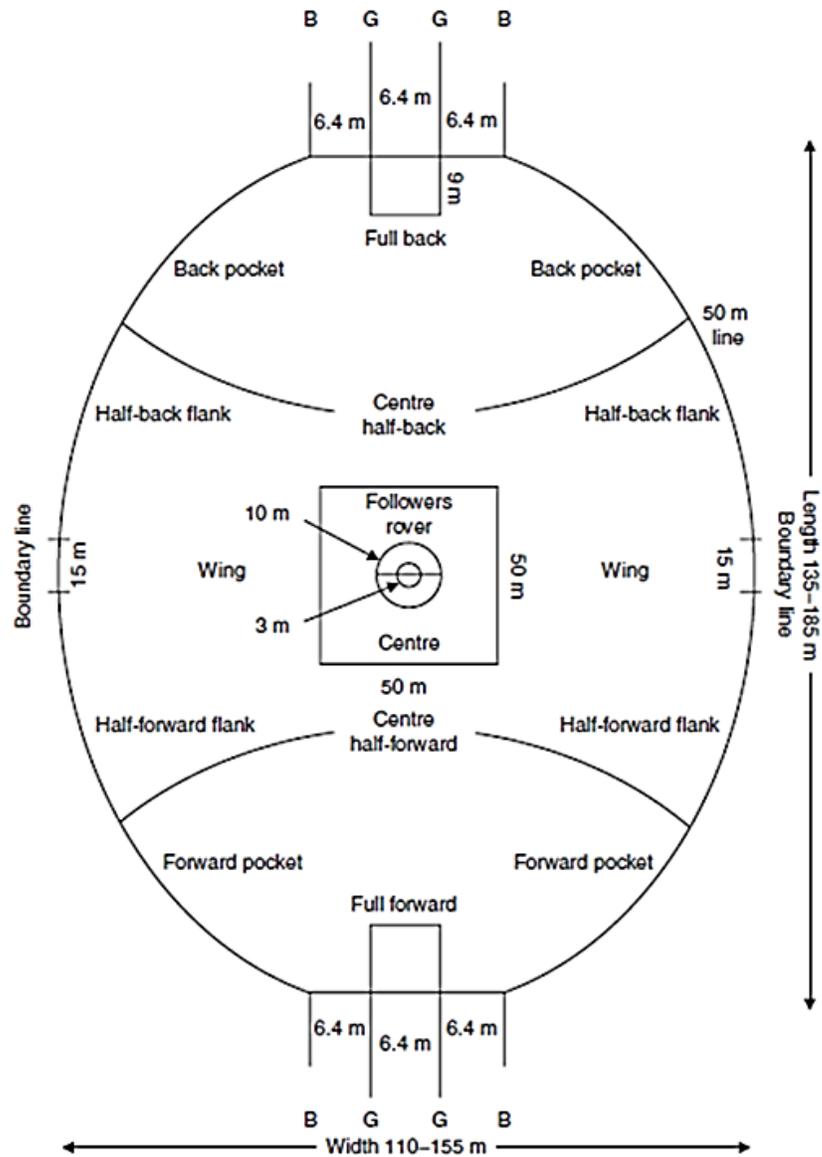


Figure 2.1: Typical player positions in professional Australian Football (Gray & Jenkins, 2010).

Match-play involves either team in possession of the ball, or competing for possession, which has often been referred to as contested play. Contested play is a unique characteristic of Australian Football and typically involves either team competing for possession. These periods of contested play typically arise from a ball up, boundary throw in or centre bounce where play is restarted by the

umpires and either team is given equal opportunity to win possession (Boyd, Ball, & Aughey, 2013). These intense elements of match-play are interspersed by periods of low-intensity activity that arise from stoppages in match-play. Stoppages can occur when an umpire signals a break in play when the ball travels over the boundary line or when the ball is 'held-up' in the field of play, resulting in a boundary throw-in or ball-up, respectively (Dillon et al., 2017). Additionally, if a player marks the ball within range to kick for goal (limit of approximately 60 meters), match-play is stopped, and the player has thirty-seconds to commence their approach for a set shot. If a goal is kicked, the offensive team is awarded six points and the ball is returned to the centre of the field for a centre bounce, where play is restarted by the field umpire. Collectively, these elements of match-play characterise the phasic nature of Australian Football, where periods that the ball is in play involves high-intensity activity, while stoppages are typically characterised by low intensity activity. Moreover, players adopt different positions on the field that involve specific technical skillsets and physical demands and their involvement in the play can vary depending on the status of ball possession in the game.

There are many positional categories in Australian Football, however the evolution of the sport has reduced the number of categories due to players adopting various roles throughout the match (Gray & Jenkins, 2010). For example, Table 1 shows three different classification systems for the positions in Australian Football with varying levels of specificity. The overall aim of the forward group is to kick goals either in general play or from a mark, whilst the defenders attempt to prevent goals being scored by the opposition. The nomadic or midfield players are predominately responsible for winning possession at stoppages and contributing to ball movement through the centre of the field (Coutts et al., 2015). Ruckmen attend every stoppage around the field and have one of the most specialised roles on the field. Each ruckman from either team compete during centre bounces, boundary throw ins or ball-ups in an attempt to win a 'tap-down' to their teams' advantage. Ball movement occurs using a combination of short and long kicking skills (10 to ~60m), as well as handballing that is often employed for short passing in congested scenarios during play. The nomadic players are primarily

responsible for ball possession in the central part of the field, while key positions players (key forward and key defender) occupy positions adjacent to either goal. These players are often the tallest and heaviest players on the field and play an integral role in accruing a positive point differential for their team.

Table 2.1: Three different positional classifications commonly used in professional Australian Football research. Contemporary research has predominantly used categories two and three.

Category 1 - Highly Specific	Category 2 - Specific	Category 3 - General
Full forward	Fixed forwards	Key position
Centre half-forward		
Full Back	Fixed defenders	
Centre half-back		
Forward pocket	Small forwards	Nomadic players
Half-forward flank		
Back pocket	Small defenders	
Half-back flank		
Wing	Midfield players	
Rovers		
Ruckmen		

The dynamic nature of Australian Football has been investigated using variety of technology and analytical techniques that aim to provide information about the physical, technical and tactical demands of competition. Coaches and conditioning staff rely on such information to design evidence-based training programs and drills that simulate specific elements of match-play. The following section of the literature review will describe in detail the use of common analytical techniques adopted in Australian Football, the use of microtechnology in Australian Football, the efficacy of causal measures of physical performance and associated limitations of these measures.

2.2 NOTATIONAL ANALYSIS IN AUSTRALIAN FOOTBALL

Prior to the emergence of microtechnology, manual notational analysis was the primary method of collecting movement and technical performance data during team sport competition (Barris & Button, 2008). Notational analysis provides an objective method of analysing sport performance which thereby allows coaches to provide informed feedback to their players. Notational analysis has been categorised into two areas: match analysis or time-motion analysis. Time-motion analysis investigates all on field activity including physical performance, while match analysis typically refers to the investigation of technical and tactical features of competition when players are involved in the play. Together, both techniques can be integrated to concomitantly analyse the context of the physical and technical demands of team sport competition.

Time-motion analysis has provided in-depth information about the physical demands of Australian Football match-play, identifying time spent, number of efforts and distance covered in a number of pre-defined speed zones (Appleby & Dawson, 2002; Dawson et al., 2004). Coaches and conditioning staff have used this information to design physical profiles of match-play that underpin the energy system demands of competition and thus direct training approaches. Match analysis typically involves the coding of technical skill involvements using pre-defined operational definitions. In Australian Football research, assessment of these technical skills has included the number and quality of kicks, handballs, tackles, marks, ruck-contests and possessions (Kempton et al., 2015b). Currently, these technical skills are coded by an independent statistics provider for the AFL who offer these statistics for both coaching and commercial purposes. Until recently, there has been little reliability and validity data pertaining to the coding accuracy of these technical skills (Robertson, Back, & Bartlett, 2016). The findings showed a high level of agreement (ICC= 0.947 to 1.000) and low absolute error (root mean square error range = 0.0 to 4.5) between the statistics provider (criterion measure) and the

researcher's coding thus suggesting that commercially available technical skill counts are acceptable for time-motion analysis research (Robertson et al., 2016). Furthermore, time motion and match-analysis data has been integrated to provide important contextual information about skill involvements and the distribution of physical performance throughout a soccer match (Di Salvo et al., 2009; Rampinini et al., 2009). This data has been investigated in congruence with individual and team performance (player or team ranking and match outcome) to determine which factors are most related to success. Coaches can then use this information to identify talent, design training programs to develop specific performance criteria and design team tactics to mitigate the influence of contextual factors on performance.

All professional Australian Football teams likely record training and competitive matches to provide feedback regarding individual and team performance measures. Coaches, performance staff and players use different camera views to analyse opposition tactics, individual player characteristics and structures during different phases of play to design their own tactics that potentially mitigate the opposition strengths. Elevated camera positions at the halfway point of the field and behind the goals are designed to capture various aspects of match-play (Spencer et al., 2005). The broadcast vision is often integrated into video-analysis packages which provides close-ups of stoppages and individual player involvements leading to improved coding precision, while the other views provide a global representation of player positions on the field. Capturing this information often requires a large degree of manual labour to film the match, however the integration of these camera views is now relatively simple with the development of video-coding software designed for team sport analysis. The availability of video footage and match-coding software permits the analysis of specific components of match-play compared to quarter or match averages. Furthermore, manual notation is associated with high levels of intra- and inter-coder reliability which indicates that performance analysts can code skill involvements in matches with a high level of precision (Dawson et al., 2004; Dogramaci & Watsford, 2006; Duthie, Pyne, & Hooper, 2003). While these coding methods can be laborious,

performance staff can investigate specific elements of match-play that provide a high level of insight for coaching staff.

While this information is clearly valuable for player feedback, match analysis and competition preparation, prior to the adoption of a match-analysis or coding methodology, rigorous reliability and validity investigations are required to determine its efficacy (Carling, Bloomfield, Nelsen, & Reilly, 2008; Hopkins, 2000). The methodologies employed to collect player movements must meet the requirements for scientific criteria for quality control. There is a need for a detailed analysis of the errors associated with the analytical procedures used by the systems so that results are interpreted alongside the normal error of measurement. If human input for data collection is still required using a contemporary system, reliability testing of the same competitive match (es) must be undertaken to assess measurement error.

MEASURES OF RELIABILITY IN NOTATIONAL ANALYSIS

Reliability has been termed as the consistency of measurements, or of an individual's performance on a test; or 'the absence of measurement error' (Atkinson & Nevill, 1998). While a degree of error is always present, reliability can be considered as the amount of measurement error that is deemed acceptable for the effective practical use of measurement tool. It is important to obtain and utilise methods that produce consistent results over time so that changes in a measure can be attributed to changes in performance. A range of team sport studies have considered ball possession during match-play and have reported various reliability statistics to illustrate coding repeatability (Casal, Maneiro, Ardá, Mari, & Losada, 2017; Gabbett et al., 2014; Gronow et al., 2014)

Intra-class correlation coefficients (ICCs) are a widely used reliability index in test-retest, intra-observer and inter-observer analysis (Hopkins, Marshall, Batterham, & Hanin, 2009). ICCs reflect both the degree of correlation and agreement between repeat measurements. Various categories based on the 95% confidence interval of the ICC estimate are common, with approximate values less than

0.50, between 0.50 and 0.69, between 0.70 and 0.89, and greater than 0.90 are indicative of low, moderate, high, and very high reliability, respectively (Dumholdt, 2000). Recently, Gronow et al. (2014) coded ball in possession, out of possession, when the ball was in-dispute and when play was dead (stoppage in play). The authors performed both inter- and intra-coder reliability assessments by coding the same match on two separate occasions. The strong correlations between the coding assessments ($r = 0.988-1.000$) suggest a high degree of association between the two coding assessments. However, a limitation of this study was that the operational definitions of the phases of play were not provided, therefore making the procedures difficult to replicate. Another study outlined a separate classification of the phases of play in Australian Football and provided brief statistics regarding the time spent in various phases of play (O'Shaughnessy, 2006). However, the only reliability information provided was that “quantity based statistics are logged at better than 99% accuracy, time is accurate to within about five seconds, and position to within 5–10 meters” (O'Shaughnessy, 2006). Clearly, further information is required to clearly define the phases of Australian Football match-play so that appropriate reliability assessments can be conducted. Additionally, the isolated use of ICCs to illustrate repeatability is problematic in reliability assessments for a number of reasons, as discussed herein.

One limitation of ICCs is that a high correlation may still exist if there is a general trend for repeat measurements to be different in a particular direction (Atkinson & Nevill, 1998; Edgecomb & Norton, 2006). For example, if re-test results are consistently greater by a similar magnitude, a high correlation can still be present. Therefore, measures of absolute reliability are included to account for the magnitude of difference between individual measures. The typical error of measurement (TEM) is commonly described as a contemporary measure of absolute reliability and has been used to determine the level of agreement between test and re-test values in numerous studies involving notational analysis of team sport competition (Duthie et al., 2003). The magnitude of TEM has been previously classified as good (<5%), moderate (5–10%) and poor (>10%) (Duthie, Pyne, & Hooper,

2005; Edgecomb & Norton, 2006). Reliability research in sport generally uses a 10% cut-off as an acceptable TEM threshold to permit legitimate implementation of certain methodology, however this cut-off is arbitrary. Indeed, one study in rugby league that has considered ball possession in different field positional zones reported intra-rater TEM to range from 0.01 to 0.05% (Gabbett et al., 2014). The clarity of possession in rugby league is perhaps more pronounced compared to Australian Football, therefore the application of these findings is limited for assessing the time spent in possession during Australian Football match-play.

Further, when conducting test-retest reliability assessments, it is important to account for factors resulting in tester bias that may include tester fatigue, learning effects and recall (Hopkins et al., 2009). To account for these effects, study designs employ a wash-out period that separates the two coding assessments (range from 2 weeks to 6 months) (Duthie et al., 2003; Gabbett et al., 2014). Systematic bias assessments are conducted to determine whether a general trend is present for measurements to be different in a particular direction (positive or negative) between the repeated tests that may occur due to learning effects or coding recall (Atkinson & Nevill, 1998). This assessment compares the means of a test and retest to determine whether there is any statistically significant bias between the tests (typically deemed significant if $p < 0.05$) using paired sample t-tests. Other measures including coefficient of variation (%CV) and smallest worthwhile change (SWC) are commonly used in reliability assessments, especially when the practitioner is attempting to identify meaningful variation in a group of athletes and identify individual responses of athletes due to daily training or following competitive matches (Cormack, Newton, McGuigan, & Doyle, 2008).

One final component of reliability assessments that is rarely considered is the determination of a minimum sample size (Hajian-Tilaki, 2014). Typically, a sample size for reliability research is determined to be sufficient if the power exceeds 80% at an alpha level of 0.05 (Walter, Eliasziw, & Donner, 1998). Power refers to the probability of rejecting the null hypothesis when the alternative hypothesis is true (type II error). The minimum accepted level is typically considered to be 80% (1-

β), which means there is an 80% chance of detecting a difference of a specified effect size. Significance level is usually set at 5% (or $p < 0.05$) ($1 - \alpha$) and refers to the probability threshold designed to minimise the risk of accidentally rejecting the null hypothesis when it is actually true (type I error) (Cleophas & Zwinderman, 2012). To reduce the risk of researchers making these errors, more stringent power and significance levels can be adopted depending on the application of the research. Most often sample size calculations are used for intervention-based studies where researchers are expecting a certain response to determine the efficacy of an intervention. Other formulae have been developed for reliability studies based on expected and acceptable intra-class correlation coefficients (Walter et al., 1998; Walter, Gafni, & Birch, 2007; Walters, 2004; Walters & Campbell, 2005). While these formulae and associated excel spreadsheets are available for public use, limited research in team sports has adopted the use of power, significance, expected and acceptable ICCs as part of their research design.

MEASUREMENT OF PHYSICAL PERFORMANCE IN AUSTRALIAN FOOTBALL

Early time-motion analysis in Australian Football primarily used manual hand notation techniques by tracking an individual player's movement using a video recording from match-play (Appleby & Dawson, 2002; Dawson et al., 2004). Player movements are then recorded using a calibrated console representative of the field or via an event recorder whereby the researcher codes activities based on a set of operational definitions (Dogramaci & Watsford, 2006; King, Jenkins, & Gabbett, 2009). In professional soccer, automated video motion systems have been used as a non-invasive physical analysis tool, and has been used in congruence with the analysis of technical skills (Carling, 2010), tactical formations (Bradley et al., 2011) and movements with and without ball possession (Dellal et al., 2011). While video-based movement tracking has been popular in Europe and the United Kingdom (Carling et al., 2008), the majority of contemporary physical performance research in Australian Football has utilised microtechnology such as global positioning satellite (GPS)

technology and local positioning measurement (LPM) systems (Malone, Lovell, Varley, & Coutts, 2016; Sweeting, Aughey, Cormack, & Morgan, 2017; Wisbey et al., 2010), which are able to indirectly quantify match-running performance during training and competition. During the 2017 season, every AFL club utilised GPS micro-technology during competitive matches and training to capture movement profiles of their players. Sport science staff collect this information in an effort to identify elevated injury risk (Buchheit & Simpson, 2017; Murray, Gabbett, Townshend, & Blanch, 2017; Murray, Gabbett, Townshend, Hulin, & McLellan, 2017), plan training approaches using historical data (Aughey, 2011a), adjust training using real-time information, assess changes in physical performance (Buchheit, Lacombe, Cholley, & Simpson, 2017), detect fatigue (Coutts et al., 2015) and analyse specific phases in match-play (Gronow et al., 2014). Furthermore, GPS technology can elicit the production of a myriad of data variables, is highly portable, simultaneously collect data from a large number of players and can be purchased at a low-cost compared to other motion capture systems, making the use of this micro-technology an appealing choice for AFL clubs.

SPEED- & DISTANCE-BASED INDICES OF PHYSICAL PERFORMANCE

Total distance is perhaps one of the most common time-motion variables reported in team sport literature (Cummins, Orr, O'Connor, & West, 2013). Total distance is a reliable measure collected by GPS devices and provides a general indication of match volume (Coutts & Duffield, 2010; Jennings et al., 2010; Kempton et al., 2015b). Indeed, depending on position, professional Australian Football players cover between 11 and 14 km per match, with approximately 30% of total distance covered at speeds greater than 14.4 km^{-1} (Brewer et al., 2010; Coutts et al., 2010; Wisbey et al., 2010). Team sports that involve high total distances are typically associated with higher aerobic demands, and thus total distance has been a widely adopted physical metric in Australian Football (Mooney et al., 2011). Measures of total distance have also been used to determine appropriate training loads to ensure that players to sustain physical output over the duration of a competitive AFL match (Johnston et al.,

2012). Sports scientists have used a variety of discrete speed zones or movement categories including low-speed running (LSR), high-speed running (HSR), very high-speed running (VHSR) and sprinting to analyse such activities. Current research in professional Australian Football suggests that the majority of distance covered is performed at low-speeds (~70%) (Coutts et al., 2015; Johnston et al., 2012; Wisbey et al., 2010). However, these low-speed speed activities are frequently interspersed with periods of high-intensity activity (Wisbey et al., 2010). These high-intensity periods of match-play represent critical periods in match-play because of their association with critical moments in the match (Austin, Gabbett, & Jenkins, 2011; Delaney, Thornton, Burgess, Dascombe, & Duthie, 2017) and are sensitive to match-related fatigue (Coutts et al., 2015). High-intensity running has also been used as a measure to differentiate movement profiles between position (Brewer et al., 2010) and are linked to measures of individual player performance rating (Johnston et al., 2016) and differentiates levels of Australian Football competition (Brewer et al., 2010; Johnston, Watsford, Austin, Pine, & Spurrs, 2015b). More recently, rolling 1-minute averages have been used to identify peak 1 minute periods of match-play (Delaney, Thornton, Burgess, Dascombe, & Duthie, 2017). This information highlights that quarter and match averages can underestimate the most intense periods of match-play. Furthermore, this type of analysis may be more beneficial for identifying match intensities while quarter and full match averages may be suitable for quantifying the volume of work performed during competition.

The ability of GPS devices to measure low-speed locomotion is relatively acceptable, however they are less precise when assessing high-speed movements that involve rapid changes in direction (Petersen, Pyne, Portus, & Dawson, 2009; Waldron, Worsfold, Twist, & Lamb, 2011). Other research has demonstrated that high-speed activities vary more significantly compared to low-speed activities between matches, which must be considered when interpreting changes or comparing differences in these parameters (Gregson, Drust, Atkinson, & Salvo, 2010). As such, the use of broader speed categories is recommended to account for reliability and validity issues surrounding the use of GPS

systems to assess movement profiles in Australian Football competition. There is also inconsistency in the speed thresholds employed for each movement category in Australian Football research, with some studies using a range of different absolute and individualised speed zones and therefore caution is required when comparing different movement classifications between studies (Varley, Jaspers, Helsen, & Malone, 2017). Nevertheless, traditional time-motion variables have been valuable in developing fundamental activity profiles of Australian Football match-play for coaches to design evidence-based training programs. More recently, a number of studies have adopted the use of accelerometry to measure sensitive locomotor movements that are thought to provide more robust information about the demands of competition (Boyd et al., 2013; Coutts et al., 2015; Johnston et al., 2016)

ACCELEROMETRY

Triaxial accelerometers are now integrated within microtechnology devices and provide highly responsive motion detection by measuring the frequency and magnitude of movement in three dimensions (*x, y and z*). Furthermore, accelerometry has improved the accuracy of GPS-derived speed- and distance-based indices via the use of integrated algorithms that consider both data feeds simultaneously (Johnston, Watsford, Austin, Pine, & Spurrs, 2015a). Newer microtechnology devices have greater ability to analyse high-intensity movements, however calibration of the accelerometry remains vital to the reliability and validity of the data (Kelly, Murphy, Watsford, Austin, & Rennie, 2015; Scott, Scott, & Kelly, 2016). In addition, frequent upgrades in technology, changes in hardware and associated algorithms used to smooth and detect accelerations and decelerations should be considered when comparing findings in different research studies (Malone et al., 2016). Recommendations for the use of accelerometry data in team sport performance research include reporting filtering techniques, minimum durations and avoiding software updates within a research study that may alter the detection of acceleration and deceleration efforts (Malone et al., 2016; Varley et al., 2017).

The ability of accelerometers to potentially quantify the rapid changes in direction, tackling and collisions in Australian Football makes the use of this technology appealing (Chambers, Gabbett, Cole, & Beard, 2015). While match-play involves high proportions of continuous running (Wisbey et al., 2010), a significant element of the game is played under contested situations where spatial constraints may limit player opportunity to reach high speeds (Boyd et al., 2013). Given that horizontal displacement may be minimal, traditional time-motion analysis variables may not capture these movements. Indeed, research that has incorporated the use of accelerometry has been used to assess the frequency of accelerations and decelerations during match-play (Coutts et al., 2015), differences in external load between training activities and match-play (Boyd et al., 2013), provided evidence of match-related fatigue (Akenhead, Hayes, Thompson, & French, 2013; Aughey, 2010) and illustrated the deleterious effects of neuromuscular fatigue on match performance (Mooney, Cormack, O'Brien B, Morgan, & McGuigan, 2013). Collectively, this research has displayed the value of accelerometry in Australian Football in assessing the accelerations and decelerations demands of match-play.

Accelerometry has also been used alongside manual video coding to assess the frequency and intensity of tackling in professional Australian Football (Gastin, McLean, Spittle, & Breed, 2013; Gastin, Mclean, Breed, & Spittle, 2014), however, despite some emerging research about automated detection of collisions (Hulin, Gabbett, Johnston, & Jenkins, 2017), video coding of tackles remains more accurate when compared to detection via microtechnology (Gastin, Mclean, Breed, & Spittle, 2014). Tackling is a vital physical and technical skill in Australian Football to create defensive pressure and minimise the oppositions ability to execute tactical elements of match-play. Other research in rugby league suggests that collisions are responsible for most injuries rugby league (Gabbett, Jenkins, & Abernethy, 2011), while missed tackles have been shown to differentiate successful and unsuccessful rugby league teams (Gabbett, 2014; Kempton et al., 2016). There is also evidence to suggest that tackling and collisions significantly contribute to post-game fatigue and

muscle damage (Johnston, Gabbett, & Jenkins, 2014). Taken together, tackling is a vital component of Australian Football match-play that relates to team sport success and is responsible for significant homeostatic disruption, however the quantification of tackling is currently best performed using manual coding techniques.

The use of accelerometry appears to be highly useful in situations involving congestion where players may not reach high-running speeds and therefore may be neglected by traditional time-motion variables. Additionally, the frequency of tackles in Australian Football match-play is also likely to be higher during congested phases of competition. However, there is limited information that describes the match context of tackling and acceleration movements in professional Australian Football. Estimations of metabolic power may contribute to assessment in this area, with this topic discussed below.

METABOLIC POWER ESTIMATIONS

Recent studies in Australian Football have incorporated the use of metabolic power calculations that can estimate the power output and energetic costs of intermittent running performance (di Prampero et al., 2005; Osgnach, Poser, Bernardini, Rinaldo, & di Prampero, 2010). Given that Australian Football movement profiles are highly intermittent, these investigations provide additional insight to previous time-motion studies that have used speed- and distance-based indices to report the demands of team sport competition. The metabolic power calculations are based on a theoretical model that allows the estimation of the energetic cost of accelerations and decelerations during intermittent running, and can be applied to a variety of sports involving similar activity profiles. The model considers accelerated running on a flat surface to be metabolically equivalent to incline running at a constant speed, where the angle of the incline is equal to the extent of forward acceleration. This method provides an “equivalent slope” which is used to calculate instantaneous measure of the energy cost of accelerated running and an estimate of metabolic power output (di Prampero et al., 2005).

The formula provided by Hader et al. (2016) reads as follows:

$$EC = (155.4 \cdot ES^5 - 30.4 \cdot ES^4 - 43.3 \cdot ES^3 + 46.3 \cdot ES^2 + 19.5 \cdot ES + 3.6) \cdot EM \cdot KT$$

where EC is the energy cost of accelerated running on grass ($J \cdot kg^{-1} \cdot m^{-1}$); ES is the equivalent slope ($ES = \tan(90 - \arctan g/a_f)$, g = Earth's acceleration of gravity, a_f = forward acceleration); EM is the equivalent body mass ($EM = (a_f^2/g^2 + 1)^{0.5}$); and KT is a constant ($KT = 1.29$).

Consequently, P_{met} ($W \cdot kg^{-1}$) is calculated multiplying EC by running speed (v , $m \cdot s^{-1}$):

$$P_{met} = EC \cdot v$$

Consequently, several studies in Australian Football (Coutts et al., 2015; Delaney et al., 2017; Johnston et al., 2016) and other team sports (Kempton et al., 2015a) have utilised measures relating to metabolic power to further understand the energetic demands of competition. The ability of metabolic power estimates to capture accelerated running where spatial constraints limit high running speeds is clearly desirable to further understanding the demands of team sport competition. The findings have shown that metabolic power varies between Australian Football positions (Coutts et al., 2015) and high and low calibre players (Johnston et al., 2016), whilst other team sport studies have used metabolic power to differentiate successful and unsuccessful rugby league teams (Kempton et al., 2016) and shown relationships to aerobic fitness in professional soccer players (Manzi, Impellizzeri, & Castagna, 2014).

Recently, researchers have assessed the reliability and validity of metabolic power and estimates of energy expenditure and questioned regarding its usefulness as a physical performance measure in team sports. For example, Buchheit, Manouvrier, Cassirame, and Morin (2015) used a soccer-specific circuit to concomitantly assess oxygen uptake and estimated metabolic power via the use of 4 Hz GPS microtechnology. The results displayed very large between-unit variability (9-32%). Additionally, metabolic power estimates largely underestimated the actual net energy costs compared to measures obtained via indirect calorimetry. These deficits were associated with periods of standing

and stationary skills, where heart-rate remained elevated during periods of reduced locomotor activity. Thus, GPS-derived metabolic power estimates may only reflect locomotor-related activity. The agreement between GPS information and VO_2 has only been deemed acceptable during continuous and linear running, but not during walking or intermittent activity. The metabolic power underestimation may be related to the fact that the current equation initially developed for maximal and linear sprint acceleration, may not be well-suited for team sport specific running patterns (e.g. including rest, irregular step frequency and stride length, upper body muscle activity and static movements) (Buchheit et al., 2015). Australian Football, like many other team sports involves intense static movements (set shot kicking, wrestling for possession of the ball) and thus, the equation may not account for metabolically demanding elements of competition that involve no locomotor activity. Although metabolic power models do not consider all the factors that influence the energy cost of locomotion outlined previously, they may be useful in providing gross estimations of energy expenditure in situations where speed is continually changing.

Metabolic power estimations appear to be useful in capturing accelerated power efforts during scenarios where spatial constraints may limit player opportunity to reach high speed thresholds. However, there is current debate regarding the reliability, validity and overall usefulness of the measure and thus caution is required when interpreting metabolic power findings (Buchheit et al., 2015; Osgnach, Paolini, Roberti, Vettor, & E di Prampero, 2016). In Australian Football, various elements of competition or training involve high-intensity movements performed in scenarios where player congestion is high, however, no study has yet evaluated specific phases in play that may involve low absolute running speeds, with high levels of accelerated running. The combination of accelerations, decelerations and continuous running indicates the need for a number of different variables to be collected in order to capture the various demands of Australian Football match-play. Nevertheless, the measures of physical and technical performance adopted for research need to be interpreted with respect to the associated reliability and variability of the measurement.

MATCH-TO-MATCH VARIABILITY OF PHYSICAL & TECHNICAL PERFORMANCE MEASURES

All measures of sporting performance, whether they be physical, technical or tactical, are subject to variation between successive matches and seasons. An understanding of the typical variation in these measures can be useful for designing applied research studies, selecting reliable performance measures and interpreting worthwhile changes in performance (Carling, Bradley, McCall, & Dupont, 2016; Gregson et al., 2010; Kempton et al., 2015b). The description of performance variability has also been used for predicting statistical power in research as well as how worthwhile a certain intervention is for performance (Atkinson & Nevill, 1998) and is often reported as a percentage of coefficient of variation (%CV). There are several factors that may contribute to this match-to-match variability which has been categorised as internal or external factors. Internal factors relate to changes within the individual player and may include current fitness status, psychological state and injuries that affect movement and performance (Kempton et al., 2015b). External factors relate to the environment in which the performance takes place, and may include the calibre of opposition, weather conditions, match location, team tactics and field size. These factors can contribute to match-to-match variability however, changes within a season (e.g. start, middle and end of season) or across seasons (2016 to 2017) of competition are more likely related to chronic changes including sport-specific fitness adaptations, changes in list personnel and modifications to the rules of the game.

Work by Kempton et al. (2015b) described the between match variation of physical and technical measures in Australian Football. Depending on player position, total distance (%CV=4.9-7.0; %SWC=1.4-2.5) and average speed ($\text{m} \cdot \text{min}^{-1}$) (%CV = 4.9 to 7.0; %SWC=1.5-2.2) were found to be relatively stable measures compared to high-speed running distance ($>14.4 \text{ km} \cdot \text{h}^{-1}$; %CV=11.7-13.8; %SWC=3.7-6.1). Furthermore, as the speed zones increased (very high-speed running= $>19.9 \text{ km} \cdot \text{h}^{-1}$; sprinting= $>23.0 \text{ km} \cdot \text{h}^{-1}$), the typical variation increased concomitantly. The results also revealed that activity measures were similar between groups, although there were some small differences, with

forwards demonstrating less variability compared to backs and midfield players, attributed to the specific roles and constraints placed on the forwards who typically remain in the offensive half of the field. The diverse tactical roles of the backs and midfield players were suggested to partly explain their greater variability in activity profiles. In addition, technical performance measures were found to display a high level of variability (%CV: 28.3-55.3%; %SWC: 5.6-19.4). Several studies in Australian Football have found that technical performance can differentiate between team and individual player success (Johnston et al., 2016; Robertson et al., 2016; Sullivan et al., 2014b; Woods, Veale, Collier, & Robertson, 2017), however the high variability should be considered when interpreting technical performance results from Australian Football competition.

One area that has not been considered to a great extent in Australian Football research is the time that the team spends with and without possession of the ball during match-play. However, previous research in professional soccer reported that match-to-match variability in high-speed running was influenced by player position and whether the reference team was either in possession (offence) or without possession (defence) (Gregson et al., 2010). This suggests that match-to-match variability increases when positions are less involved in the phase of play (Figure 2.2). The attackers recorded higher variability when the team was out of possession and similarly, defenders demonstrated higher variability when the team was in possession of the ball. Furthermore, position movement profiles appear more stable when the phase of play or context of possession is specific to the positional role (Gregson et al., 2010).

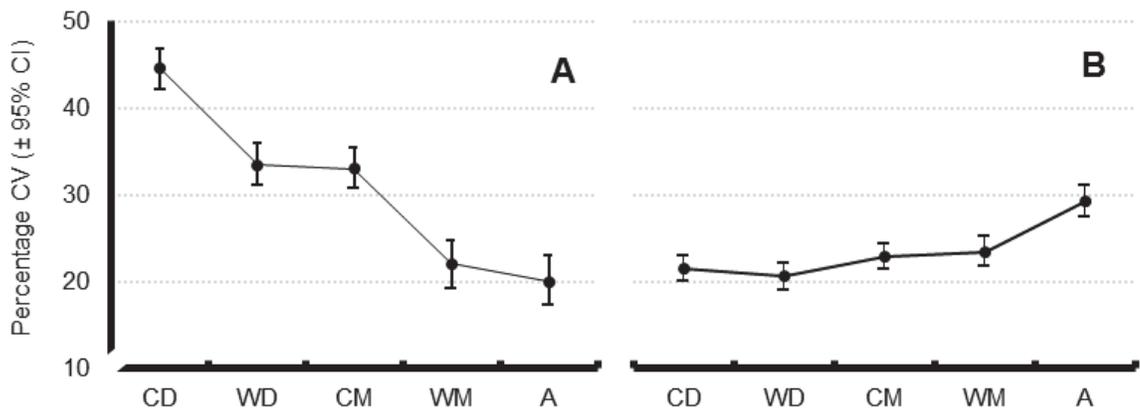


Figure 2.2: Influence of position on between match-variation for high-speed activities in soccer when a) the reference team is in possession and b) when the reference team is out of possession. CD = Central Defender, WD = Wide Defender, CM = Centre Midfielder, WM = Wide Midfielder, A = Attacker (Gregson et al., 2010).

Taken together, this literature suggests that total distance and average speed provide relatively stable indicators of physical performance, while high speed running distance and technical indicators had higher typical variation, that is attributed to internal and external factors. Furthermore, match-running profiles during elements of possession (with or without) in soccer suggest that player variability is reduced when match-running performance is considered in relation to phases in play that most relate to the positional roles of players within the team. Given that match running profiles are somewhat dependent on player position in Australian football (Brewer et al., 2010; Coutts et al., 2015; Coutts et al., 2010; Wisbey et al., 2010), the integrated analysis of the phases in play may provide further insight into the factors that contribute to movement variability.

SUMMARY

The use of notation analysis systems has provided coaches with valuable information about the technical skills and contextual detail of Australian Football competition. Furthermore, GPS microtechnology is able to capture both continuous running and rapid changes in movement speed

and has been valuable for developing an understanding of the movement profiles in Australian Football. While each data collection method has inherent limitations, they offer practically useful tools to investigate the physical and technical demands of match-play. Moreover, given that physical and technical actions rarely occur in isolation during competition, there is an emerging theme in applied team sport research that these measures are integrated to provide a more accurate representation to Australian Football performance. The use of video coding can also be used to segregate the analysis depending on the context of the match. Collectively, these measures permit the investigation of the physical and technical demands during the different phases of match-play.

2.3 COMMON FACTORS AFFECTING PHYSICAL & TECHNICAL PROFILES IN AUSTRALIAN FOOTBALL

There are a number of different factors that are known to affect the physical and technical profiles of Australian Football match-play. When preparing for competition, Australian Football coaches require specific information that can be utilised to direct training preparation that ultimately improves the likelihood of competition success. The following section of this literature review will discuss the common situational factors that are known to contribute to physical and technical profiles in Australian Football match-play. These situational factors are discussed with respect to the confounding influence of ball possession and the phases of play associated with Australian Football.

PLAYER POSITION

Specific knowledge of the individual requirements of different positions in Australian Football is highly important to coaching and conditioning staff. The premise of collecting this information is that training programs can be designed to optimise physical and technical qualities that are specific to each position. As such, a number of Australian Football studies have assessed the influence of

position of the physical demands of match-play using a variety of positional classifications. Broadly, professional Australian Football players can be categorised as nomadic, key position or ruckmen. The athletic profiles of nomadic, key position and ruck players vary significantly and reflect the physiological and anthropometric characteristics that are essential for the physical, technical and tactical demands during the various phases of match-play.

Nomadic players are generally leaner, faster, more agile and have greater aerobic fitness compared to key position and ruck players (Pyne, Gardner, Sheehan, & Hopkins, 2006; Young et al., 2005). Previous studies have shown that nomadic players perform the highest match running volume and intensities when compared to all other positions (Brewer et al., 2010; Coutts et al., 2015; Coutts et al., 2010; Wisbey et al., 2010). Contemporary research indicates that total distance covered ranges from 12 to 14 km, with approximately 30% of total distance run at speeds $>14.4 \text{ km}\cdot\text{h}^{-1}$ (Coutts et al., 2015). However, only a small portion of total distance involves steady-state running, which underpins the intermittent nature of match-play (Wisbey et al., 2010). Additionally, nomadic players produce greater metabolic power outputs compared to other positional groups (Coutts et al., 2015). These differences are likely indicative of the minimal spatial limitations involved with specific elements of match-play.

Tall forwards and tall backs, collectively termed key position players, share relatively similar match running profiles, suggesting a level of efficacy when grouping these two positions. Indeed, Coutts et al. (2015) reported that a number of speed, distance and metabolic power indices were similar between tall forwards and tall backs. These findings may suggest that key defenders mimic the movements of opposition key forwards, thus sharing similar movement profiles. Key position players typically remain in their defensive or offensive positions on the field to maintain team structures, which perhaps explains why these positions perform less locomotor activity compared to nomadic players. Furthermore, key position players often change positions during the match depending on the team's need to increase offensive or defensive bias.

Ruckmen have the most specialised position in professional Australian Football. The ruckmen from each team contest the restart of match-play following a centre bounce, boundary throw in or ball up (Gray & Jenkins, 2010). While ruckmen typically cover the least total distance, high-speed running, rapid accelerations and decelerations per match, they reportedly cover the highest volumes of low-speed running compared to other positions (Boyd et al., 2013). These findings indicate the need for ruckmen to follow the play and run to each contest at any location on the field, however, the physical demands of ruckmen during stoppage periods in Australian Football are currently unknown. Other research has revealed that ruckmen rest for substantially longer periods during training compared to other positions (Appleby & Dawson, 2002; Dawson et al., 2004). It is likely that training approaches have become more individualised since 2004, however, there is an absence of current information on this topic. While ruckmen may perform a large proportion of activity during stoppages in Australian Football, stoppage periods during training drills represent important opportunities for coaches to provide feedback to their players. Specific considerations may be important to account for the reduced opportunity for ruckmen to perform appropriate volumes of low-speed activity during training (Boyd et al., 2013), however, information pertaining to the physical demands of during different stoppage phases of match-play is relatively scarce.

A recent Australian Football study reported that forwards spend more time performing high-speed running in offence, while defenders spend more time running at high speeds when in defence (Gronow et al., 2014). Compared to nomadic players, forwards and defenders have greater tactical constraints and space to perform high-speed activity which may account for some of the differences in positional running profiles. The contextual distribution of match-running performance is highly valuable for coaching and conditioning staff to enable the design of training programs that address the movement demands of specific phases in play. Unfortunately, only information relating to time spent in different speed zones was provided by the authors which is relatively uncommon in Australian Football research, thus making comparisons with other research challenging. Other studies have used a

combination of speed and distance-based indices to provide a broad description of the multi-factorial demands of match-play (e.g. total distance, average speed etc). Additionally, positional information was only provided for phases of possession (with and without). Interestingly, Boyd et al. (2013) found that match-practice drills failed to replicate low-velocity locomotion for all positions when compared to competitive matches. While not necessarily leading to direct point scoring opportunities, low-velocity locomotion is an essential component of match-play and overall work during training and competition is an important component of analysis. It is important to understand the movement demands of all positional categories during stoppage periods of play, given the important tactical, technical and possibly physical features of these stoppages. Furthermore, speed and distance-based indices indicative of the physical demands during the different phases of play are beneficial to compare to current Australian Football research describing the physical demands of competition.

MATCH-RELATED FATIGUE

Match-induced fatigue relates to a player's ability to continually perform efficient and precise movements in Australian Football. There is a general consensus that fatigue accumulated throughout a match has a deleterious effect on end-game physical performance (Black, Gabbett, Naughton, & McLean, 2016; Coutts et al., 2015; Coutts et al., 2010). The investigation of match-induced fatigue may be important to identify elements of match-play where reductions in performance manifest, and as such, training programs may be focused on particular areas. Temporal changes in physical performance measures have been used as evidence of match-related fatigue in professional Australian Football (Aughey, 2010; Coutts et al., 2015; Coutts et al., 2010). These studies have utilised fixed time periods to assess transient and cumulative fatigue including: comparing the peak 3-min period of activity to the subsequent 3-min period and mean of all other 3-min periods (Black et al., 2016), first player rotation period to subsequent rotation periods (Aughey, 2010), and more recently, a moving average using ten different durations (1–10 min) with the maximum value recorded for each duration (Delaney et al., 2017). Several factors have been attributed to these reductions in physical

performance measures including decreases in available energy substrate (Gollnick et al., 1973; Iaia, Perez-Gomez, Nordsborg, & Bangsbo, 2010), disturbances in electrolyte balance across the muscle membrane (McKenna, Bangsbo, & Renaud, 2008), impaired calcium release from the sarcoplasmic reticulum reducing muscle contractile function (Allen, Lamb, & Westerblad, 2008), accumulation of hydrogen ion (H⁺) and central factors (Taylor & Gandevia, 2008) and more recently, player experience (Black et al., 2016). These factors reportedly alter running and technical skill performance via afferent feedback to the brain and thus effect the feedback loop to the working muscles. In addition, it has been suggested that reductions in physical performance may be a consequence of pacing strategies employed by players to ensure that they are able to finish the match (Coutts et al., 2010; Duffield, Coutts, & Quinn, 2009). As such, players reduce their physical output at low intensities to maintain their ability to perform high-intensity movements that are potentially more important to the outcome of the match (Austin et al., 2011). These studies suggest that fatigue is multifactorial in nature and provide evidence of match-related fatigue following the most intense periods of match-play and during the final quarter of a game

Recently, certain authors have expressed caution when interpreting findings related to match-induced fatigue that do not account for time spent in possession or when the ball is out of play (Carling, 2013; Kempton & Coutts, 2016). Theoretically, reductions in movement intensities may be the result of stoppages in match-play that primarily involve low-intensity activity. In Australian Football, high-intensity periods of offence, defence or contested play can be proceeded by stoppages of varying durations. These stoppages can be due to the ball travelling over the sideline or 'held-up' in the field of play, during a set shot for goal or during a goal reset where the ball is returned to the centre of the field where play is recommenced. Clearly, further knowledge can be fostered by analysing the phases of match-play during AF competition. Specifically, this analysis could potentially identify whether reductions in match-running performance are global or isolated to specific phases of match-play. It is difficult to determine whether reductions in physical output are due to the state of match-play or due

to physiological factors that lead to reductions in physical output. For example, Austin et al. (2011) suggested that the most intense elements of rugby league match-play occur immediately prior to a try being scored. If this is the case in Australian Football, a goal is immediately followed by a stoppage in play until the ball is returned to the centre square. It is also the only stoppage with an adequate duration that affords broadcasters an only opportunity to play advertisements during a quarter. Without considering these stoppages throughout the match that are essentially due to the rules and regulations of the game, reductions in physical output may be attributed to match related fatigue, when in fact the lower locomotor profiles simply reflect player opportunity to perform activity. As such, some studies have separated the match into ball in play and stoppage periods to further elucidate information that relates to the intermittent nature of professional Australian Football competition.

ACTIVITY AND RECOVERY CYCLES

The analysis of activity and recovery periods have provided unique insight into the physical demands of several team sports including rugby league and rugby union (Gabbett, 2012, 2013a, 2015a, 2015b; Gabbett & Hulin, 2017; McLean, 1992). To elucidate this information, researchers code the time the ball is continuously in play, which is defined as ‘activity’, while stoppages that segregate the activity periods are termed ‘recovery’. Activity typically involves periods when either team has possession of the ball (offence and defence) or when either team is competing for possession, whilst recovery periods may arise from the ball going out of play, points being scored or injuries that result in the match officials stopping the match. Rolling calculations of two sequential activity cycles and segregating recovery periods have then been incorporated to identify activity: recovery ratios of match-play (Gabbett, 2012). In a practical sense, this data can be used to develop game-specific testing protocols and training drills that replicate the wide-ranging durations relating to the passages of play.

While there is limited information available in Australian Football, the activity and recovery cycles reported in rugby league and rugby union suggest that physical preparation should involve prolonged, high-intensity activity that is interspersed with brief recovery periods aimed at replicating the intermittent nature of the game. Over the course of a match, the ball is in play approximately 15 minutes more in rugby league compared to rugby union. Moreover, the average activity cycle in rugby league is 82 seconds, which is four times higher than rugby union (Gabbett, 2015a; McLean, 1992). Taken together, this information suggests that rugby league players have less time to recover and potentially require greater aerobic fitness qualities. The total time that the ball is in and out of play in professional Australian Football is currently unknown, which is possibly due to limited studies that have defined and coded the phases in match-play. Other studies have shown that activity cycles are influenced by level of competition, team ranking and match fixture quality (both teams ranked in top 4) (Gabbett, 2012, 2013a; Gabbett & Hulin, 2017). Collectively, higher levels of competition and matches involving high calibre teams involve longer activity cycles and shorter recovery cycles, indicating that successes related to a greater ability to maintain a high match intensity. While activity and recovery information are available to rugby league coaching staff, there is currently limited data that describes the normative and most demanding activity and recovery cycles of professional Australian Football.

To maintain high intensities over the course of a match, coaches often prepare their players by designing training drills that reproduce the most demanding passages of match-play. The ‘worst-case scenario’ is defined as the most demanding passage of match-play and typically involves the longest period where the ball continuously remains in play. Indeed, Gabbett (2012) demonstrated that the longest passage of play in professional rugby league was 667 seconds, which was more than eight times greater than the average activity cycle. It is postulated that if players are only exposed to the average demands of matches in training, then there is a relatively high likelihood that a player will experience deleterious effects during such scenarios in competition. These effects can manifest as

reductions in physical performance (e.g. reductions in match running output) and poorer skill execution. Conversely, if players are frequently exposed to the most demanding periods of a game in a training setting, they may develop the capacity to still produce high physical outputs and exhibit high skill proficiency in the presence of fatigue.

The intermittent demands of Australian Football have been well documented; however, no study has been able to derive the activity and recovery cycles associated with match-play. Similar to rugby league and rugby union, there are periods of play that involve consecutive changes in offence, defence or contested play. Moreover, stoppages can arise for several reasons, including a boundary throw in or ball up, set shot kick or goal resets. Given that stoppages in team sports typically involve low-intensity activity, basing training drill prescription on match data that includes time in stoppages is likely to underestimate the intensities when the ball is in play. Nevertheless, it would be remiss to neglect the tactical, technical and physical demands of these stoppages in training given their importance in Australian Football. While information exists in rugby league and rugby union pertaining to the activity and recovery cycles of match-play, limited data is available in Australian Football. Clearly information that assists coaching staff design training drills that replicate the normative and worst-case scenarios associated with match-play are beneficial. One limitation of previous research that has investigated the activity and recovery cycles in team sports may be the absence of technical skill and physical performance information that describes the movement intensities and frequency of technical skills. Studies that examine the physical and technical demands of the activity and recovery cycles would add useful information to the normative data about time spent in activity and recovery in Australian Football.

LEVEL OF COMPETITION

Competition level is also relatively common factor recognised to contribute to the physical and technical demands of match-play. As the level of professionalism has evolved in Australian team

sports, the intensity and speed of competition has increased and furthermore, the gap between competitions has also diverged significantly (Bradley et al., 2009; Burgess, Naughton, & Norton, 2012b). In Australian Football, comparisons between different levels of competition are valuable to isolate where differences exist with regards to the physical and technical demands, ultimately leading to the ability to design training programs to accelerate improvements in these areas and prepare players for the higher intensities of match-play. Moreover, the quantification of differences in match profiles can be used to advance physical preparation programs, determine player longevity and create developmentally suitable progressive overloading (Burgess et al., 2012b). Professional team sport competitions, including Australian Football involve markedly higher match intensities when compared to sub-elite Australian Football competition (Brewer et al., 2010; Johnston et al., 2015b). Furthermore, AFL reports suggest that injury incidence and prevalence is greater in first-year players compared to mature players (Fortington et al., 2016) which has been attributed to the unaccustomed intensity of match-play and training. To minimise injury risk and to improve physical resilience in first year players, training strategies such as those designed to improve maximal aerobic speed, repeat sprint training and the use of small sided games have been proposed (Burgess, Naughton, & Norton, 2006; Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011). However, despite this apparent need there is little information describing the context of match running and technical skills in Australian Football. Development coaches could use this detail to design progressive training programs that considers the intermittent nature of Australian Football and specific phases of match-play, however this information is currently unavailable.

The level of draft position has also been considered as a focal point for research in Australian Football (Burgess, Naughton, & Hopkins, 2012a; Coutts, Kempton, & Vaeyens, 2014; Robertson, Woods, & Gastin, 2015; Woods et al., 2017). Such investigations were designed to identify factors related to individual success, which can therefore become key features of the development of training programs to optimise a player's chance of becoming drafted by an AFL club. Using a linear-mixed model

approach, Woods et al. (2017) reported that contested possessions and contested marks were closely associated with earlier draft selection in under-18 Australian Football players. A similar study found that contested possessions and number of inside-50s were the most influential match variables associated with draft selection for under-18 state representative players (Woods, Joyce, & Robertson, 2016). Taken together, sub-elite Australian Football players who can win possession during contested phases in play are more likely to graduate from sub-elite to elite competition level. The authors suggest that junior coaches could implement training drills that promote improvements in contested match-play, such as the use of small-sided games (Farrow, Pyne, & Gabbett, 2008; Woods, Bruce, Veale, & Robertson, 2016) However, there is little empirical information available to coaches regarding the physical and technical demands of contested elements in Australian Football to create evidence-based training approaches for the development of sub-elite players.

2.4 CONTEXTUAL MATCH FACTORS & PHYSICAL & TECHNICAL PROFILES IN AUSTRALIAN FOOTBALL

Along with level of competition, match-related fatigue and the time the ball is in play, there are several match-related factors that are known to influence the physical and technical profiles of professional Australian Football match-play. As such, coaches often consider the game location and calibre of the opposing team when preparing for the upcoming match. Furthermore, match profiles of successful and unsuccessful performances can be used to direct training programs and areas of focus that maximise the likelihood of match success. As such, the following section discusses the three most common contextual factors known to affect physical, technical and tactical performance. These factors are discussed with specific reference to ball possession and the phases of match-play in professional Australian Football.

MATCH LOCATION

Home advantage has been the basis of a number of research studies in professional sport (Clarke, 2005; Goumas, 2014; Pollard & Pollard, 2005) and is characterised by the tendency for teams to be more successful when competing at their home ground. Home advantage in professional Australian Football has been illustrated by a greater probability of winning matches or average point margin when compared to playing away, particularly for teams situated outside of Victoria (Clarke, 2005). A recent study in Australian Football showed that matches played away from home were associated with reductions in average speeds and high-speed running distances (Ryan et al., 2017). Similar findings have been reported in professional rugby league and soccer where playing away from home was related to reductions in physical output (Kempton & Coutts, 2016; Lago et al., 2010). There are numerous factors that are thought to contribute to the home advantage and include the deleterious effects of travel (Youngstedt & O'Connor, 1999), familiarity with field conditions (Clarke, 2005), crowd support (Downward & Jones, 2007) and territoriality (Terry, Walrond, & Carron, 1998). The effects of travel may be related to interrupted sleep in other sports, current research in Australian Football suggests that while sleep quality is affected when travelling away from home, there are no observed reductions in game performance (measured via game rating points) (Richmond et al., 2007) or increases in injury prevalence (Dennis, Dawson, Heasman, Rogalski, & Robey, 2016). Familiarity with field conditions may also be relevant in Australian Football, given that ground dimensions and shape can vary significantly (Gray & Jenkins, 2010). Anecdotally, teams often adopt different tactical structures, player rotation strategies and emphasise methods of ball movement that optimise the likelihood of a successful outcome. Others have shown that that territoriality, defined as the protective response to the invasion of one's perceived territory, may also contribute to team aggression (Terry, Walrond, & Carron, 1998b). Given that Australian Football involves a contested element of match-play, it is possible that increases in player aggression contribute to the home advantage during contested or defensive elements of competition. There is minimal research in

Australian Football that has assessed the influence of match location on physical and technical performance, and even less information pertaining to performance during the individual phases of match-play. Such information would be highly useful for coaching staff in order to mitigate the effects of playing away from home by focusing on particular components during the week leading into away matches. The available data in team sports suggest that there are reductions in physical output during matches played away from home, however the phase of play in which these reductions occur is relatively unknown.

CALIBRE OF THE OPPOSING TEAM

One measure of success in sport is a team's final ranking at the conclusion of a season. Such a measure represents a degree of performance consistency. Studies in team sports have either compared differences between high and low calibre teams playing in the same match (influence of the opposition) (Gabbett, 2013b; Kempton & Coutts, 2016; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007; Ryan et al., 2017), the physical and technical match profiles at the conclusion of the season (top 4 vs bottom 4) (Gabbett & Hulin, 2017; Hoppe et al., 2015; Rampinini et al., 2009) or finals matches compared to regular in-season matches (Aughey, 2011b). Nevertheless, the overarching premise to identify factors that differentiate relatively successful and unsuccessful teams and therefore training programs can be designed that develop various associated with strong teams. One study in Australian Football compared top 6 teams against bottom 6 teams (strong vs weak opposition; middle 6 teams excluded) and showed that matches played against strong opposition were associated with increases in average speed, but no changes in high-speed running (Dillon et al., 2017). In contrast, other studies in rugby league have shown that playing against higher calibre opposition was associated with increases high-speed running, but not total distance (Kempton et al., 2016). These contrasting findings may be related to the calibre of the reference team, given that higher calibre teams tend to perform more high-speed running when competing against lower calibre opposition (Gabbett, 2013b). Other studies in rugby league have also suggested that higher calibre teams are

differentiated by their technical skill ability and not physical performance measures (Kempton et al., 2016). Future studies that identify the influence of opposition calibre on measures of both physical and technical performance during Australian Football match-play are clearly warranted.

Similar to the findings of Ryan et al. (2017), research in professional soccer has shown that top ranked teams in the English Premier League (EPL) and Italian Serie A cover less high-speed running distance than low ranked teams (Di Salvo et al., 2009; Rampinini et al., 2009). However, higher calibre teams perform more total distance and high-speed running when in possession of the ball, compared to less successful teams. Another professional soccer study with German Bundesliga teams revealed that match running performance alone had no correlation with the final competition points accumulated across a season (Hoppe et al., 2015). However, total distance covered with ball possession was positively correlated with final point accumulation ($r=0.77$; $p<0.01$) and accounted for 60% of the variance in the final points accumulated by the conclusion of the season. Furthermore, other high-ranking soccer teams have more involvements with ball, which include a higher frequency of short passes, successful short passes and tackles compared with low-ranked teams (Castellano et al., 2012; Lago-Penas & Lago-Ballesteros, 2011; Lago & Martin, 2007; Link & Hoernig, 2017; Rampinini et al., 2009). Taken together, it appears that higher calibre teams perform more physical work when in possession of the ball. Future research that considers the calibre of the opposition, as well as match-running and technical skill performance during different phases of possession would provide more detailed information about the context of these purported reductions in match performance associated with playing against high calibre opposition.

MATCH OR QUARTER OUTCOME

Playing against high calibre opposition is often linked to match outcome, where playing against higher calibre opposition reduces the likelihood of successful match outcome. Research in professional Australian Football has compared win and loss in quarters and also full matches. Ryan

et al. (2017) reported that when accounting for opposition quality, successful match outcomes were associated with higher average speeds but less high-speed running. Similarly, another study revealed reductions in both average speed and high-speed running in quarters that were won (Sullivan et al., 2013) (Sullivan et al., 2014a). These findings are in agreement with research in soccer that showed that less successful teams cover more total and high-speed distance compared to their more successful counterparts (Castellano et al., 2012; Lago et al., 2010). The authors suggested that the increased physical activity evident in losses can be attributed to less time in possession and thus more high-intensity defensive running to attempt to regain possession. This hypothesis appears to somewhat agree with the findings of a recent Australian Football study investigated the influence of quarter outcome on time spent performing high-speed running during offence and defence (Gronow et al., 2014). The results of this study showed that time in possession was higher in quarter wins, while the time that the ball was in-dispute and percentage of high-speed running during offence was lower. However, the study also showed that time spent performing high and very-high speed running during defence was the strongest predictor of quarter success when compared to other physical performance measures. While the match running demands of offence and defence in Australian Football is yet to be empirically described, these collective findings provide tenuous evidence that in one AFL team at least, high-speed running during specific phases of match-play may be related to the likelihood of quarter success. In addition, Sullivan et al. (2014a) also reported increases in ball involvement during quarter wins compared to losses. The reduction in time that the ball was in-dispute, along with increased time in offence suggests that winning possession of the ball, and maintaining it may be an important attribute to successful Australian Football match-play. Indeed, some research in professional soccer suggests that successful teams are more proficient at winning possession of the ball when it is lost (Gómez, Gómez-Lopez, Lago, & Sampaio, 2012). Research that investigates the physical and technical profiles during the various phases of match-play in relation to match or quarter outcome are clearly warranted.

Other studies in Australian Football have used technical skills measures to explain match outcomes in Australian Football. Robertson et al. (2016) showed that a higher number of team kicks and greater goal conversion efficiency were vital performance discriminators between wins and losses. Inside 50's, marks inside 50, marks and contested possessions also contribute to models predicting match outcomes (Robertson et al., 2016; Stewart, Mitchell, & Stavros, 2007). Taken together, this information suggests that is vital to win possession during contested elements of match-play, move the ball into point scoring positions during offensive phases in play and finally convert shots at goal. Interestingly, there is little information that has investigated the differences in technical performance during the different phases in match-play in Australian Football. Such a study may provide further insight into the importance of performance during different elements of match-play and how they relate to match success. Match running performance and technical skills appear most related to team success when these measures are considered during phases of possession, yet no study has assessed the effect of match or quarter outcome on physical and technical performance during the phases of play in professional Australian Football.

2.5.4 SUMMARY

The availability of detailed technical skill and physical performance data is commonplace in professional Australian Football. Several studies have investigated these areas in isolation by describing quarter and entire match profiles, however, more recent studies have integrated these measures to provide a more accurate representation of Australian Football performance. An area that is yet to receive detailed attention is the investigation of ball possession during competition. This may be due to the absence of operational definitions that clearly define the phases of match-play in Australian Football. Furthermore, it is currently unknown whether a researcher can accurately code the proposed phases of play, particularly given the chaotic nature of Australian Football competition. The development of reliable coding procedures of the phases of match-play would also permit the investigation of the distribution of the physical and technical demands in the game. While current

research has provided descriptions of the global demands of match-play, the high and low intensity periods of match-play are concealed without delineating the phases in competition. The activity and recovery cycles have been thoroughly investigated in rugby league, providing coaches with valuable information about the normative and worst-case scenarios associated with match-play. However, such information is absent for Australian Football coaching and conditioning staff to design training drills that reflect the intermittent nature of match-play. The physical demands of Australian Football have been investigated with respect to player position, however, the distribution of match running for different positions in Australian Football is currently unknown. A number of studies have revealed differences in positional match-running demands. However, it is unknown whether the distribution of match-running in the phases in play is identical between positions. Match-related fatigue has also been well researched in professional Australian Football, showing that locomotion gradually reduces as the match progresses. Recently, however, several authors have suggested the match context (whether the ball is in or out of play) must be considered when assessing match-related fatigue because reductions in locomotion can simply reflect changes in the game phase.

While there is an emerging body of research that has concomitantly assessed the physical and technical demands of Australian Football match-play, there is scarce research that has considered the influence of the time spent in the phases of play. Recent research has also suggested that considering the technical performance with respect to the time spent in the various phases of match-play may provide more robust information due to the contaminating effects of ball possession and possibly account for differences in tactics that determine high or low possession strategies. Clearly, further research examining the physical and technical demands of Australian Football match-play, while concurrently considering the contextual factors may provide further detail about areas of focus when preparing players for competition.

CHAPTER THREE

PHASES OF MATCH-PLAY IN PROFESSIONAL AUSTRALIAN FOOTBALL: DESCRIPTIVE ANALYSIS AND RELIABILITY ASSESSMENT

Rennie, M.J., Watsford, M.L., Kelly, S.J., Spurrs, R.W., & Pine, M.J. (2018). Phases of match-play in professional Australian Football: Descriptive analysis and reliability assessment. *Journal of Science and Medicine in Sport*, 21(6), 635-639.

ABSTRACT

Objectives: To examine the frequency and time spent in the phases of Australian Football (AF) match-play and to assess the intra-assessor reliability of coding these phases of match-play.

Design: Observational, intra-reliability assessment.

Methods: Video footage of 10 random quarters of AF match-play were coded by a single researcher. Phases of offence, defence, contested play, umpire stoppage, set shot and goal reset were coded using a set of operational definitions. Descriptive statistics were provided for all phases of match-play. Following a 6-month washout period, intra-coder reliability was assessed using typical error of measurement (TEM) and intra-class correlation coefficients (ICC).

Results: A quarter of AF match-play involved 128 ± 20 different phases of match-play. The highest proportion of match-play involved contested play (25%), followed by offence (18%), defence (18%) and umpire stoppages (18%). The mean duration of offence, defence, contested play, umpire stoppage, set shot and goal reset were 14, 14, 10, 11, 28 and 47 s, respectively. No differences were found between the two coding assessments ($p > 0.05$). ICCs for coding the phases of play demonstrated very high reliability ($r = 0.902\text{--}0.992$). TEM of the total time spent in each phase of play represented moderate to good reliability (TEM = 1.8–9.3%). Coding of offence, defence and contested play tended to display slightly poorer TEMs than umpire stoppages, set shots and goal resets (TEM = 8.1 vs 4.5%).

Conclusions: Researchers can reliably code the phases of AF match-play which may permit the analysis of specific elements of competition.

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Rennie, M.J., Watsford, M.L., Kelly, S.J., Spurrs, R.W., & Pine, M.J. (2018). Phases of match-play in professional Australian Football: Descriptive analysis and reliability assessment. *Journal of Science and Medicine in Sport*, 21(6), 635-639.

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CHAPTER FOUR

PHASES OF MATCH-PLAY IN PROFESSIONAL AUSTRALIAN FOOTBALL: DISTRIBUTION OF PHYSICAL & TECHNICAL PERFORMANCE

Rennie, M.J., Watsford, M.L., Kelly, S.J., Bush, S., Spurrs, R.W., & Austin, D.J. Phases of Match-Play in Professional Australian Football: Distribution of physical and technical performance. *Under Review*.

ABSTRACT

Purpose: To describe the distribution of physical and technical performance during the various phases of play during Australian Football competition.

Methods: Global positioning system (GPS) data was collected during 18 matches from a team competing in the Australian Football League. Matches were coded for phases of offence, defence, contested play, umpire stoppages, set shots and goal resets. Absolute and relative physical performance data was derived from each phase of play and categorised as low-speed running (LSR; $<14.4 \text{ km}\cdot\text{h}^{-1}$), high-speed running (HSR; $>14.4 \text{ km}\cdot\text{h}^{-1}$), accelerations ($>2.78 \text{ m}\cdot\text{s}^{-2}$) and decelerations ($>-2.78 \text{ m}\cdot\text{s}^{-2}$). Technical skill data was time aligned to each phase of match-play and activity and recovery cycles were also derived from the phases.

Results: Small to trivial differences existed between offence and defence for total running, HSR, LSR accelerations and decelerations. Contested play most likely involved the highest proportion of total distance, LSR, accelerations, decelerations and tackles compared to other phases. Offence and defence most likely involved the highest relative speed ($163\text{-}169 \text{ m}\cdot\text{min}^{-1}$) and proportion of HSR distance ($1153 \text{ m}\text{-}1288 \text{ m}$) compared to contested play ($134.5 \text{ m}\cdot\text{min}^{-1}$, 1010 m) and other stoppage phases ($67\text{-}99 \text{ m}\cdot\text{min}^{-1}$, $109\text{-}220 \text{ m}$). Small to very large differences in technical performance existed between all phases. Activity and recovery cycles involved relative speeds of ~ 160 and $\sim 84 \text{ m}\cdot\text{min}^{-1}$ and mean durations of ~ 110 and $\sim 39 \text{ s}$, respectively.

Conclusions: Differences in physical and technical measures were evident for all phases of match-play. These differences should be considered when interpreting Australian Football time motion data and when preparing players for competition.

INTRODUCTION

Australian Football (AF) is a popular team sport that involves elements of match-play and stoppages. Match-play is characterised by high intensity activity comprising of physical (prolonged high-speed running, acceleration and decelerations), technical (long and short kicking, handballs and tackling) and tactical elements (offensive and defensive team structures, player match-ups and ball movement). The entirety of the game can be categorised by periods of match-play or stoppages. Match-play can involve either team in possession of the ball or competing for possession, often defined as the contested element of AF match-play. There are also stoppages during match-play. These stoppages can arise when an umpire signals a break in play, often when the ball travels over the boundary line or when the ball is 'held-up' in the field of play, resulting in a boundary throw-in or ball-up, respectively. Additionally, if a player marks the ball within range to kick for goal, match-play is stopped and the player has thirty-seconds to commence their approach for a set shot. If the player kicks a goal and is awarded six points, the ball is returned to the centre of the field for a centre bounce, whereby play recommences with both teams having equal opportunity to win possession of the ball. Collectively, these elements of match-play characterise the intermittent nature of AF, where periods of match-play typically involve high-intensity activity, while stoppages involve low intensity activity. However, the differences in physical and technical skill between the various elements of match-play are yet to be elucidated.

Recent team sport studies have integrated global positioning system (GPS) technology and technical skill data from video coding to assess various factors that influence player match profiles. Indeed, pacing strategies,¹ declines in available substrate,² aerobic fitness capacity,³ and player experience⁴ have all been attributed variations in match-play intensities. However, the phases of match-play during AF competition have received little attention and the influence of the phases of match-play on game intensities are unknown. Previous research in team sport performance has suggested that the temporal changes in match intensity may be related to the time the ball is in play and thus, physical

profiles may reflect a player's opportunity to engage in activity.⁵ Furthermore, if the amount of time the ball is out of play is considered, the active element of competition can be further delineated. Thus, physical and technical performance measures can be reported relative to time spent in the various phases of match-play and therefore, more robust information pertaining to the demands of competition can be elicited.

Contemporary research has aimed to identify the most intense periods of AF match-play to prepare players for the most demanding passages of play, as opposed to the average demands. As such, a recent study in professional AF assessed the peak periods of match-play by using 10 different rolling average durations (1-10 minutes).⁶ The maximum intensity in a 1-min period was $\sim 200 \text{ m}\cdot\text{min}^{-1}$, which is markedly higher than the mean relative speed previously reported in quarters of match play ($\sim 130 \text{ m}\cdot\text{min}^{-1}$).^{1,6,7} Another study also identified intense phases of match-play by using 3-min rolling averages. The peak 3-min periods reported over four quarters of match-play involved relative speeds that ranged between $160\text{-}180 \text{ m}\cdot\text{min}^{-1}$, which was again markedly higher than the subsequent and mean 3-min periods ($\sim 110\text{-}130 \text{ m}\cdot\text{min}^{-1}$).⁴ These studies suggest that intense periods of match-play exist throughout the course of a game and, combined with the frequency of stoppages in AF, it is likely the individual phases of play contribute to periods of high and low intensity activity.

To date, only one study has assessed the physical demands of the phases of match-play in AF. Gronow et al.⁸ compared the time spent in four different speed zones when the reference team was either in possession of the ball, without possession of the ball, when the ball was in dispute and when the ball was dead (i.e. a stoppage). The findings showed that when the quarter was won, time spent in possession of the ball was higher (8.7%) and high-speed running was greater (5.7%) without possession, suggesting that maintaining possession and running performance during defence was pertinent to quarter success. However, movement data was only derived for offence and defence. One unique characteristic of AF is the element of contested match-play, whereby neither team has clear possession of the ball. These scenarios typically occur following stoppages in match-play where both

teams have an opportunity to win possession. Furthermore, the type of stoppage during match-play and associated physical demands were not delineated. Stoppages in match-play can arise from an umpire stoppage, during a set shot for goal or following a goal being scored. As such, information pertaining to these phases of play are important to understanding the active recovery element of competition and identifying activity and recovery cycle information for training purposes.⁹⁻¹¹

Clearly, there is a paucity of research on the influence of phase of match-play on the demands of AF competition. This information is important to further understand the intermittent nature of match-play so that conditioning staff and coaches can improve the preparation of players for competition. Therefore, the aim of this study was to: (1) describe the physical and technical profiles of the various phases of match-play and (2) examine the activity and recovery cycles associated with match-play.

METHODS

Subjects

Thirty-three professional AF players participated in the study (24.8 ± 4.2 years, 88.3 ± 8.7 kg, 1.88 ± 0.8 m). Following approval from the University ethics board, approval from the participating club and informed consent from all participating players, video and match running data was collected from a single Australian Football League (AFL) season. Data that involved <75% of total game time was excluded from the analysis. In total, eighteen matches were examined, yielding 360 complete player files with a mean of 10.9 ± 5.3 per player. Matches were played against various opposition calibres (14 wins, 4 losses), at various times (8 day, 10 night) and locations (9 home, 9 away). The reference team finished first after the regular season and second after the finals series.

Design

Movement data was collected using portable GPS units (Minimax S5, Firmware 6.7, Catapult Innovations, 10 Hz, Melbourne, Australia). The GPS unit was fitted into a custom pouch in the players' guernsey between the scapulae. All players wore the same unit for each game during the

season to minimise inter-unit error. The data was categorized into total distance, relative total distance ($\text{m}\cdot\text{min}^{-1}$), high-speed running (HSR) ($>14.4\text{ km}\cdot\text{h}^{-1}$) and low-speed running (LSR) distance ($<14.4\text{ km}\cdot\text{h}^{-1}$). Acceleration and deceleration efforts were classified as two consecutive samples (0.4 s) exceeding the threshold of $2.78\text{ m}\cdot\text{s}^{-2}$ and $-2.78\text{ m}\cdot\text{s}^{-2}$, respectively.^{2,12} The validity and reliability of these GPS units along with the use of the physical performance measures has been reported elsewhere.^{12,13} Technical skill data (tackles, handballs and kicks) were provided by the statistics provider for the AFL (Champion Data, Melbourne, Australia).

Following each match, video footage was coded for phases of offence, defence, contested play, umpire stoppage, set shot and goal reset. The operational definitions for these phases of play are described in Table 4.1. The phases of play were coded using three different camera views (one positioned at halfway, one positioned behind the goals and the broadcasters view). The footage was downloaded to a computer and the phases of play were manually coded using SportsCode (SportsTec Limited, version 9.4.1, Warriewood, Australia). A single trained researcher coded all matches to maximize data reliability. The average intra-coder typical error of measurement was 6.9%, 8.2%, 9.3%, 9.0%, 2.7% and 1.8% for offence, defence, contested play, umpire stoppage, set shot and goal reset, respectively. Intra-class correlation coefficients ranged from 0.865-0.992. Following video analysis, a time-coded transcript of the phases of play was uploaded to a custom-built Microsoft Excel spreadsheet (Microsoft, Redmond, USA). The spreadsheet was imported into the GPS proprietary software (Sprint 5.1.7, Catapult Sports, Melbourne, Australia) which produced a file including physical movement data for each phase of play for each player. A total of 33398, 33642, 67148, 35204, 8252 and 7396 individual player transcripts were analysed for offence, defence, contested play, umpire stoppage, set shot and goal reset, respectively. The technical skills were also time aligned within each phase of match-play. Activity was defined as a continual passage of play that involved any combination of offence, defence, contested play or umpire stoppage. Umpire stoppages were

excluded from the analysis if they were due to injury or goal review. Recovery was defined as a continual passage of play that involved any composite of set shot and goal reset.

Table 4.1: Operational definition for each phase of play coded during the analysis.

<i>Offence</i>	The reference team has clear control of the ball via a hard ball get, a mark, handball or an intercept during open play. A turnover from penalty, infringement or behind also constitutes a change in possession.
<i>Defence</i>	The opposition team has clear control of the ball via a hard ball get, a mark, handball or an intercept during open play. A turnover from penalty, infringement or behind also constitutes a change in possession.
<i>Contested Play</i>	Neither team has clear control or possession of the ball due to tackling or opposition pressure. The ball is not secured via a mark or clean receive from a team mate.
<i>Umpire Stoppage</i>	The umpire signals a stoppage in play to indicate a ball up, boundary throw-in. Blood rules or stoppages due to injury were excluded from the analysis.
<i>Set Shot</i>	Commences the moment a player marks the ball in a scoring position, executes the shot and the umpire indicates either a goal or behind. If an umpire requests a score review, the phase is defined as an umpire stoppage.
<i>Goal Reset</i>	Includes the duration between the umpire signalling a goal has been scored to the proceeding centre bounce.

Statistical Analysis

Assessment of differences between the phases of play was first analysed using a linear mixed effects model (*lme4* package) to account for pseudo-replication within the dataset. Each individual participant was included as a random effect, while the phases of play were defined as fixed effects. The assumptions of normality were verified prior to parametric analysis. When significant main effects were observed, pairwise comparisons with Tukey’s Honest Significant Difference tests were applied. Due to the number of phases of play analysed in the study, there was a greater likelihood of a significant p value. Subsequently, a magnitude-based approach was used to assess the likelihood of

a true practical difference existing between the phases of match-play for each physical and technical performance variable (i.e. greater than the smallest worthwhile change [SWC]). The between-subject standard deviation for all metrics was obtained via a separate mixed model with random effects for individual players. A progressive magnitude-based inference approach was then used to assess the chances that the effect statistic was greater than the smallest worthwhile change (calculated as $0.20 \times$ the between-subject standard deviation).¹⁴ Quantitative chances of real differences in the variables were assessed and qualitatively defined as: <1%, almost certainly not; 1% to 5%, very unlikely; 5% to 25%, probably not; 25% to 75%, possibly; 75% to 97.5%, likely; 97.5% to 99%, very likely; >99%, most likely. If the chances of a variable having higher and lower differences were >5%, the true effect was deemed to be unclear. Effect size values of <0.2, 0.21–0.6, 0.61–1.20, 1.21–2.00 and >2.01 were interpreted as trivial, small, moderate, large and very large differences, respectively.¹⁴ Statistical analysis was performed using R statistical software (R.3.2.2, R Foundation for Statistical Computing) or Microsoft Excel. Significance was set at $p < 0.05$ for the linear models. Data is presented as mean \pm 95% confidence intervals (CI) for physical performance and technical skill data.

RESULTS

The mean and 95% CIs for all physical performance metrics in each phase of play are shown in Table 4.2. Linear mixed models revealed significant main effects for phase of play and each physical performance metric ($F=2325$, $p < 0.001$). Table 2 shows the highest proportion of game time was spent in contested play, followed by offence and defence which involved similar proportions of game time. Umpire stoppages involved a higher proportion of game time compared to set shots and goal resets. Possible small to trivial differences existed in offence and defence for total and relative distance. Contested play involved more total distance compared to offence and defence, but involved a lower relative distance. There were clear differences in HSR distance between all phases of play, however the magnitude of difference between offence and defence was relatively small. The results for LSR distance were similar to HSR distance, except for offence and defence where only trivial differences

existed. The results for time spent performing HSR were also similar to those evident for HSR distance, with the exception of umpire stoppage and goal reset where only small differences existed. Contested play involved the highest number of accelerations and decelerations when compared to all other phases. Offence and defence involved a similar number of accelerations, however defence likely involved more decelerations. Umpire stoppages involved more accelerations and decelerations than set shot and goal resets (Table 4.3). The number of kicks and handballs were highest during offence when compared to contested play, while the number of tackles made during contested play was higher than defence (Table 4.4). The mean activity and recovery cycles, maximum activity and minimum recovery cycles, mean frequency of phases of play per activity cycle, relative distance for each activity and recovery cycle and frequency of technical skills are displayed in Table 4.5.

Table 4.2: The distribution of match running performance and technical skills by phase of play.

	Offence	Defence	Contested Play	Umpire Stoppage	Set Shot	Goal Reset	Follow-up Tests (Tukey HSD)	^a Distribution or Difference from Mean (%)
Game Time (mm:ss)	22:21 (20:26–24:16)	21:45 (19:53–23:37)	28:27 (25:06–31:48)	17:39 (14:49–20:29)	11:06 (09:08–13:04)	17:47 (14:10–21:24)	CP>(OF=DF)>(GR=US)>SS*	19-18-24-15-9-15
Total Distance (m)	3026 (2973–3079)	2875 (2822–2927)	3128 (3065–3191)	1413 (1380–1446)	616 (598–634)	1077 (1046–1107)	CP>OF>DF>US>GR>SS*	25-24-26-12-5-9
Relative Distance (m·min ⁻¹)	169 (167–171)	163 (161–164)	135 (133–136)	99 (98–101)	67 (66–69)	72 (71–73)	OF>DF>CP>US>GR>SS*	↑27-↑23-↑5-↓26-↓63-↓57
HSR Distance (m)	1289 (1252–1326)	1153 (1122–1183)	1011 (977–1044)	220 (206–234)	109 (102–117)	182 (171–193)	OF>DF>CP>US>GR>SS*	33-29-26-6-3-5
LSR Distance (m)	1746 (1712–1780)	1729 (1697–1761)	2118 (2076–2160)	1191 (1163–1218)	509 (494–524)	898 (872–924)	CP>(OF=DF)>US>GR>SS*	21-21-26-15-6-11
HSR Time (mm:ss)	03:16 (03:09–03:22)	02:56 (02:51–03:02)	02:30 (02:21–02:39)	00:38 (00:34–00:43)	00:19 (00:17–00:21)	00:35 (00:31–00:38)	OF>DF>CP>(US=GR)>SS	32-29-24-6-3-6
LSR Time (mm:ss)	11:49 (11:35–12:04)	11:54 (11:40–12:06)	16:14 (15:55–16:33)	11:12 (10:57–11:26)	07:49 (07:37–08:01)	12:47 (12:26–13:08)	CP>GR>(DF=OF)>US>SS*	16-17-23-16-11-18
Accelerations (n)	6.4 (6.1–6.8)	6.9 (6.5–7.2)	14.6 (14.1–15.1)	1.9 (1.7–2.1)	1 (0.9–1.1)	1.7 (1.5–1.9)	CP>(DF=OF)>(US=GR)>SS*	20-21-45-6-3-5
Decelerations (n)	9.7 (9.3–10.1)	11.5 (11–12)	18 (17.3–18.6)	2.6 (2.3–2.8)	0.7 (0.6–0.8)	0.6 (0.5–0.8)	CP>DF>OF>US>(SS=GR)*	23-27-42-6-2-1
Handballs (n)	4.3 (2.5-6.3)	-	3.7 (2.0-6.5)	-	-	-	OF>CP*	53-47
Kicks (n)	6.0 (3.1-8.0)	-	3.3 (2.3-6.5)	-	0.6 (0.2-1.0)	-	(OF>CP)>SS*	60-34-6
Tackles (n)	-	0.4 (0.1-0.8)	3.0 (2.2-4.6)	-	-	-	CP>DF*	13-87

Values are presented as mean (95% Lower CI-Upper CI). Game time is inclusive of bench time. HSR, High speed running (>14.4 km·h⁻¹); LSR, Low speed running (<14.4 km·h⁻¹); Accelerations, > 2.78 m·s⁻²; Decelerations, >-2.78 m·s⁻²; OF, Offence; DF, Defence; CP, Contested Play; US, Umpire Stoppage; SS, Set Shot; GR, Goal Reset. *p<0.05 (Adjusted p values following Tukey HSD corrected multiple comparisons). Phases are ranked in descending order according to analysed metric; >, Significantly greater than; (=), Collectively no difference. ^aShows the distribution of each variable for offence, defence, contested play, umpire stoppage, set shot and goal reset.

Table 4.3: Likelihood and effect size matrix representing the differences in physical performance variables between the phases of play.

Phase of Match-Play Comparison		Game Time	Total Distance	Relative Distance	HSR Distance	LSR Distance	HSR Time	LSR Time	Accelerations	Decelerations	
Offence	Defence	Possibly	Possibly	Possibly	Likely	Very likely	Possibly	Very likely	Likely	Likely	
		<i>Trivial</i>	<i>Small</i>	<i>Trivial</i>	<i>Small</i>	<i>Trivial</i>	<i>Small</i>	<i>Trivial</i>	<i>Trivial</i>	<i>Small</i>	
	Contested Play	Most likely	Unclear	Most likely	Most likely	Most likely	Likely	Most likely	Most likely	Most likely	
		<i>Moderate</i>	<i>Trivial</i>	<i>Large</i>	<i>Small</i>	<i>Moderate</i>	<i>Moderate</i>	<i>Large</i>	<i>Large</i>	<i>Large</i>	
	Umpire Stoppage	Most likely	Likely	Most likely	Most likely						
<i>Moderate</i>		<i>Very Large</i>	<i>Very Large</i>	<i>Very Large</i>	<i>Large</i>	<i>Very Large</i>	<i>Small</i>	<i>Large</i>	<i>Large</i>		
Set Shot	Most likely										
	<i>Very Large</i>	<i>Large</i>	<i>Very Large</i>	<i>Very Large</i>							
Goal Reset	Most likely	Possibly	Most likely	Most likely							
	<i>Moderate</i>	<i>Very Large</i>	<i>Small</i>	<i>Large</i>	<i>Large</i>						
Defence	Contested Play	Most likely	Most likely	Most likely	Likely	Most likely	Most likely	Most likely	Most likely	Most likely	
		<i>Large</i>	<i>Small</i>	<i>Moderate</i>	<i>Small</i>	<i>Moderate</i>	<i>Small</i>	<i>Large</i>	<i>Large</i>	<i>Moderate</i>	
	Umpire Stoppage	Most likely	Likely	Most likely	Most likely						
		<i>Moderate</i>	<i>Very Large</i>	<i>Very Large</i>	<i>Very Large</i>	<i>Large</i>	<i>Very Large</i>	<i>Small</i>	<i>Large</i>	<i>Large</i>	
Set Shot	Most likely										
	<i>Very Large</i>	<i>Large</i>	<i>Very Large</i>	<i>Very Large</i>							
Goal Reset	Most likely	Possibly	Most likely	Most likely							
	<i>Moderate</i>	<i>Very Large</i>	<i>Small</i>	<i>Large</i>	<i>Very Large</i>						
Contested Play	Umpire Stoppage	Most likely									
		<i>Large</i>	<i>Very Large</i>	<i>Very Large</i>	<i>Very Large</i>	<i>Large</i>	<i>Very Large</i>	<i>Large</i>	<i>Very Large</i>	<i>Very Large</i>	
	Set Shot	Most likely									
<i>Very Large</i>		<i>Very Large</i>									
Goal Reset	Most likely										
	<i>Large</i>	<i>Very Large</i>	<i>Moderate</i>	<i>Very Large</i>	<i>Very Large</i>						
Umpire Stoppage	Set Shot	Most likely	Likely	Most likely	Most likely	Most likely					
		<i>Large</i>	<i>Very Large</i>	<i>Large</i>	<i>Moderate</i>	<i>Very Large</i>	<i>Moderate</i>	<i>Large</i>	<i>Moderate</i>	<i>Moderate</i>	
Goal Reset	Very likely	Most likely	Most likely	Very likely	Most likely	Likely	Most likely	Likely	Most likely		
	<i>Trivial</i>	<i>Moderate</i>	<i>Large</i>	<i>Small</i>	<i>Moderate</i>	<i>Small</i>	<i>Small</i>	<i>Trivial</i>	<i>Small</i>		
Set Shot	Goal Reset	Most likely	Most likely	Likely	Most likely	Most likely	Likely	Most likely	Most likely	Likely	
		<i>Large</i>	<i>Large</i>	<i>Trivial</i>	<i>Small</i>	<i>Large</i>	<i>Moderate</i>	<i>Large</i>	<i>Small</i>	<i>Small</i>	
Likelihood		Unclear	Possibly	Likely	Very likely	Most likely					
ES		Trivial	Small	Moderate	Large	Very Large					

The description below refers to **Table 4.3**.

Values are: Chance (%) that magnitude of change between two phases of play is higher/no difference/lower (100/0/0) and magnitude of difference between the mean effect. HSR, high-speed running ($>14.4 \text{ km}\cdot\text{h}^{-1}$); LSR, Low-speed running ($<14.4 \text{ km}\cdot\text{h}^{-1}$); Accelerations, $>2.78 \text{ m}\cdot\text{s}^{-2}$; Decelerations, $>-2.78 \text{ m}\cdot\text{s}^{-2}$. Chance of real world differences described as: almost certainly not ($<1\%$), very unlikely (1-5%), probably not (5-25%), possibly (25-75%), likely (75-97.5%), very likely (97.5-99%) and most likely ($>99\%$). Effect size values described as: trivial (<0.2), small (0.21–0.6), moderate (0.61–1.20), large (1.21–2.00) and very large (>2.01).

Table 4.4: Comparison between the frequency of technical skills during the phases of match-play.

Comparison	Handballs (#)	Kicks (#)	Tackles (#)
Offence vs Contested Play	Very likely Very Large	Likely Small	
Offence vs Set Shot	Most likely Very Large	Most likely Very Large	
Defence vs Contested Play			Most likely Very Large
Contested Play vs Set Shot		Most likely Very Large	

Chance of real world differences described as: almost certainly not (<1%), very unlikely (1-5%), probably not (5-25%), possibly (25-75%), likely (75-97.5%), very likely (97.5-99%) and most likely (>99%). Effect size values described as: trivial (<0.2), small (0.21–0.6), moderate (0.61–1.20), large (1.21–2.00) and very large (>2.01).

Table 4.5: Descriptive analysis of the activity and recovery cycles in Australian Football match-play.

<i>Duration and relative distance of activity and recovery cycles</i>	
Mean activity cycle duration (s)	110.2 (102-118.4)
Mean recovery cycle duration (s)	38.9 (37.4-40.4)
Activity: recovery (ratio)	2.8:1
Mean activity relative distance ($\text{m}\cdot\text{min}^{-1}$)	160.3 (155.6-165)
Mean recovery relative distance ($\text{m}\cdot\text{min}^{-1}$)	84 (79.7-88.3)
Maximum activity cycle duration (s)	721
Minimum recovery cycle duration (s)	11
<i>Number of phases of play per activity cycle</i>	
Mean activity and recovery cycles per match (n)	38 (36-40)
Frequency of offence per activity cycle (n)	2.6 (2.4-2.8)
Frequency of defence per activity cycle (n)	2.6 (2.4-2.7)
Frequency of contested play per activity cycle (n)	5.1 (4.8-5.5)
Frequency of umpire stoppages per activity cycle (n)	2.7 (2.4-2.9)
<i>Total number of technical skills performed per activity cycle (reference team only)</i>	
Total handballs per activity cycle (n)	4.2 (3.9-4.6)
Total kicks per activity cycle (n)	4.9 (4.5-5.2)
Total tackles per activity cycle (n)	1.8 (1.6-2.0)

DISCUSSION

This study empirically assessed the physical and technical profiles of the phases of match-play in professional AF. Activity and recovery cycles were also derived from the phases of match-play. The main findings showed that the physical and technical demands of AF competition are influenced by the phases of match-play. Match-play in AF is characterized by brief periods of activity (~110 s) separated by short (~36 s) recovery cycles. The movement demands of each phase differ between total distance, HSR, acceleration, deceleration and technical demands of competition and thus, several practical applications can be extracted from the findings to enhance the understanding of the demands of match-play.

In congruence with previous research, our findings suggest that the inclusion or exclusion of stoppage data can markedly affect the reported match intensities and volumes.^{5,9,11} The mean relative distance for all matches analysed in the present study was $133 \pm 17 \text{ m} \cdot \text{min}^{-1}$ which is comparable to the $120\text{--}135 \text{ m} \cdot \text{min}^{-1}$ previously reported.^{1,15,16} However, in the present study, the relative distance of the phases of match-play ranged from 72 to $169 \text{ m} \cdot \text{min}^{-1}$, which illustrates the range of intensities performed by players throughout the match. Furthermore, the exclusion of stoppage data (umpire stoppage, set shot and goal reset) results in an underestimation of total distance and HSR distance by 25% and 13%, respectively. The inclusion of stoppage data in match analysis appears to reduce time-relative metrics and provides more accurate reflections of total match loads. A global analysis of match-play may therefore be more relevant for player monitoring purposes. Comparatively, the analysis of specific phases of match-play may be more valuable for practitioners when designing training drills that replicate the dynamic demands of match-play. A pragmatic approach to the analytics of selected elements of competition is clearly necessary.⁵

In the present study, few practical differences were evident in physical performance between offence and defence. Indeed, only small to trivial differences existed for total distance, relative distance and

HSR, which concur with the findings of Gronow et al.⁸ who reported no difference between offence and defence for time spent performing HSR and LSR. In the present study, HSR accounted for 33% of total time spent running in offence and 29% in defence (Table 4.2). In contrast, Gronow et al.⁸ reported that players spent 21% of time HSR during offence and 23% during defence. Differences in game tactics utilised by the teams as well as the size of the team's home ground in both studies may explain this discrepancy. Nevertheless, a common offensive tactic in AF is to spread quickly away from contests to create space when their team has won the ball. The defensive team likely attempts to mirror the movement pattern of the opposite team¹⁶ which may explain the similarities in movement profiles between the two phases of play. Furthermore, the HSR demands of offence and defence are markedly higher than the other phases of play. A higher number of rotations and shorter on-field bouts have been related to improved running performance in AF,^{3,17} thus, it appears important to consider the time spent in offence and defence during competition and manage player rotations to maintain HSR performance during these phases of possession.¹⁸

A novel aspect of this research was the analysis of the contested play which involved the highest proportion of game time, total distance, LSR and tackles when compared with all other phases. In contrast, Gronow et al.⁸ reported 29% less time in contested play compared to the present study. Unfortunately, the definitions for coding were not provided, therefore, it is possible that the differences in time spent in contested play could be explained by differences in the operational definitions used or game styles of the teams assessed in the two different studies. Nevertheless, the high number of acceleration and deceleration movements during contested play may reflect the change of direction demands and unpredictable nature of this phase. Acceleration and deceleration movements along with the number of tackles have also been attributed to exercise-induced muscle fatigue and damage due to the involvement of eccentric muscle actions and blunt force trauma.^{19,20} Furthermore, among other metrics, contested possessions and contested marks have been shown to be influential in probability models that explain match outcomes in AF.²¹ In order to optimally

prepare players for success during contested elements of match-play, adequate training time should be dedicated to maximising performance in this area. Considering however, the physical and technical demands may impose a higher physical load and possibly a higher contact-injury risk compared to other phases. As such, the prescription of training drills that involve contested elements of match-play should be closely scrutinized.

Umpire stoppages, set shots and goal resets collectively encompassed of 45% of total game time. Furthermore, 26% of total distance and 15% of HSR was performed during these phases which taken together, suggests that these phases of play typically involve low intensity activity ($\sim 105 \text{ m}\cdot\text{min}^{-1}$). These findings are in agreement with other team sport studies reporting reduced intensity of activity when the ball is out of play.⁹ Nevertheless, these stoppages still involve important physical, technical and tactical elements. During umpire stoppages, players need to quickly organize offensive and defensive structures and jostle for superior position to win the ball. Furthermore, a set shot represents an opportunity to convert a kick into points, while the defending team must limit the potential for the offensive team to improve their kicking position. In addition, goal resets present stoppages in play where teams have opportunities to make rotations, which may explain the small proportion of HSR during this phase. Indeed, an interesting question pertains to the timing of rotations during these stoppage periods. Given the relatively low intensity of these phases during a match and the time associated with a set shot and goal reset combined (~ 75 seconds), recovery from in-play periods may occur while the player remains on field. Alternatively, these phases of play present opportunities for rotations which mitigate the risk of players being caught out of position.

The activity and recovery cycles from match-play were derived from the data in this study (Table 4.4). The average activity cycle during match-play was ~ 110 seconds, which is more than 30% greater than the average length reported in 9- and 13-a-side rugby league.^{10,11} The mean recovery cycle was ~ 39 seconds, which was slightly higher than those reported in rugby league. Regardless, the activity: recovery ratios were higher compared to both versions of rugby league (2.8:1 vs 2-1.6:1). The

structure and evolution of AF match-play is likely to contribute to the activity and recovery cycles observed in the present study. Furthermore, the maximum activity cycle was approximately 12 minutes, which may be representative of the ‘worst-case scenario’ in AF and which is slightly higher than those reported in rugby league.^{10,22} The relative distances, frequency of phases and technical skills of activity and recovery cycles in AF can be used by conditioning coaches to prescribe training drills that replicate the demands of match-play. Small-sided games that involve relative speeds of $\sim 160 \text{ m}\cdot\text{min}^{-1}$ during activity and $\sim 84 \text{ m}\cdot\text{min}^{-1}$ during recovery may represent normative intensities of AF match-play. Furthermore, manipulations to field size, rules and coordination of activity and recovery cycles could target specific physical or technical qualities to optimally prepare players for competition.^{11,23}

While this study provides relevant information for the practitioner, some inherent limitations should be addressed with future research. The results observed in the present study likely reflect the characteristics of the participating individual players. In contrast, the time spent in various phases of play and associated activity: recovery ratios may be more generalizable to other teams due to the consideration of the opposition team. The use of traditional time motion metrics used in the present study provides a basis for assessing the distribution of running, however, metabolic power estimates may provide more detailed information relating to the metabolic cost and fatigue profiles of the phases of play.^{15,16} Nevertheless, our study describes the distribution of physical and technical skills from a high-calibre team and presents practically important information regarding AF match-play.

PRACTICAL APPLICATIONS

- The phase of match-play intricately influences the temporal physical demands and technical skills of AF competition. The time spent and associated demands of each phase of play should be considered when assessing AF physical and technical performance data and preparing players for competition.

- The mean (~110 s) and maximum (~720 s) activity cycles, along with the mean (~39 s) and minimum (~11 s) recovery cycles should be implemented during the preparation of AF players for the normative and worst-case scenarios in competition.

CONCLUSION

This study was the first to describe the distribution of physical and technical demands of match-play in AF. Offence and defence involved the most high-speed running and relative distance, while contested play involved the highest number of accelerations, decelerations and total distance. Umpire stoppages, set shots and goal resets typically involved low-intensity activity. The average and worst-case scenario activity and recovery cycles should be considered when preparing players for competition. Collectively, this study describes the distribution of physical and technical performance in AF which may assist practitioners in the preparation of players for the demands of competition.

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REFERENCE LIST

1. Coutts AJ, Quinn J, Hocking J, Castagna C, Rampinini E. Match running performance in elite Australian Rules Football. *J Sci Med Sport*. 2010;13(5):543-548.
2. Aughey RJ. Australian football player work rate: evidence of fatigue and pacing? *Int J Sports Physiol Perform*. 2010;5(3):394-405.
3. Ryan S, Coutts AJ, Hocking J, Kempton T. Factors Affecting Match Running Performance in Professional Australian Football. *Int J Sports Physiol Perform*. 2017:1-19.
4. Black GM, Gabbett TJ, Naughton GA, McLean BD. The effect of intense exercise periods on physical and technical performance during elite Australian Football match-play: A comparison of experienced and less experienced players. *J Sci Med Sport*. 2016;19(7):596-602.
5. Carling C. Interpreting physical performance in professional soccer match-play: should we be more pragmatic in our approach? *Sports Med*. 2013;43(8):655-663.
6. Delaney JA, Thornton HR, Burgess DJ, Dascombe BJ, Duthie GM. Duration-specific running intensities of Australian Football match-play. *J Sci Med Sport*. 2017;20(7):689-694.
7. Wisbey B, Montgomery PG, Pyne DB, Rattray B. Quantifying movement demands of AFL football using GPS tracking. *J Sci Med Sport*. 2010;13(5):531-536.
8. Gronow D, Dawson B, Heasman J, Rogalski B, Peeling P. Team movement patterns with and without ball possession in Australian Football League players. *Int J Perform Anal Sport*. 2014;14(3):635-651.
9. Gabbett TJ. Influence of ball-in-play time on the activity profiles of rugby league match-play. *J Strength Cond Res*. 2015;29(3):716-721.
10. Gabbett TJ. Activity and recovery cycles of National Rugby League matches involving higher and lower ranked teams. *J Strength Cond Res*. 2013;27(6):1623-1628.
11. Kempton T, Coutts AJ. Physical and Technical Demands of Rugby League 9s Tournament Match Play: A Preliminary Study. *Int J Sports Physiol Perform*. 2015;10(6):774-779.
12. Johnston RJ, Watsford ML, Austin D, Pine MJ, Spurrs RW. Player acceleration and deceleration profiles in professional Australian football. *J Sports Med Phys Fitness*. 2015;55(9):931-939.
13. Johnston RJ, Watsford ML, Kelly SJ, Pine MJ, Spurrs RW. Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. *J Strength Cond Res*. 2014;28(6):1649-1655.
14. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41(1):3-13.

15. Johnston RJ, Watsford ML, Austin DJ, Pine MJ, Spurrs RW. Movement Profiles, Match Events, and Performance in Australian Football. *J Strength Cond Res.* 2016;30(8):2129-2137.
16. Coutts AJ, Kempton T, Sullivan C, Bilsborough J, Cordy J, Rampinini E. Metabolic power and energetic costs of professional Australian Football match-play. *J Sci Med Sport.* 2015;18(2):219-224.
17. Dillon PA, Kempton T, Ryan S, Hocking J, Coutts AJ. Interchange rotation factors and player characteristics influence physical and technical performance in professional Australian Rules football. *J Sci Med Sport.* 2017. PubMed doi: 10.1016/j.jsams.2017.06.008. [Epub ahead of print]
18. Rampinini E, Impellizzeri FM, Castagna C, Coutts AJ, Wisloff U. Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *J Sci Med Sport.* 2009;12(1):227-233.
19. Young WB, Hepner J, Robbins DW. Movement demands in Australian rules football as indicators of muscle damage. *J Strength Cond Res.* 2012;26(2):492-496.
20. McLellan CP, Lovell DI, Gass GC. Biochemical and endocrine responses to impact and collision during elite Rugby League match play. *J Strength Cond Res.* 2011;25(6):1553-1562.
21. Robertson S, Back N, Bartlett JD. Explaining match outcome in elite Australian Rules football using team performance indicators. *J Sports Sci.* 2016;34(7):637-644.
22. Gabbett TJ. Activity and recovery profiles of state-of-origin and national rugby league match-play. *J Strength Cond Res.* 2015;29(3):708-715.
23. Hill-Haas SV, Dawson B, Impellizzeri FM, Coutts AJ. Physiology of small-sided games training in football: a systematic review. *Sports Med.* 2011;41(3):199-220.

CHAPTER FIVE

PHASES OF MATCH-PLAY IN PROFESSIONAL AUSTRALIAN FOOTBALL: POSITIONAL DEMANDS & MATCH-RELATED FATIGUE

Rennie, M.J., Watsford, M.L., Kelly, S.J., Bush, S., Spurrs, R.W., Bower, R.G., Austin, D.J. & Pine, M.J. Phases of Match-Play in Professional Australian Football: Positional Demands and Match-Related Fatigue. *Under Review*

ABSTRACT

Purpose: To examine the influence of player position and game quarter on the phases of play during Australian Football competition.

Methods: Global positioning satellite data was collected from 18 matches from an Australian Football League team for nomadic, key position and ruck players. Distance, speed and metabolic power indices were derived from each phase of offence, defence, contested play, umpire stoppages, set shots and goal resets. A magnitude-based statistics approach assessed the differences within-positions, between-positions and across game quarters.

Results: There were clear differences between positions for low-speed running, high-speed running, total distance and relative distance. The nomadic players generally had the highest match running outputs, followed by key position players and ruckmen. Within each position, offence and defence involved the highest intensities, followed by contested play and then stoppage periods. Across the four quarters, there were small to large reductions in relative distance, high-speed running, average metabolic power and energy expenditure during offence, defence and contested play, but not during stoppages.

Conclusions: Match running performance during the phases of match-play is influenced by both player position and game quarter. Accordingly, conditioning staff should consider the intermittent intensities of the phases of match-play for each position in order to optimally prepare players for competition. Reductions in match intensities were evident during active periods of play, but not during stoppages. Real-time monitoring of active match-play periods may optimise the timing of rotations. Finally, metabolic power indices may be highly useful for quantifying the demands of contested match-play periods where spatial constraints may limit high running speeds.

INTRODUCTION

Time motion analysis research in professional Australian Football (AF) has evolved progressively over the last 40 years and has been integral in understanding the high intensity, intermittent nature of competitive match-play.¹ The breadth of analysis has increased with advancements in technology, whereby now all teams in the Australian Football League (AFL) utilize global positioning satellite (GPS) technology to quantify the physical performance of their players. Depending on position, players typically cover total distances of 11-14 km, with 22-33% performed above 14.4 km·h⁻¹.² Furthermore, there is a consensus in the literature that match-running performance is influenced by a myriad of dynamic factors including match-related fatigue,³ playing position,⁴ player caliber,⁵ quarter outcome⁶ and technical proficiency.⁷

Recently, the integration of video analysis and GPS has elicited the ability to assess specific elements of match-play that may provide more robust information compared to entire match or quarter-by-quarter analyses. Several studies in English Premier League (EPL) and Spanish soccer have shown that match-running profiles are influenced by both playing position and phase of match-play.⁸⁻¹⁰ Typically, these studies have assessed periods of offence and defence and reported disparate findings. For example, central attacking midfielders in the professional Spanish League performed more high-speed running (HSR) during offence, however the opposite was found for central attacking midfielders in the EPL.¹⁰ This information indicates that player match running profiles may be dependent on, not only the competitive league, but also the players' specific tactical role within the team. In contrast, fixed position players (central forwards and defenders) typically performed the majority of running that was reflective of their positional role (i.e. forwards performance more HSR during offence).¹⁰ Several AF studies have described the influence of player position on the physical demands of match-play,^{2,4,11} however, research is yet to consider the influence of the phase of match-play. Traditional time motion variables along with metabolic power estimates have shown that nomadic/ midfield players typically perform the highest match-running loads, followed by fixed

defenders and forwards, and then ruck players. Recently, research from professional rugby league has demonstrated that while defending was found to be more physically demanding overall when compared to offence,¹² this was only the case for forwards and pivots, and there was no difference for outside backs.¹³ While these observations were drawn from only three competitive matches, it is plausible to assume that higher physical outputs are required from different positions depending on the phase of match-play. Currently, AF research has yet to explore the influence of the phases of match-play on positional demands during competition.

One area that has received detailed attention is the incidence of match-induced fatigue during AF match-play which has typically been demonstrated by decrements in HSR and relative distance. Several studies have utilised fixed time periods to assess transient and cumulative fatigue including: comparing the peak 3-min period of activity to the subsequent 3-min period and mean of all other 3-min periods,¹⁴ first player rotation period to subsequent rotation periods,¹⁵ and more recently, a moving average using ten different durations (1–10 min) with the maximum value recorded for each duration.¹⁶ Collectively, these studies have demonstrated evidence of match-related fatigue following the most intense periods of match-play and during the final quarter of a game. Recently, authors have expressed caution when interpreting findings related to match-induced fatigue that do not account for time spent in possession or when the ball is out of play.^{17,18} Theoretically, reductions in movement intensities may be the result of stoppages in match-play that primarily involve low-intensity activity. In AF, high-intensity periods of offence, defence or contested play can be proceeded by stoppages of varying durations. These stoppages can be due to the ball travelling over the boundary line or ‘held-up’ in the field of play, during a set shot for goal or during a goal reset where the ball is returned to the centre of the field where play is recommenced. Clearly, further knowledge can be fostered by analysing the phases of match-play during AF competition. Specifically, this analysis could potentially identify (a) how the positional demands differ depending on the phase of match-play and (b) whether reductions in match-running performance are global or isolated to specific phases of

match-play. Thus, the aim of this study was to assess the effect of the phases of AF match-play on player position and match quarter activity profiles.

METHODS

Thirty-three professional AFL players from one club participated in the study (age: 24.8 ± 4.2 years, body mass: 88.3 ± 8.7 kg, height: 1.88 ± 0.8 m, total match observations: 9.6 ± 5.3 ; mean \pm SD). Eighteen in-season matches were analysed, eliciting 356 player files following exclusion criteria being applied. Players were categorized as either nomadic ($n=22$ [227]), key position ($n=7$ [85]) or ruck ($n=4$ [44]) depending on their primary role for the match. University ethics approval, consent from the AFL club and participating players was obtained prior to data collection.

Movement data was collected using portable GPS technology (Optimeye S5, 10-Hz, Catapult Sports, Victoria, Australia) that was fitted into a custom-designed pouch at the back of the players' jersey. Players wore the same GPS unit for each game to minimize inter-unit error. Time between quarter breaks and interchange periods was omitted prior to analysis. Players who played less than 75% of total match time were excluded from the analysis. For the positional analysis, data was categorized into total (m, TD) and relative distance ($\text{m} \cdot \text{min}^{-1}$), while high-speed running ($>14.4 \text{ km} \cdot \text{h}^{-1}$, HSR) and low-speed running ($<14.4 \text{ km} \cdot \text{h}^{-1}$, LSR) were reported relative to field time ($\text{m} \cdot \text{min}^{-1}$). The validity and reliability of these GPS units and metrics have been previously reported.^{19,20} Additionally, estimates of average metabolic power ($\text{W} \cdot \text{kg}^{-1}$, P_{met}) and total energy expenditure ($\text{kJ} \cdot \text{kg}^{-1}$) were calculated using methods developed by others^{21,22} and reported for phases of match-play and quarter for nomadic players only.

Video footage was manually coded by a single researcher for phases of offence, defence, contested play, umpire stoppages, set shots and goal resets using SportsCode (SportsTec Limited, version 9.4.1, Warriewood, Australia). Intra-class correlation coefficients ranged from 0.992-0.865 for absolute reliability and intra-coder typical error of measurement was 6.9%, 8.2%, 9.3%, 9.0%, 2.7% and 1.8%

for offence, defence, contested play, umpire stoppage, set shot and goal reset, respectively. Following coding, a time-stamped transcript of the phases of play was uploaded to a custom-built Microsoft Excel spreadsheet (Microsoft, Redmond, USA). The spreadsheet was imported into the GPS proprietary software and produced a total of 33398, 33642, 67148, 35204, 8252 and 7396 individual player transcripts for offence, defence, contested play, umpire stoppage, set shot and goal reset, respectively.

Data was analysed using a generalized linear mixed effects model (lme4 package) to determine the interaction between phase of play, position and quarter for each physical performance metric. Each individual player was included as a random effect to account for pseudo-replication. The assumptions of normality were verified a priori for parametric analysis. Separate two-way analysis of variance (ANOVA) were then used to test for differences in phases of play (6) by position (3) and then by quarter (4). When significant main effects were observed, pairwise comparisons with Tukey's Honest Significant Difference test were applied. Effect sizes, calculated from the ratio of the mean difference to the pooled standard deviation, were also derived to provide a description of the practical differences between the position and quarter with respect to the phases of match-play. Values of <0.20, 0.21–0.60, 0.61–1.20, 1.21–2.00 and >2.01 represented trivial, small, moderate, large and very large differences, respectively.²³ Statistical analysis was performed using R statistical software (R.3.2.2, R Foundation for Statistical Computing) or Microsoft Excel. Significance was set at $p < 0.05$ for the linear models. Data is presented as mean \pm 95% confidence intervals (CI).

RESULTS

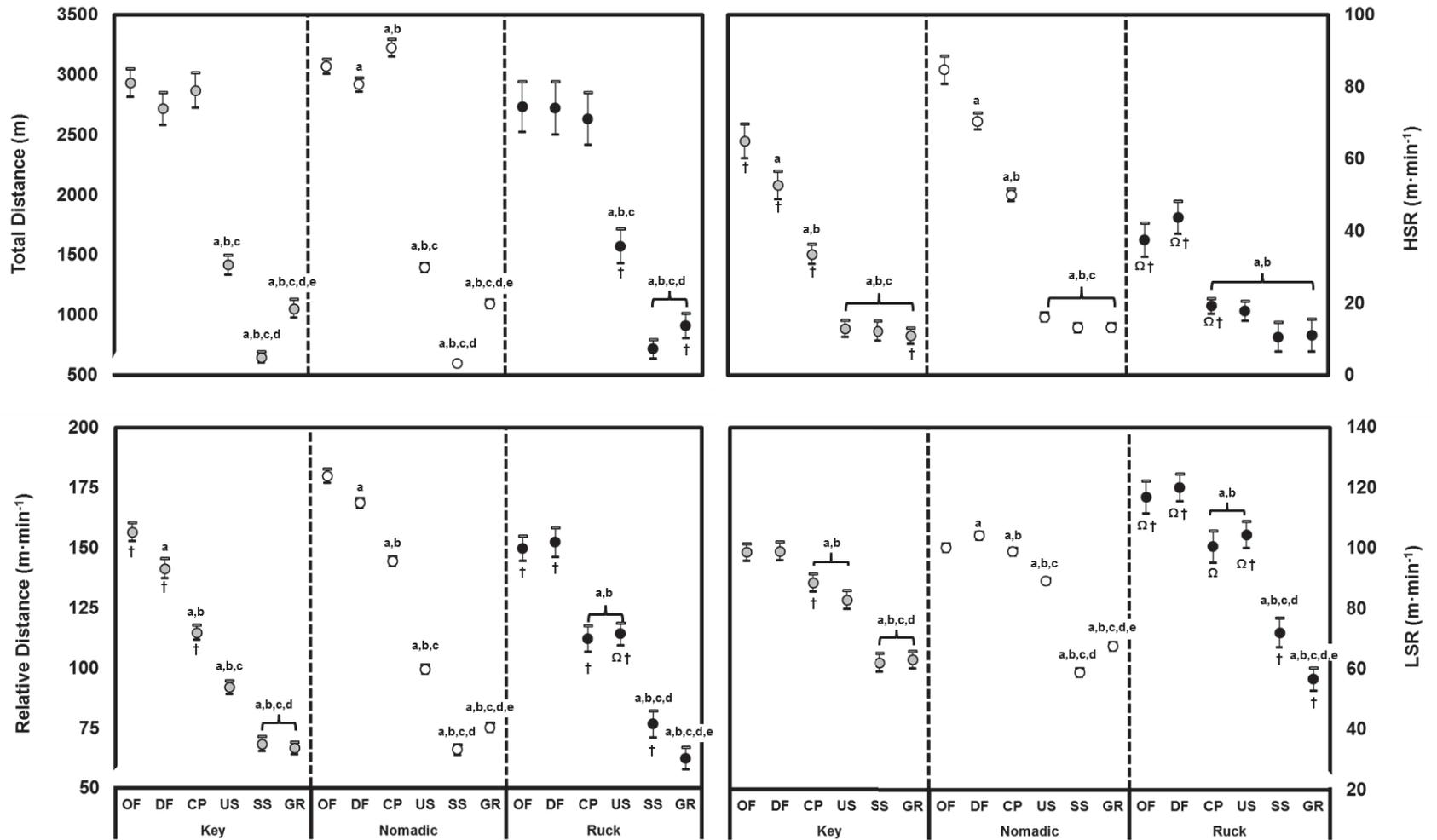
Linear mixed models revealed significant main effects for all positions and quarters of match-play ($F=63.35$, $p < 0.001$). Figure 5.1 shows that for key position players, trivial to small differences existed between offence, defence and contested play for TD (d : 0.09-0.33). Collectively, these phases of match-play comprised >75% of TD covered per match. Umpire stoppages consisted of 12% of TD,

while goal resets and set shots comprised of 9% and 6%, respectively. Relative distance was higher in offence compared to defence, contested play and umpire stoppages (d : 0.55, 1.81, 2.96). Trivial existed between set shots and goal resets ($d=0.11$). HSR followed a similar profile (d : 0.51-1.71), although trivial to small differences existed between umpire stoppage, set shot and goal reset (d : 0.12-0.32). Offence and defence involved the highest LSR, with both higher than the remaining phases of play (d : 0.79-3.12). Small to trivial differences existed in LSR for contested play and umpire stoppages ($d=0.37$), and set shot and goal resets ($d=0.08$).

For nomadic players, small to very large differences were observed between phases with respect to TD (d : 0.20-4.93) (Figure 5.1). TD was highest in contested play (26%), followed by offence (25%), defence (24%), umpire stoppage (11%), goal reset (9%) and set shot (5%). All phases of play differed for relative distance (d : 0.22-5.06) with the highest being offence, followed by defence and contested play. Similarly, HSR was highest in offence, followed by defence ($d=0.26$) and contested play ($d=1.38$). HSR during contested play was higher than umpire stoppages ($d=2.43$), while trivial differences existed between set shot and goal reset ($d=0.12$). Defence involved the highest LSR compared to offence and contested play (d : 0.24-0.37). Umpire stoppages involved more LSR compared to goal reset and set shot (d : 1.55-2.16).

For ruckmen, Figure 5.1 shows trivial differences between the distribution of TD for offence, defence and contested play (all 23-24%; d : 0.02-0.14). Umpire stoppages also involved a higher proportion of TD when compared to goal reset and set shot (d : 1.66-2.37). Trivial differences in relative distance were evident between offence and defence ($d=0.12$), with both being higher than umpire stoppages and contested play (d : 0.64-1.29). Comparatively, differences in HSR during defence and offence ($d=0.09$) and contested play, umpire stoppages, goal resets or set shots were trivial (d : 0.05-0.14). Small effects existed between offence and defence for LSR ($d=0.25$). Differences in contested play and umpire stoppages were trivial ($d=0.14$), which were both higher than set shots and goal resets ($d=1.48, 2.69$).

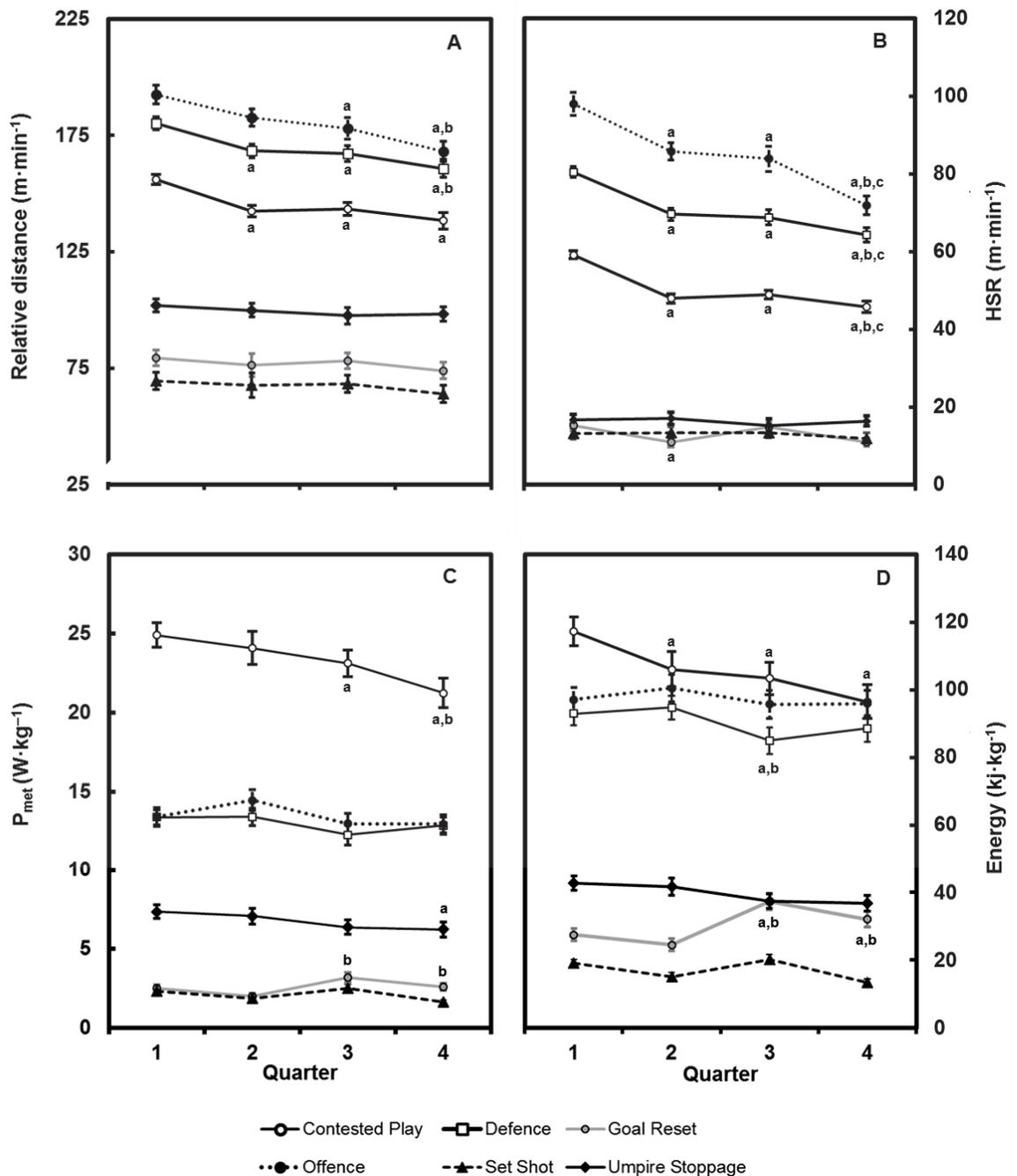
Figure 5.1: Positional analysis of (A) total distance (m), (B) relative distance ($\text{m}\cdot\text{min}^{-1}$), (C) high-speed running ($\text{m}\cdot\text{min}^{-1}$) and (D) low-speed running during the phases of professional Australian Football match-play. Values are mean \pm 95% CI.



OF=Offence, DF=Defence, CP=Contested Play, US=Umpire Stoppage, SS=Set Shot, GR=Goal Reset. ^aSignificantly different to OF, ^bSignificantly different to DF, ^cSignificantly different to CP, ^dSignificantly different to US, ^eSignificantly different to SS ($p<0.05$). Ω = Significantly different to key position players, † = significantly different to nomadic players.

Figure 5.2 shows temporal changes in physical performance measures by quarter and phase of play. Post hoc analysis revealed no differences in total field time for all quarters of match-play ($p=0.46$, d : 0.12-0.20). However, total time in offence was higher in the second ($d=0.36$) and fourth quarter ($d=0.64$) when compared to the first. Additionally, the total time spent in contested play and umpire stoppages during the fourth quarter was less than the first ($d=0.23$; 0.37). Compared to the first quarter, relative distance decreased in the second, third and fourth quarter for offence (d : 0.51-0.90), defence (d : 0.63-0.89) and contested play (d : 0.77-0.92). There were small differences in relative distance for umpire stoppages, goal reset and set shot among the four quarters (d : 0.22-0.25). Reductions in HSR were evident in offence, defence and contested play in the second (d : 0.35-0.78), third (d : 0.44-0.68) and fourth quarters (d : 0.72-0.78), when compared to the first. Offensive running during the fourth quarter was less than all other quarters (d : 0.30-0.76). A reduction in HSR during goal resets was evident during the second ($d=0.32$) and fourth quarters ($d=0.56$) only, while trivial differences were observed for umpire stoppages and set shots. There was a reduction in P_{met} during the fourth quarter ($d=0.66$) for contested play, while increases were observed during the third ($d=0.75$) and fourth quarter ($d=0.35$) during goal resets. In contrast, there were trivial differences in P_{met} observed for offence, defence, umpire stoppages and set shots (d : 0.03-0.19). Energy expenditure during the first quarter was higher than all other quarters during contested play (d : 0.37-0.70), while trivial differences were observed during offence. A reduction in energy expenditure was observed in the third quarter compared to the first ($d=0.33$) and second quarter ($d=0.40$) during defence. In contrast, an increase was observed in the third (d : 0.71-0.91) and fourth quarter (d : 0.34-0.55) goal resets compared to the opening two quarters.

Figure 5.2: Match analysis by quarter for (A) Relative distance ($\text{m}\cdot\text{min}^{-1}$), (B) high-speed running ($\text{m}\cdot\text{min}^{-1}$), (C) average metabolic power (P_{met}) and (D) energy expenditure ($\text{kJ}\cdot\text{kg}^{-1}$) during the phases of professional Australian Football match-play. Values are mean \pm 95% CI. ^asignificantly different to quarter 1, ^bsignificantly different to quarter 2, ^csignificantly different to quarter 3.



DISCUSSION

The present study examined the effect of the phases of AF match-play when considering player position and game quarter in a high calibre professional team via the use of integrated video and GPS analysis. The results revealed that speed and distance variables differ both within and between player positions. Reductions in both speed-based and metabolic power-based estimates during offence, defence and contested match-play were evident but not during selected stoppage periods. Collectively, these results suggest that running performance during the phases of match-play are influenced by player position and game quarter during competitive matches. There are a number of practical outcomes arising from these findings that have implications for sport science and conditioning staff.

Recently, several professional AF studies have described fluctuations in running intensity throughout a match.^{2,16} Similarly, the movement profiles of each position during the phases of match-play highlight the intermittent nature of AF competition (Figure 1). Recently, Delaney et al.¹⁶ described peak relative distances ranging from 199-223 $\text{m}\cdot\text{min}^{-1}$ for a variety of player positions, with midfield players having the highest intensities. In the current study, offence and defence generally involved the highest intensities for all positions (range: 150-180 $\text{m}\cdot\text{min}^{-1}$). While these intensities are lower than those reported by Delaney et al.¹⁶ these findings demonstrate that collective player intensities during these phases of match-play greatly differ from quarter and entire match averages ($\sim 130 \text{ m}\cdot\text{min}^{-1}$).^{2,5,7} It appears highly relevant for conditioning staff to consider both the peak running intensities and the contextual nature of high-intensity periods of AF match-play when planning training for different positions.

It is widely accepted that nomadic positions in AF involve the higher running demands compared to other positions.^{2,3,11} Equally, the current results suggest that nomadic players had the highest total and relative distance during offence, defence and contested match-play when compared to other positions. Furthermore, LSR and HSR were highest during these active elements of match-play. While limited information exists regarding positional movement profiles during the phases

of match-play, these results are not surprising given nomadic players have lower body mass, higher aerobic fitness ability and are interchanged more frequently.^{2,24} Additionally, nomadic players typically have a direct influence on the team's offensive and defensive running patterns, indicating high levels of involvement with determining match-play intensities. Thus, it appears pertinent to consider the timing of rotations for teams to maintain HSR performance during the offensive and defensive elements of AF match-play.

In the present study, key position players had similar movement profiles to nomadic during the phases of match-play, however, the relative distance and HSR intensities were less. These results concur with previous research where key backs and key forwards had less overall running demands than all other positions except for ruckmen.¹⁶ Indeed, key position players typically remain in their defensive or offensive positions on the field to maintain team structures and thus, these movement demands possibly reflect a lesser involvement in active periods of match-play due to their fixed positioning on the field. Nevertheless, key position players often change positions during the match depending on the team's need to increase offensive or defensive numbers. This evidence suggests that the movement profiles of key and nomadic position players are similar, however the intensities performed in each phase of match-play differ. Key position and nomadic players could potentially share similar training approaches, however, considerations to total workloads, intensities and technical skill demands are recommended.

The results of the present study highlight the specific movement profiles of ruckmen during professional AF competition,⁴ as demonstrated by the different profiles between each phase of match-play. Interestingly, ruckmen performed more LSR during offence, defence and umpire stoppages than nomadic and key position players. Additionally, higher relative distances were observed for ruckmen during umpire stoppages. Ruckmen typically attend each stoppage anywhere on the field to compete with the opposition ruckmen and assist the nomadic players to win the ball during contested match-play. Indeed, Dawson et al.²⁵ reported that ruckmen, along with midfield players, have the highest frequency of involvements during the game. Additionally, the difference in running demands for the various phases of play was less in ruckmen when

compared to nomadic and key position players. These findings provide evidence of a more continuous running profile for ruckmen when considering the phases of match-play, and thus has implications for training and conditioning approaches to this specific position in AF.

Previous AF studies have reported reductions in movement profiles across the four quarters of match-play.^{2,3,15} Similarly, our results show decrements in running intensities for both speed-based and metabolic power estimates over the match. However, the reductions in running performance were not identical among the various phases of match-play. Generally, our results show that relative and HSR distance was reduced during offence, defence and contested match-play in the second, third and fourth quarter compared to the first. For the most part, this suggests that running performance is maintained during stoppages across the four quarters, while reductions in movement intensities are isolated to periods of active match-play. These results differ from previous findings where AF players reduced low-intensity activity to potentially maintain high-intensity movements during the latter periods of match-play.^{3,26} It is possible that the evolution of training practices, tactics adopted by either team and relative calibre of the teams may explain this discrepancy, nonetheless, there are notable implications for training prescription originating from these findings.

The present results also show that reductions in speed and distance were only synonymous with metabolic power indices during contested play and not during the other analysed phases. P_{met} and energy expenditure generally did not change over the four quarters during offence and defence phases. With the exception of contested play, these findings suggest that accelerated and decelerated running appears to be maintained over the four quarters during each phase of match-play. In fact, P_{met} and energy expenditure increased during goal resets in the third and fourth quarter when compared to the first and second. These results may be due to positional changes during the later stages of the match due to injury, increased rotations or changes to team structures. Furthermore, recent research has highlighted the value of metabolic power indices in capturing accelerated power efforts during scenarios where spatial constraints may limit player opportunity to reach high speed thresholds.² Indeed, the distance and speed profiles differed from the

metabolic power profiles over the four quarters. Specifically, P_{met} and energy expenditure were notably higher during contested play where players compete for possession of the ball in congested scenarios. Notwithstanding the reliability concerns of these metrics,²⁷ these findings may have implications for elements of competition or training that involve a high proportion of contested play (e.g. during wet weather games) where HSR performance may be limited. Clearly, the incorporation of metabolic power estimates can provide valuable information about AF match-play.

This study presents information pertaining to player position and match quarter during the various phases of match-play in AF and the findings have wide-ranging practical applications. Nevertheless, there are limitations and further research questions related to this study that should be addressed. A single team participated in this study and thus, the results may not be generalisable to other teams competing in the AFL or lower tiers of competition. Nevertheless, the data utilised in this research was from a high calibre team that finished first at the conclusion of the regular season, thus representing a high level of data ecological validity. Future studies involving multiple teams would provide a greater basis for determining whether differences exist between successful and unsuccessful teams. Additionally, several factors may influence the movement profiles during the various phases of match-play including environmental conditions, calibre of the opposition, match location and within match point differential. Future studies should assess the interaction effects of these factors to further understand the demands of the various phases of match-play.

CONCLUSION

This study assessed the influence of position and quarter on the match running demands during the phases of AF match-play in a high calibre team. The results showed that speed and distance physical performance indices differed within positions. Generally, the highest intensities performed by all positions were during offence, defence and then contested match-play. The nomadic players had the highest game intensities, while ruckmen differed to nomadic and key

position players. Additionally, reductions in speed and metabolic power metrics were evident across the four quarters of match-play during offence, defence and contested play, but not during stoppage periods. Collectively, this study demonstrates that physical performance during the phases of match-play are influenced by player position and game quarter during competitive matches.

PRACTICAL APPLICATIONS

- Nomadic players shared similar movement profiles to key position during the phases of match-play; however, the volume and relative movement intensities for key position players was less. Additionally, the movement profiles of ruckmen during the various phases of play represented a more continuous running profile compared to the other positions.
- When considering the evolving match intensity, reductions in running performance existed in active match-play phases (offence, defence and contested play) but not during stoppages. Real-time monitoring of running performance during these periods of match-play could be used to strategically time rotations to mitigate fatigue.
- Metabolic power indices may be useful for quantifying contested elements of AF competition or training where spatial constraints limit high running speeds.

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REFERENCE LIST

1. Gray AJ, Jenkins DG. Match analysis and the physiological demands of Australian football. *Sports Med.* 2010;40(4):347-360.
2. Coutts AJ, Kempton T, Sullivan C, Bilsborough J, Cordy J, Rampinini E. Metabolic power and energetic costs of professional Australian Football match-play. *J Sci Med Sport.* 2015;18(2):219-224.
3. Coutts AJ, Quinn J, Hocking J, Castagna C, Rampinini E. Match running performance in elite Australian Rules Football. *J Sci Med Sport.* 2010;13(5):543-548.
4. Brewer C, Dawson B, Heasman J, Stewart G, Cormack S. Movement pattern comparisons in elite (AFL) and sub-elite (WAFL) Australian football games using GPS. *J Sci Med Sport.* 2010;13(6):618-623.
5. Johnston RJ, Watsford ML, Pine MJ, Spurrs RW, Murphy A, Pruyn EC. Movement demands and match performance in professional Australian football. *Int J sports Med.* 2012;33(2):89-93.
6. Sullivan C, Bilsborough JC, Cianciosi M, Hocking J, Cordy J, Coutts AJ. Match score affects activity profile and skill performance in professional Australian Football players. *J Sci Med Sport.* 2014;17(3):326-331.
7. Johnston RJ, Watsford ML, Austin DJ, Pine MJ, Spurrs RW. Movement Profiles, Match Events, and Performance in Australian Football. *J Strength Cond Res.* 2016;30(8):2129-2137.
8. Bradley PS, Sheldon W, Wooster B, Olsen P, Boanas P, Krstrup P. High-intensity running in English FA Premier League soccer matches. *J Sports Sci.* 2009;27(2):159-168.
9. Di Salvo V, Gregson W, Atkinson G, Tordoff P, Drust B. Analysis of high intensity activity in Premier League soccer. *Int J Sports Med.* 2009;30(3):205-212.
10. Dellal A, Chamari K, Wong dP, et al. Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. *Euro J Sport Sci.* 2011;11(1):51-59.
11. Wisbey B, Montgomery PG, Pyne DB, Rattray B. Quantifying movement demands of AFL football using GPS tracking. *J Sci Med Sport.* 2010;13(5):531-536.
12. Gabbett TJ, Polley C, Dwyer DB, Kearney S, Corvo A. Influence of field position and phase of play on the physical demands of match-play in professional rugby league forwards. *J Sci Med Sport.* 2014;17(5):556-561.
13. Sykes D, Twist C, Nicholas C, Lamb K. Changes in locomotive rates during senior elite rugby league matches. *J Sports Sci.* 2011;29(12):1263-1271.

14. Black GM, Gabbett TJ, Naughton GA, McLean BD. The effect of intense exercise periods on physical and technical performance during elite Australian Football match-play: A comparison of experienced and less experienced players. *J Sci Med Sport*. 2016;19(7):596-602.
15. Aughey RJ. Australian football player work rate: evidence of fatigue and pacing? *Int J Sports Physiol Perform*. 2010;5(3):394-405.
16. Delaney JA, Thornton HR, Burgess DJ, Dascombe BJ, Duthie GM. Duration-specific running intensities of Australian Football match-play. *J Sci Med Sport*. 2017;20(7):689-694.
17. Carling C. Interpreting physical performance in professional soccer match-play: should we be more pragmatic in our approach? *Sports Med*. 2013;43(8):655-663.
18. Kempton T, Coutts AJ. Factors affecting exercise intensity in professional rugby league match-play. *J Sci Med Sport*. 2016;19(6):504-508.
19. Johnston RJ, Watsford ML, Austin D, Pine MJ, Spurrs RW. Player acceleration and deceleration profiles in professional Australian football. *J Sports Med Phys Fitness*. 2015;55(9):931-939.
20. Johnston RJ, Watsford ML, Kelly SJ, Pine MJ, Spurrs RW. Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. *J Strength Cond Res*. 2014;28(6):1649-1655.
21. di Prampero PE, Fusi S, Sepulcri L, Morin JB, Belli A, Antonutto G. Sprint running: a new energetic approach. *J Exp Biol*. 2005;208(Pt 14):2809-2816.
22. Osgnach C, Poser S, Bernardini R, Rinaldo R, di Prampero PE. Energy cost and metabolic power in elite soccer: a new match analysis approach. *Med Sci Sport Exerc*. 2010;42(1):170-178.
23. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sport Exerc*. 2009;41(1):3-13.
24. Dillon PA, Kempton T, Ryan S, Hocking J, Coutts AJ. Interchange rotation factors and player characteristics influence physical and technical performance in professional Australian Rules football. *J Sci Med Sport*. 2018;21(3):317-321.
25. Dawson B, Hopkinson R, Appleby B, Stewart G, Roberts C. Player movement patterns and game activities in the Australian Football League. *J Sci Med Sport*. 2004;7(3):278-291.
26. Duffield R, Coutts AJ, Quinn J. Core temperature responses and match running performance during intermittent-sprint exercise competition in warm conditions. *J Strength Cond Res*. 2009;23(4):1238-1244.
27. Buchheit M, Al Haddad H, Simpson BM, et al. Monitoring accelerations with GPS in football: time to slow down? *Int J Sports Physiol Perform*. 2014;9(3):442-445.

CHAPTER SIX

FACTORS AFFECTING PHYSICAL AND TECHNICAL PERFORMANCE DURING THE PHASES OF AUSTRALIAN FOOTBALL MATCH-PLAY.

Rennie, M.J., Watsford, M.L., Kelly, S.J., Bush, S., Spurrs, R.W. & Bower, R.G. Factors affecting physical and technical performance during the phases of Australian Football match-play. *Under Review*.

ABSTRACT

Objectives: To examine the factors that influence physical and technical profiles during the different phases of Australian Football.

Design: Longitudinal, observational study.

Methods: Phases of offence, defence, contested play, umpire stoppages, set shots and goal resets were manually coded from video footage from 18 professional Australian Football League matches. Global positioning system and technical skill data was time aligned and extracted from each phase of match-play. Linear mixed models in conjunction with a magnitude-based inference approach were used to examine the influence of quarter outcome, opposition calibre and match location on physical and technical performance during the phases of play.

Results: When quarters were won, there was most likely an increase HSR during contested play (effect size [ES]=0.20). There was also an increase in the time spent in offence (ES=0.34), the frequency of handballs during offence (ES=0.26) and the number of set shot kicks for goal (ES=0.26). When competing against higher calibre opposition, there was most likely a small reduction in time spent in offence and goal resets (ES= -0.21, -0.20, respectively). Most likely, there were small reductions in HSR during umpire stoppages (ES= -0.22), and the number of contested possessions and handballs in offence (ES= -0.25 to -0.22) against high calibre teams. Home games were characterised by increases in average speed during contested play (ES=0.20), while there were reductions in average speed and HSR during umpire stoppages (ES= -0.23).

Conclusions: As indicated by the results, many contextual factors influence physical and technical performance during the phases of Australian Football match-play. The findings can be used to create training environments that aim to mitigate the strengths of high calibre opposition and factors associated with matches played away from home.

INTRODUCTION

Match performance in professional Australian Football, like other team sports, involves a myriad of physical,¹⁻³ technical,⁴ tactical^{5, 6} and psychological elements.⁷ While the relative importance of each performance element can depend on specific conditions and scenarios during the match, they are rarely performed in isolation, either during competition or training. As such, research in Australian Football has evolved to assess the interactive effects of various contextual factors on the physical and technical demands of match-play.⁸⁻¹⁰ From a practical perspective, this research has enabled coaches and performance analysts to focus on specific metrics that relate to individual or team performance and effectively guide athlete development and training practices.

It is now commonplace for Australian Football League (AFL) clubs to use commercially available global positioning satellite (GPS) technology and commercial statistics providers to quantify the physical and technical performance of their players. As such, several studies have utilised these technologies in isolation or concomitantly to identify metrics that relate to successful individual^{11, 12} or team performance.⁶ The consensus from the available literature in Australian Football is that technical proficiency, and not physical performance, is most related to individual and team success.^{3, 8} Indeed, technical skills, including the frequency of effective kicks, handballs, disposals, contested and uncontested possessions are reportedly greater in higher calibre players^{3, 9} and when quarters were won by large score margins.⁸ Conversely, physical performance metrics were negatively related to measures of player match performance. In addition, Robertson and colleagues⁶ have shown that a higher number of team kicks and superior goal conversion rate compared to the opposition were the strongest predictors of successful match outcomes. Other technical skill metrics including contested possessions, contested marks, handballs and frequency of penetrating the offensive 50m zone also contributed to the accuracy of the models designed to explain match outcomes. Collectively, this information suggests that technical performance metrics appear to be predictive to individual and team success compared to measures of physical performance.

Related research in professional soccer has shown that contextual factors including time in possession of the ball, match status, match location and the quality of the opposition can influence the technical and physical profiles of players. Specifically, studies have demonstrated reductions in the time spent in possession of the ball when playing against higher calibre opposition and when playing away from home.¹³ Furthermore, other studies in soccer have found that technical indicators are somewhat dependent on the time spent with or without ball possession.¹⁴ To date, only one Australian Football study has also considered the influence of ball possession on physical profiles and quarter success.¹⁵ The results of this study suggest that during successful quarters, the reference team had a greater amount of time in possession and performed more high-speed running without possession (i.e. while defending). As previously discussed, there are tenuous links between physical performance and match success. However, few studies have examined the influence of either the technical or physical profiles in relation to time spent in the different phases of match-play in Australian Football.¹⁵ Recent research has also suggested that considering the technical performance with respect to the time spent in the various phases of match-play may provide more robust information due to the contaminating effects of ball possession¹⁶ and possibly account for differences in tactics that determine high or low possession strategies. Clearly, further research examining the physical and technical demands of Australian Football match-play, while concurrently considering the contextual factors may provide further detail about areas of focus when preparing players for competition. As such, the primary aim of this study was to compare the time spent in the various phases of match-play, along with physical and technical profiles during successful and unsuccessful quarters, against high and low calibre opposition and when playing home or away. It was hypothesised that contextual factors influence physical and technical performance during the phases of match-play.

METHODS

Thirty-three professional AFL players from a single club participated in the study (25 ± 4 years, 88.3 ± 8.7 kg, 1.88 ± 0.08 m). Following approval from the University ethics board, approval

from the participating club and informed consent from all participating players, video, technical skill and match running data was collected from eighteen matches (n=18) during a single in-season of AFL competition.

Each quarter of match-play was classified according to quarter result (win [n=50] or loss [n=22]), opposition calibre (top eight [n=36] or bottom ten [n=36] team according to the final ladder position at the end of the regular season) and match location (home [n=36] or away [n=36]). Video footage from three different camera views (one positioned at halfway, one positioned behind the goals and the broadcaster footage) was downloaded to a desktop computer and phases offence, defence, contested play, umpire stoppages, set shots and goal resets were manually coded using SportsCode (SportsTec Limited, version 9.4.1, Warriewood, Australia). The operational definitions for these phases of play are described in detail elsewhere. A single trained researcher coded all matches to maximise data reliability. The average intra-coder typical error of measurement was 6.9%, 8.2%, 9.3%, 9.0%, 2.7% and 1.8% for offence, defence, contested play, umpire stoppage, set shot and goal reset, respectively. Intra-class correlation coefficients were excellent and ranged from 0.902-0.992.

Movement data was collected using portable GPS units (Minimax S5, Firmware 6.7, Catapult Innovations, 10 Hz, Melbourne, Australia). The GPS unit was fitted into a custom pouch in the players' guernsey between the scapulae. All players wore the same unit for each game during the season to minimise inter-unit error. The data was categorised into average speed ($\text{m}\cdot\text{min}^{-1}$) and high-speed running (HSR) ($>14.4 \text{ km}\cdot\text{h}^{-1}$; $\text{m}\cdot\text{min}^{-1}$) to account for differences in field time. The available satellites and horizontal dilution of precision (HDOP) were 18.2 ± 1.1 (range 14–19) and 1.1 ± 0.1 arbitrary units (AU) (range 0.5–1.2), respectively.¹⁷ The validity and reliability of these GPS units along with the use of the physical performance measures has been reported elsewhere.¹⁸ Technical skill data (number of handballs, kicks, contested possessions and tackles) were provided by the statistics provider for the AFL (Champion Data, Melbourne, Australia). Reliability and validity assessments between Champion Data statistics and the manual coding of

these technical skills by other researchers show an excellent level of agreement (ICC range = 0.947–0.996) and low absolute error (root mean square error range = 1.9–3.2).⁶

All phase of play, GPS and each technical skill event for each player was time aligned from the first centre bounce of each quarter and cumulated if multiple skill events occurred during a single phase of match-play. To integrate the GPS and technical skill data, a time-coded transcript of each phase of match-play was produced from the SportsCode software and uploaded to a custom-built spreadsheet (Microsoft, Redmond, USA). The spreadsheet was formatted and subsequently imported into the GPS proprietary software which produced a file that included movement data for each phase of play for each individual player. A total of 33398, 33642, 67148, 35204, 8252 and 7396 individual player transcripts were analysed for offence, defence, contested play, umpire stoppage, set shot and goal reset, respectively.

Statistical Analysis

Linear mixed models (*lme4* package) with fixed effects for quarter outcome, opposition calibre and location were used to assess the total time spent, average speed and HSR distance ($\text{m}\cdot\text{min}^{-1}$) in each phase of match-play. Individual players were included as a random effect to account for pseudo-replication within the dataset. Further linear models with fixed effects only were used to assess for interactions in technical performance variables. The assumptions of normality were verified prior to parametric analysis. When significant main effects were observed, pairwise comparisons with Tukey's Honest Significant Difference tests were applied. A magnitude-based approach was used to assess the likelihood of a true practical difference existing between the phases of match-play (i.e. greater than the smallest worthwhile change [SWC]). The SWC was calculated as 0.2 times the between-participant SD that was obtained via a separate mixed model for reliability analysis with individual players as random effects. Quantitative chances of real differences in the variables were assessed and qualitatively defined as: <1%, almost certainly not; 1% to 5%, very unlikely; 5% to 25%, probably not; 25% to 75%, possibly; 75% to 97.5%, likely; 97.5% to 99%, very likely; >99%, most likely.¹⁹ If the chances of a variable having higher and lower differences were >5%, the true effect was deemed to be unclear. Effect size values of <0.2,

0.21–0.6, 0.61–1.20, 1.21–2.00 and >2.01 represented trivial, small, moderate, large and very large differences, respectively.¹⁹ Statistical analysis was performed using R statistical software (R.3.2.2, R Foundation for Statistical Computing) or Microsoft Excel. Significance was set at $p < 0.05$ for the linear models. Data is presented as mean \pm 95% confidence intervals (CI) for physical performance and technical skill data.

RESULTS

Significant main effects were observed for quarter outcome, opposition calibre and match location ($F = 86.32$, $p < 0.001$). When comparing quarters won and lost, there were clear differences in field time, HSR and technical skills (Table 6.1). Specifically, time spent in phases of offence and set shot were *most likely* higher during quarters won (ES = 0.21–0.34). Additionally, HSR was *most likely* greater during contested play during quarters won (ES = 0.20). There was *most likely* a higher number of set shot kicks (ES = 0.26) and handballs during offence (ES = 0.26) in quarters won compared to quarters lost

Table 6.1: Differences in physical and technical performance measures when comparing between successful and unsuccessful quarters during the phases of match-play.

Variable	Phase of Play	Quarter Result		Difference between Quarter Win and Loss			
		Win (Mean ± 95% CI)	Loss (Mean ± 95% CI)	Effect Statistic	Effect Size (d)	Likelihood of Difference	Outcome
Field time (sec)	Offence	275 (271-279)	254 (248-261)	21.0	0.34	(100/0/0)	<i>Most likely small</i>
	Defence	259 (255-264)	260 (254-265)	-1.0	-0.01	(29/21/50)	<i>Unclear</i>
	Contested Play	331 (325-336)	338 (331-345)	-7.0	-0.09	(4/5/91)	<i>Likely trivial</i>
	Umpire Stoppage	208 (203-213)	202 (196-207)	6.2	0.09	(92/6/3)	<i>Likely trivial</i>
	Set Shot	140 (137-143)	131 (125-135)	9.0	0.21	(100/0/0)	<i>Most likely small</i>
	Goal Reset	215 (209-221)	207 (198-215)	8.4	0.09	(92/4/4)	<i>Likely trivial</i>
Average speed (m·min)	Offence	178 (175-180)	176 (172-179)	2.1	0.06	(70/23/7)	<i>Unclear</i>
	Defence	173 (171-176)	174 (171-178)	-1.5	-0.04	(11/29/60)	<i>Unclear</i>
	Contested Play	146 (144-147)	144 (141-147)	2.0	0.06	(72/24/4)	<i>Possibly trivial</i>
	Umpire Stoppage	106 (104-108)	105 (103-107)	1.0	0.04	(50/43/7)	<i>Unclear</i>
	Set Shot	70.1 (68.2-71.9)	72.6 (69.6-75.5)	-2.5	-0.09	(2/17/80)	<i>Likely trivial</i>
	Goal Reset	79.4 (73.2-76.5)	77.0 (74.5-79.5)	2.4	-0.08	(82/17/1)	<i>Likely trivial</i>
HSR (m·min)	Offence	77.1 (74.6-79.5)	72.6 (69.0-76.3)	4.5	0.12	(94/5/1)	<i>Likely trivial</i>
	Defence	70.2 (68.3-72.2)	68.6 (65.9-71.4)	1.6	0.05	(64/30/7)	<i>Unclear</i>
	Contested Play	47.6 (46.1-49.0)	43.6 (41.8-45.5)	4.0	0.20	(99/1/0)	<i>Most likely small</i>
	Umpire Stoppage	15.9 (14.7-17.1)	14.9 (13.7-16.1)	1.0	0.06	(50/49/1)	<i>Possibly trivial</i>
	Set Shot	11.9 (10.7-13.1)	12.3 (10.7-14.0)	-0.4	-0.03	(9/63/28)	<i>Unclear</i>
	Goal Reset	11.2 (10.2-12.2)	9.6 (8.3-10.9)	2.9	0.11	(76/24/0)	<i>Likely trivial</i>
Kicks (n)	Offence	29.9 (28.0-31.8)	25.4 (22.6-28.2)	4.5	0.15	(98/2/0)	<i>Very likely trivial</i>
	Contested Play	12.7 (11.5-13.9)	12.5 (10.6-14.3)	0.2	0.01	(25/62/13)	<i>Unclear</i>
	Set Shot	3.6 (2.9-4.3)	1.5 (0.8-2.1)	2.2	0.26	(99/1/0)	<i>Most likely small</i>
Handballs (n)	Offence	22.7 (21.2-24.3)	16.8 (14.7-19.0)	5.9	0.26	(100/0/0)	<i>Most likely small</i>
	Contested Play	16.8 (15.3-18.2)	15.3 (13.3-17.4)	1.4	0.07	(63/34/3)	<i>Possibly trivial</i>
Contested possessions (n)	Offence	14.2 (13.0-15.4)	12.9 (11.2-14.7)	1.3	0.07	(59/39/2)	<i>Possibly trivial</i>
	Defence	3.4 (2.7-4.0)	3.1 (2.2-4.0)	0.2	0.03	(9/90/1)	<i>Likely trivial</i>
	Contested Play	17.0 (15.5-18.6)	17.4 (15.2-19.6)	-0.3	-0.01	(16/52/32)	<i>Unclear</i>
Tackles (n)	Defence	1.3 (0.9-1.6)	2.2 (1.5-2.9)	-0.9	-0.15	(0/59/41)	<i>Possibly trivial</i>
	Contested Play	11.5 (10.4-12.7)	12.7 (10.8-14.7)	-1.2	-0.07	(3/39/58)	<i>Possibly trivial</i>

When competing against top 8 teams, there were *most likely* small reductions in time spent in phases of offence (ES= -0.21) and goal resets (ES= -0.20), while there was *most likely* a small increase in time spent in contested play (ES = 0.26) (Table 6.2). Reductions were also observed in HSR during umpire stoppages (ES= -0.22), handballs during offence (ES = -0.25) and contested possessions during offence (ES = -0.21). *Most likely* trivial to unclear differences were evident for average speed, kicks or tackles when accounting for opposition calibre.

Table 6.2: Differences in physical and technical performance measures when comparing quarters against top-8 and bottom-10 ranked teams during the phases of match-play.

Variable	Phase of Play	Opposition Calibre		Difference between Top 8 and Bottom 10 opposition			
		Top 8 (Mean ± 95% CI)	Bottom 10 (Mean ± 95% CI)	Effect Statistic	Effect Size (d)	Likelihood of Difference	Outcome
Field time (sec)	Offence	260 (255-265)	274 (269-279)	-14	-0.21	(0/0/100)	<i>Most likely</i> small
	Defence	260 (256-264)	256 (251-261)	4	0.06	(82/12/6)	<i>Unclear</i>
	Contested Play	348 (342-355)	325 (318-332)	23	0.26	(100/0/0)	<i>Most likely</i> small
	Umpire Stoppage	201 (196-207)	212 (207-218)	-11	-0.16	(0/0/100)	<i>Most likely</i> trivial
	Set Shot	134 (129-138)	137 (133-141)	-3	-0.06	(10/16/74)	<i>Unclear</i>
	Goal Reset	201 (194-209)	220 (213-227)	-19	-0.20	(0/0/100)	<i>Most likely</i> small
Average speed (m·min)	Offence	178 (175-180)	177 (174-180)	0.7	0.02	(44/38/19)	<i>Unclear</i>
	Defence	175 (172-177)	174 (171-176)	1	0.03	(50/36/14)	<i>Unclear</i>
	Contested Play	147 (144-149)	144 (142-146)	2.7	0.10	(89/10/1)	<i>Likely</i> trivial
	Umpire Stoppage	104 (102-106)	108 (106-109)	-3.6	-0.16	(0/2/98)	<i>Very likely</i> trivial
	Set Shot	73.0 (70.7-75.3)	70.6 (68.3-72.8)	2.4	0.08	(80/18/2)	<i>Likely</i> trivial
	Goal Reset	78.7 (76.7-80.8)	74.0 (72.2-75.8)	4.7	0.19	(100/0/0)	<i>Most likely</i> trivial
HSR (m·min)	Offence	73.8 (70.9-76.7)	78.1 (75.3-81.0)	-4.3	-0.12	(1/5/94)	<i>Likely</i> trivial
	Defence	69.3 (67.1-71.5)	70.4 (68.2-72.7)	-1.1	-0.04	(10/38/52)	<i>Unclear</i>
	Contested Play	46.2 (44.6-47.9)	46.9 (45.2-48.6)	-0.7	-0.03	(8/52/40)	<i>Unclear</i>
	Umpire Stoppage	13.9 (12.9-14.9)	17.6 (16.1-19.1)	-3.7	-0.22	(0/0/100)	<i>Most likely</i> small
	Set Shot	11.8 (10.6-13.0)	12.6 (11.1-14.1)	-0.8	-0.04	(3/55/42)	<i>Possibly</i> trivial
	Goal Reset	10.5 (9.3-11.7)	11.8 (10.5-13.0)	-1.3	-0.08	(0/36/63)	<i>Possibly</i> trivial
Kicks (n)	Offence	26.8 (24.6-29.0)	29.6 (27.4-31.8)	-2.8	-0.10	(1/13/86)	<i>Very likely</i> trivial
	Contested Play	13.6 (12.1-15.2)	11.9 (10.7-13.2)	1.7	0.09	(74/26/1)	<i>Possibly</i> trivial
	Set Shot	3.0 (2.2-3.7)	2.9 (2.2-3.6)	0.1	0.01	(4/94/2)	<i>Likely</i> trivial
Handballs (n)	Offence	17.5 (15.8-19.2)	23.3 (21.5-25.1)	-5.8	-0.25	(0/0/100)	<i>Most likely</i> small
	Contested Play	18.0 (16.2-19.9)	14.4 (12.9-15.9)	3.6	0.20	(98/2/0)	<i>Very likely</i> small
Contested possessions (n)	Offence	11.9 (10.5-13.2)	15.3 (13.9-16.7)	-3.4	0.21	(0/1/99)	<i>Most likely</i> small
	Defence	3.8 (3.0-4.6)	2.9 (2.2-3.5)	0.9	0.10	(42/58/0)	<i>Possibly</i> trivial
	Contested Play	18.4 (16.5-20.3)	15.9 (14.3-17.6)	2.5	0.11	(87/12/0)	<i>Likely</i> trivial
Tackles (n)	Defence	1.8 (1.3-2.3)	1.4 (1.0-1.8)	0.4	0.10	(3/97/0)	<i>Likely</i> trivial
	Contested Play	13.8 (11.9-14.9)	10.8 (9.5-12.1)	3	0.14	(98/2/0)	<i>Very likely</i> trivial

In home games, there was *most likely* a small increase in average speed and time spent in contested play (ES = 0.20–0.21) (Table 6.3). In contrast, there were *most likely* small reductions in average speed and HSR during umpire stoppages (ES= -0.23). There were *very likely* trivial to unclear differences in technical performance measures when accounting for match location.

Table 6.3: Differences in physical and technical performances measures when comparing between home and away matches during the phases of match-play.

Variable	Phase of Play	Match location		Difference between Home and Away matches			
		Home (Mean ± 95% CI)	Away (Mean ± 95% CI)	Effect Statistic	Effect Size (<i>d</i>)	Likelihood of Difference	Outcome
Field time (sec)	Offence	272 (266-277)	264 (260-269)	7.4	0.12	(96/3/1)	<i>Likely</i> trivial
	Defence	258 (253-263)	258 (254-262)	-0.4	-0.01	(34/23/43)	<i>Unclear</i>
	Contested Play	345 (339-352)	328 (321-335)	17.3	0.21	(100/0/0)	<i>Most likely</i> small
	Umpire Stoppage	208 (203-213)	207 (201-212)	1.2	0.02	(52/20/28)	<i>Unclear</i>
	Set Shot	134 (130-138)	135 (131-139)	-1.2	-0.02	(22/25/53)	<i>Unclear</i>
	Goal Reset	217 (209-224)	205 (198-211)	11.7	0.12	(98/1/1)	<i>Very likely</i> trivial
Average speed (m·min)	Offence	176 (174-179)	178 (175-181)	-2	-0.06	(6/25/69)	<i>Unclear</i>
	Defence	173 (170-175)	176 (173-178)	-2.8	-0.08	(2/15/83)	<i>Likely</i> trivial
	Contested Play	148 (146-150)	143 (141-145)	5.3	0.20	(100/0/0)	<i>Most likely</i> small
	Umpire Stoppage	104 (102-105)	108 (106-110)	-4.5	-0.23	(0/0/100)	<i>Most likely</i> small
	Set Shot	72.9 (70.5-75.2)	70.4 (68.2-72.5)	2.5	0.08	(82/17/2)	<i>Likely</i> trivial
	Goal Reset	76.9 (74.8-79.0)	75.8 (73.9-77.6)	1.1	0.04	(53/40/7)	<i>Unclear</i>
HSR (m·min)	Offence	76.4 (73.6-79.2)	75.2 (72.3-78.1)	1.1	0.03	(53/32/15)	<i>Unclear</i>
	Defence	69.5 (67.3-71.8)	70.0 (67.8-72.2)	-0.4	-0.01	(19/45/36)	<i>Unclear</i>
	Contested Play	48.0 (46.4-49.6)	45.2 (43.5-47.0)	2.8	0.13	(93/7/0)	<i>Likely</i> trivial
	Umpire Stoppage	13.9 (13.0-14.9)	17.6 (16.1-19.2)	-3.7	-0.23	(0/0/100)	<i>Most likely</i> small
	Set Shot	12.5 (11.1-13.8)	12.0 (10.6-13.4)	0.5	0.03	(30/63/7)	<i>Unclear</i>
	Goal Reset	11.0 (9.9-12.2)	11.8 (10.4-13.1)	-0.7	-0.04	(3/58/39)	<i>Possibly</i> trivial
Kicks (n)	Offence	29.9 (27.6-32.3)	26.8 (24.7-28.9)	3.1	0.11	(91/9/1)	<i>Likely</i> trivial
	Contested Play	12.9 (11.5-14.4)	12.5 (11.2-13.9)	0.4	0.02	(29/63/8)	<i>Unclear</i>
	Set Shot	3.3 (2.5-4.1)	2.6 (1.9-3.2)	0.7	0.08	(29/71/0)	<i>Possibly</i> trivial
Handballs (n)	Offence	21.0 (19.1-22.8)	20.3 (18.5-22.1)	0.7	0.03	(40/51/10)	<i>Unclear</i>
	Contested Play	18.1 (16.2-19.9)	14.4 (12.9-15.9)	3.7	0.17	(99/1/0)	<i>Very likely</i> trivial
Contested possessions (n)	Offence	13.1 (11.8-14.5)	14.2 (12.8-15.7)	-1.1	-0.06	(2/46/52)	<i>Possibly</i> trivial
	Defence	2.8 (2.2-3.5)	3.7 (2.9-4.4)	-0.8	-0.09	(0/62/38)	<i>Possibly</i> trivial
	Contested Play	18.3 (16.3-20.3)	16.0 (14.4-17.6)	2.3	0.1	(84/15/1)	<i>Likely</i> trivial
Tackles (n)	Defence	1.4 (1.0-1.8)	1.8 (1.3-2.2)	-0.4	-0.06	(0/97/3)	<i>Likely</i> trivial
	Contested Play	12.9 (11.4-14.4)	11.2 (9.8-12.5)	1.7	0.09	(77/23/0)	<i>Likely</i> trivial

DISCUSSION

This case-study examined the influence of contextual factors on physical and technical performance measures during the phases of match-play in professional Australian Football. The results revealed a myriad of factors that could be considered by coaches and performance analysts to potentially maximise the likelihood of a successful match outcome, when playing against high calibre opposition and when playing away from home.

In the present study, there were small increases in time spent in offence and set shot phases of play during successful quarters. Disparate findings have been reported in other invasion sports where more successful teams spent more time in possession of the ball.²⁰ Factors associated with higher time spent in possession may include greater ability at recovering possession during defensive elements of match-play and more efficient technical skill that permits the maintenance of possession.²¹ Indeed, an increase in the number of handballs during offence in successful quarters was observed, which may relate to the team's ability to maintain possession and move the ball quickly away from congested areas on the field. Furthermore, our findings suggest that HSR during contested play was elevated during successful quarters of match-play. In contrast, previous research in Australian Football has suggested that elevated physical activity profiles are related unsuccessful match performance from both a team⁸ and individual perspective.^{3, 9} However, these studies did not delineate physical performance within the phases of match-play. Indeed, other studies in both Australian football and soccer have found that match running performance during specific elements of match-play may be related to match success.^{15, 22} The differences in these study findings may be related to the methodology used to demarcate match running performance, tactics used by the respective teams and changes in team personnel over time.^{3, 11} Finally, we observed an increase in the number of set shot kicks during successful quarters of match-play. Similarly, Robertson et al.⁶ found that kicks and goal conversion were the most influential in explaining match outcomes in Australian Football. Taken

together, this information highlights the importance for teams to create opportunities to take set shots at goal and equally, convert their chances to maximise the likelihood of favourable results.

With respect to high calibre opposition whom finished in the top 8, reductions in the time spent in offence and goal resets were evident. In contrast, there was an increase in the time spent in contested play. Similarly, playing against strong opposition has been associated with a reduction in time spent in possession of the ball in professional soccer and greater likelihood of an unsuccessful match outcome.^{21, 23} Furthermore, the current results suggest that playing against higher calibre opposition resulted in a decrease of the number of handballs during offence and concomitantly, increased the number of handballs during contested play. Moreover, an increase in the time spent in contested play was observed when competing against high calibre opposition. According to the definition of contested play used in this study, this information may suggest that players are under more pressure or have less time to dispose of the ball by hand effectively when competing against higher calibre opposition teams. While there is limited information pertaining to Australian Football in this area, studies in professional soccer suggest that higher calibre teams are more effective recovering possession when the ball is turned over.²⁴ It is possible then that higher calibre teams can apply more pressure, either actual or perceived, to the opposition that leads to changes in possession. Further research is clearly warranted to determine the physical and technical profiles of high and low calibre teams with respect to the phase of match-play in Australian Football. Nevertheless, the information provided here could be used to develop training drills that replicate the demands of competing against higher calibre opposition. Coaches could manipulate player density during training drills to reduce the available time for players to dispose of the ball and increase pressure when attempting to gain possession of the football. Additionally, goal kicking practice under direct supervision may also increase the perceived pressure experienced by the player to convert the set shot kick for goal.²⁵

Reductions in average speed and time spent in contested play were evident in matches played away from home. These results somewhat agree with previous research in soccer²⁶ and rugby league²⁷

where the authors observed reductions in average speed and HSR distance in matches played away from home. Home advantage in professional Australian Football has been illustrated by a greater probability of winning matches or average point margin when compared to playing away, particularly for teams situated outside of Victoria.²⁸ Indeed, 61% of the reference team's losses occurred away from home with similar findings reported in other team sports.^{24,29} Potential mechanisms that support home advantage include crowd effects, territoriality and ground familiarity.^{28,30} While the literature describing home advantage in professional Australian Football is limited, it may be possible that the increase in average speed during contested play observed in this study is related to the effects of the crowd, psychological territoriality, increased self-confidence, vigour and assertive attitude during home matches.^{31,32} Comparatively, the reductions in HSR during umpire stoppages may be related to greater knowledge of the environment including the familiarity with team structures in relation to pitch dimensions.²⁴ Unlike professional soccer and rugby league, the pitch size is not identical throughout the AFL competition. It is worth noting that the ground size of the reference team, based on the length and width of the field, is one of the smallest in the AFL. It may be possible that the displacement between repetitive umpire stoppages may be reduced due to a smaller ground and may therefore explain the reduction in HSR during this element of match-play when playing at home. Further research is clearly warranted to determine whether these differences are evident across the entire AFL. Nevertheless, modifying the size of the training pitch to replicate the field size in preparation for an upcoming match may be useful to improve familiarity with ground sizes.

The data provided in the present study is the first to describe the influence of contextual factors on the physical and technical demands during the phases of Australian Football match-play. The practical recommendations offered herein can be applied by coaches and sport scientists during training to improve the likelihood of quarter success, create environments that are reflective of competing against high calibre opposition and when playing away from home. Future collaborative studies should aim to integrate datasets from multiple clubs across the AFL to validate the results

presented here. As such, a limitation of this study was the use of a single club and therefore the results may only be applicable to the club and players involved due to various tactical approaches and physiological profiles of different teams. Nevertheless, this season-long analysis of professional Australian Football match-play is the first to assess the phases of match-play together with contextual factors that provide a wide range of practical implications. Indeed, these findings can directly influence training design to improve the likelihood of quarter success, create training environments that replicate playing against high calibre opposition and improve familiarity when playing away from home.

CONCLUSION

For the first time, this research examined the influence of contextual factors on the physical and technical performance during the various phases of match-play in Australian Football. The results show that successful quarters of match-play were characterised by higher levels of possession, skill involvements and movement intensity during contested play. Playing against high calibre opposition involved an increase in several areas relating to contested elements of match-play and finally, match running demands were higher during umpire stoppages when playing away from home. Collectively, these findings can be used to inform training practices and design specific drills that optimise Australian Football performance.

PRACTICAL APPLICATIONS

- Training programs should aim to maximise a team's ability to maintain possession, create set shot kick opportunities at goal and maintaining high-speed running during contested elements of match-play.

- To prepare for competition against high calibre teams, training programs should aim to optimise a team's ability to win possession during contested play scenarios. Technical skills such as handballing should be practiced under heightened pressure conditions.
- The manipulation of field sizes in preparation for upcoming matches away from home may improve player familiarity with pitch dimensions.

REFERENCE LIST

1. Coutts AJ, Quinn J, Hocking J, et al. Match running performance in elite Australian Rules Football. *J Sci Med Sport*. 2010; 13(5):543-548.
2. Coutts AJ, Kempton T, Sullivan C, et al. Metabolic power and energetic costs of professional Australian Football match-play. *J Sci Med Sport*. 2015; 18(2):219-224.
3. Johnston RJ, Watsford ML, Pine MJ, et al. Movement demands and match performance in professional Australian football. *Int J Sports Med*. 2012; 33(2):89-93.
4. Kempton T, Sullivan C, Bilsborough JC, et al. Match-to-match variation in physical activity and technical skill measures in professional Australian Football. *J Sci Med Sport*. 2015; 18(1):109-113.
5. O'Shaughnessy DM. Possession Versus Position: Strategic Evaluation in AFL. *J Sports Sci Med*. 2006; 5(4):533-540.
6. Robertson S, Back N, Bartlett JD. Explaining match outcome in elite Australian Rules football using team performance indicators. *J Sports Sci*. 2016; 34(7):637-644.
7. Gucciardi DF, Gordon S, Dimmock JA. Towards an Understanding of Mental Toughness in Australian Football. *J Appl Sport Psychol*. 2008; 20(3):261-281.
8. Sullivan C, Bilsborough JC, Cianciosi M, et al. Match score affects activity profile and skill performance in professional Australian Football players. *J Sci Med Sport*. 2014; 17(3):326-331.
9. Sullivan C, Bilsborough JC, Cianciosi M, et al. Factors affecting match performance in professional Australian football. *Int J Sports Physiol Perform*. 2014; 9(3):561-566.
10. Dillon PA, Kempton T, Ryan S, et al. Interchange rotation factors and player characteristics influence physical and technical performance in professional Australian Rules football. *J Sci Med Sport*. 2017. doi:10.1016/j.jsams.2017.06.008
11. Johnston RJ, Watsford ML, Austin DJ, et al. Movement Profiles, Match Events, and Performance in Australian Football. *J Strength Cond Res*. 2016; 30(8):2129-2137.
12. Robertson S, Gupta R, McIntosh S. A method to assess the influence of individual player performance distribution on match outcome in team sports. *J Sports Sci*. 2016; 34(19):1893-1900.
13. Lago C. The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *Journal of Sports Sciences*. 2009; 27(13):1463-1469.

14. Carling C, Dupont G. Are declines in physical performance associated with a reduction in skill-related performance during professional soccer match-play? *J Sports Sci.* 2011; 29(1):63-71.
15. Gronow D, Dawson B, Heasman J, et al. Team movement patterns with and without ball possession in Australian Football League players. *Int J Perform Anal Sport.* 2014; 14(3):635-651.
16. Bradley PS, Lago-Penas C, Rey E, et al. The effect of high and low percentage ball possession on physical and technical profiles in English FA Premier League soccer matches. *J Sports Sci.* 2013; 31(12):1261-1270.
17. Malone JJ, Lovell R, Varley MC, et al. Unpacking the Black Box: Applications and Considerations for Using GPS Devices in Sport *Int J Sports Physiol Perform.* 2016; 12(Suppl 2):S2-18-S12-26.
18. Johnston RJ, Watsford ML, Kelly SJ, et al. Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. *J Strength Cond Res.* 2014; 28(6):1649-1655.
19. Hopkins WG, Marshall SW, Batterham AM, et al. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009; 41(1):3-13.
20. Collet C. The possession game? A comparative analysis of ball retention and team success in European and international football, 2007–2010. *Journal of Sports Sciences.* 2013; 31(2):123-136.
21. Lago C, Martin R. Determinants of possession of the ball in soccer. *J Sports Sci.* 2007; 25(9):969-974.
22. Rampinini E, Impellizzeri FM, Castagna C, et al. Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *J Sci Med Sport.* 2009; 12(1):227-233.
23. Bradley PS, Lago-Penas C, Rey E, et al. The influence of situational variables on ball possession in the English Premier League. *J Sports Sci.* 2014; 32(20):1867-1873.
24. Gómez MA, Gómez-Lopez M, Lago C, et al. Effects of game location and final outcome on game-related statistics in each zone of the pitch in professional football. *Eur J Sport Sci.* 2012; 12(5):393-398.
25. Hill-Haas SV, Dawson B, Impellizzeri FM, et al. Physiology of small-sided games training in football: a systematic review. *Sports Med.* 2011; 41(3):199-220.
26. Lago C, Casais L, Dominguez E, et al. The effects of situational variables on distance covered at various speeds in elite soccer. *Eur J Sport Sci.* 2010; 10(2):103-109.

27. Kempton T, Coutts AJ. Factors affecting exercise intensity in professional rugby league match-play. *J Sci Med Sport*. 2016; 19(6):504-508.
28. Clarke SR. Home advantage in the Australian Football League. *J Sports Sci*. 2005; 23(4):375-385.
29. Pollard R, Gómez MA. Home advantage in football in South-West Europe: Long-term trends, regional variation, and team differences. *Eur J Sport Sci*. 2009; 9(6):341-352.
30. Pollard R, Pollard G. Long-term trends in home advantage in professional team sports in North America and England (1876-2003). *J Sports Sci*. 2005; 23(4):337-350.
31. Terry PC, Walrond N, Carron AV. The influence of game location on athletes' psychological states. *J Sci Med Sport*. 1998; 1(1):29-37.
32. Sampaio J, Ibanez SJ, Gomez MA, et al. Game location influences basketball players' performance across playing positions. *International Journal of Sport Psychology*. 2008; 39(3):205-216.

CHAPTER SEVEN

GENERAL DISCUSSION

7.1 MAIN FINDINGS

Match performance in professional Australian Football involves a dynamic and complex interaction between the physical, technical and tactical constructs that are inherent to the rules and structure of the game. Several studies have assessed causal factors related to these performance constructs and more recently, others have investigated contextual factors that contribute to changes in performance. However, the influence of the time spent in the different phases of match-play on the physical and technical demands of competition has yet to be empirically assessed. This is surprising given that a number of studies in professional soccer and rugby league have shown that the game context influences physical and technical profiles. Therefore, this thesis aimed to investigate the influence of the time spent in the phases of match-play on the physical, technical and tactical demands of Australian Football competition. A series of applied research studies were conducted to improve understanding of the phases of Australian Football match-play. The four studies followed a logical sequence by first assessing the reliability of coding the phases of play and by providing a descriptive analysis of the frequency and average duration of the various phases of match-play (*study one*). A series of operational definitions for the phases of play were developed using input from coaching staff and previously published literature that purported the different elements of match-play. This information was imperative to develop reliable methodology that would be pivotal to the data extraction in the following three studies. By incorporating the coding methodology outlined in *study one*, GPS and technical skill data were derived from each individual phase of match-play for each player during a season of Australian Football competition (*study two*). This data served to describe the distribution of physical and technical performance during the individual phases of match-play. Furthermore, the elucidation of the physical and technical demands of the phases of play permitted the identification of common activity and recovery cycles, which provide practical information to coaches about the normative, maximum and minimum continuous periods of match-play and periods of stoppages. *Study three* elaborated on the findings of *study two* by considering contextual factors

including player position and match quarter. While previous research has established differences in the match-running demands between position, this research identified differences between the phases of play both within positions (e.g. nomadic offence vs nomadic defence) and between positions (e.g. nomadic offence vs key position offence). Furthermore, the average physical output across the four quarters within each phase of match-play provided new information pertaining to match-related fatigue in Australian Football. Finally, *study four* investigated differences in physical and technical performance during the various phases of play and accounted for quarter success (win or loss), opposition calibre (top 8 or bottom 10 teams) and match location (home and away). The final study determined variables that discriminated successful performances, differences when playing against high calibre opposition and when playing away from home. Collectively, the four studies provided a unique approach to the analysis of Australian Football match-play and contribute to current understanding of the various constructs that relate to performance. Each subcomponent of the four studies are discussed herein with respect to the main findings of topical importance.

CODING THE PHASES OF PROFESSIONAL AUSTRALIAN FOOTBALL MATCH-PLAY

The adoption of notational coding methods is highly dependent on the reliability of the proposed methodology. As such, *study one* in this thesis assessed the ability of an experienced researcher to code the phases of match-play. To assess intra-coder reliability, ten quarters from ten different matches were coded on two occasions separated by a 6-month wash-out period. The intra-class correlation coefficients between both coding assessments data revealed that the phases of Australian Football match-play can be coded with an acceptable level of precision ($r = 0.90 - 0.99$). Additionally, the TEM of the total time spent in each phase of play represented good to moderate reliability (%TEM = 1.8 - 9.3). No systematic error was detected between the two different coding assessments suggesting that there was no learning or recall effects between the two coding assessments. Consequently, experienced performance analysts in Australian Football can utilise the operational

definitions identified in this study to code the phases of match-play. Given the acceptable reliability, these methods present the potential for future time motion studies in Australian Football to integrate these phases of play to better understand match related-fatigue and identify performance indicators related to the physical, technical and tactical aspects of match-play.

DURATION AND FREQUENCY OF THE PHASES OF PROFESSIONAL AUSTRALIAN FOOTBALL MATCH-PLAY

The intermittent nature of Australian Football has been described using manual notation data and information collected from microtechnology including GPS. However, there is limited information regarding the intermittent nature of match-play in relation to the phases of match-play. This information is important to contextualise the intermittent nature of match-play. The intermittent demands of Australian Football have been described using a variety of methods including the number of high-intensity efforts and proportions of high and low-speed running. However, the game context that underpins this intermittent match profile is generally unknown. The game context of Australian Football is likely to be linked with the rules and regulations of the game that contribute to the maintenance of possession, duration of stoppages and abrupt shifts in the context of play. *Study two* demonstrated that the intermittent nature of Australian Football is underpinned by frequent and abrupt shifts in the game context. Indeed, the results indicated that the phase of play changed more than 500 times per match, which reflects frequent changes in possession and periods of stoppages. Furthermore, stoppages comprised approximately 40% of the total game time. This information has consequences for current time motion studies that have not considered stoppage time as the inclusion of these time periods may lead to a misrepresentation of ‘match-play’ intensities. Furthermore, studies assessing match-related fatigue should consider the phases of match-play in their analysis as reductions in match intensities may reflect a greater amount of time spent in stoppages, thereby diminishing player opportunities to perform high-intensity movements. These findings suggest that the intermittent nature of Australian Football match-play may be related to the frequent changes in

phase of play. Additionally, these findings also highlight considerations for future research that examines physical and technical performance in Australian Football.

DISTRIBUTION OF PHYSICAL AND TECHNICAL DEMANDS OF PROFESSIONAL AUSTRALIAN FOOTBALL

Previous research has described the physical and technical demands of Australian Football in a high level of detail; however, no study has described the distribution of these demands during the different phases of match-play. This research is important to understand the match context where physical and technical performance takes place. *Study two* showed that the highest proportion of game time was contested play, followed by offence, defence and umpire stoppages. Furthermore, very large differences existed between all phases of match-play. Offence and defence involved the largest proportions of high-speed running, while contested play involved the highest number of accelerations (45%), decelerations (42%) and tackles (87%). The results also revealed that a large proportion of technical skills occurred during contested elements of match-play. These results underline the importance of considering the context of physical and technical performance in Australian Football. Subsequently, sport-specific training approaches can be adopted that reflect common scenarios during competitive match-play. In addition, the large difference in physical and technical demands between each phase of play suggests that the intermittent nature of Australian Football competition is closely linked to the current phase of match-play. To accurately describe the intensities of active match-play, stoppage periods should be excluded from the analysis. On the other hand, the inclusion of stoppage periods permits the design of activity and recovery cycles while providing a greater representation of the total match demands. This understanding may help coaches contextualise the nature of physical performance and skill execution, and contribute to the design of match-specific training programs.

ACTIVITY AND RECOVERY CYCLES IN PROFESSIONAL AUSTRALIAN FOOTBALL

The analysis of activity and recovery cycle information provides a greater understanding of the average and longest periods of when the ball is in play, which can be subsequently applied by practitioners during training sessions to simulate the context of the work and recovery cycles associated with match-play. *Study two* derived the average and maximum activity cycles, and average and minimum recovery cycles as a product of the phases of match-play. The results showed that the average activity and recovery duration were approximately 110 and 39 seconds respectively. Furthermore, the longest continuous passage of play was approximately 721 seconds (or 12 minutes), which may be representative of the ‘worst-case scenario’ in Australian Football. These findings can be easily adopted into training regimes by conditioning and coaching staff to expose players to game like scenarios that enable players to be conditioned to the most demanding passages of play.

POSITIONAL DEMANDS DURING THE PHASES OF PROFESSIONAL AUSTRALIAN FOOTBALL MATCH-PLAY

Several studies have described the positional demands of Australian Football. This study expanded on previous knowledge by assessing the positional demands within each phase of play. Nomadic and key position players shared similar match-running profiles during the phases of play whereas ruckmen performed higher volumes and intensity of movement. For ruckmen, the magnitude of difference of the physical demands between each phase of play was less than other positions, suggesting a more continuous running profile. Furthermore, ruckmen performed more movement during umpire stoppages compared to other positions. Commonly in training, coaches use stoppage time to provide direct feedback to their players regarding their performance. Notwithstanding the value of this feedback, it may be pertinent to consider that ruckmen perform a significant amount of work when the ball is out of play. Collectively, these findings highlight different positional demands

that depend on the game phase of play which has important implications for the design of training programs for specific positions in Australian football.

MATCH-RELATED FATIGUE DURING THE PHASES OF PROFESSIONAL AUSTRALIAN FOOTBALL MATCH-PLAY

Most studies that have observed reductions in match-running performance have not considered the influence of time in the different phases of match-play. Reductions in match-running performance have been attributed to cumulative or transient fatigue. However, it is possible that intermittent changes in movement intensity are related to the game context and current phase of match-play. *Study three* demonstrated that reductions in average speed ($\text{m}\cdot\text{min}^{-1}$) and high-speed running ($\text{m}\cdot\text{min}^{-1}$) were only evident during active elements of competition (offence, defence and contested play). In contrast, no changes in match running performance were evident during stoppage periods (umpire stoppages, set shot or goal resets). These findings disagree with previous research where players reduced low-intensity movement to maintain their ability to perform high-intensity movements during the latter periods of the game. These results suggest that monitoring player output during the active elements of match-play may be important to manage rotations during competition. Furthermore, the results highlight the importance of considering the time spent in the phases of match-play when assessing match-related fatigue. Along with traditional time motion analysis metrics such as total and high-speed running distance, metabolic power estimates were included to consider acceleration movements that may not be detected using typical speed-based thresholds. Notwithstanding the current validity and reliability issues with metabolic power, these results suggest that metabolic power estimates or accelerometry may be useful for assessing contested elements of match-play where spatial limitations inhibit high-speed running. Indeed, *study two* showed that the acceleration and deceleration demands of contested play were higher than all other phases of play. This study highlighted the importance of using a variety of time-motion analysis measures to obtain an accurate reflection of the varying demands during professional Australian Football match-play.

CONTEXTUAL FACTORS AFFECTING PHYSICAL AND TECHNICAL PERFORMANCE IN PROFESSIONAL AUSTRALIAN FOOTBALL

Study four aimed to determine the influence of quarter success on physical and technical performance measures during the phases of play. Additionally, the study also investigated the influence of other common contextual factors including the opposition calibre and match location. While other studies have considered these contextual factors in Australian Football, *study four* also integrated physical and technical performance during the various phases of play. The findings demonstrated that during successful quarters, players performed more high-speed running during contested play. Successful quarters were also characterised by increased time in offence, a high number of handballs during offence and more set shot kicks at goal. These results demonstrate that both physical and technical performance during contested play and offence differentiate between successful and unsuccessful quarter outcomes. These findings can be used to direct training approaches that maximise the likelihood of team success. When competing against higher calibre opposition, there were reductions in the time in offence and goal resets, decrements in high-speed running during umpire stoppages and reductions in the number of contested possessions and handballs during offence. The results demonstrated that competing against higher calibre opposition resulted in an increase in the contested element of match-play, thereby reducing time spent in possession. The reduction in handballs during offence may suggest that it more difficult to move the ball by hand when competing against higher calibre opposition. Coaches can use this information to create training environments that reflect the challenges when playing against high calibre opposition. Finally, games played away from home were associated with reductions in average speed during contested play. These findings tenuously support evidence of 'home advantage', where reductions in contested play movement speed may be related to the effects of the opposition crowd, reductions in territoriality, vigour and assertiveness. Increases in high-speed running during umpire stoppages when playing away are possibly related to the small home ground of the reference team which may reduce the displacement location between

stoppages. Coaches can potentially modify field sizes and employ tactics to optimise performance during contested play scenarios in preparation for away matches.

7.2 CONTRIBUTION OF THE THESIS

An important evolution in performance research over the past few years is the integration of physical and technical information, alongside contextual data, so that these performance constructs can be examined in relation to the context of match-play. Given that the physical, technical and tactical constructs are rarely performed in isolation during competition, the most useful information to practitioners comes from integrated datasets. This concept formed an important theme that was continuous throughout the completion of this research. As such, this was the first research of its kind in professional Australian Football to integrate the physical and technical demands in the context of the phases during the match-play. The collection of studies examined contemporary issues regarding competition in professional Australian Football, specifically elements of possession and stoppages during match-play. This collection of studies identifies an important contextual factor (phase of play) that should be considered in future Australian Football research. This recommendation is made on the basis that the phases of match-play underpin the physical and technical demands of competition and ultimately relates to performance in Australian Football (Figure 7.1).

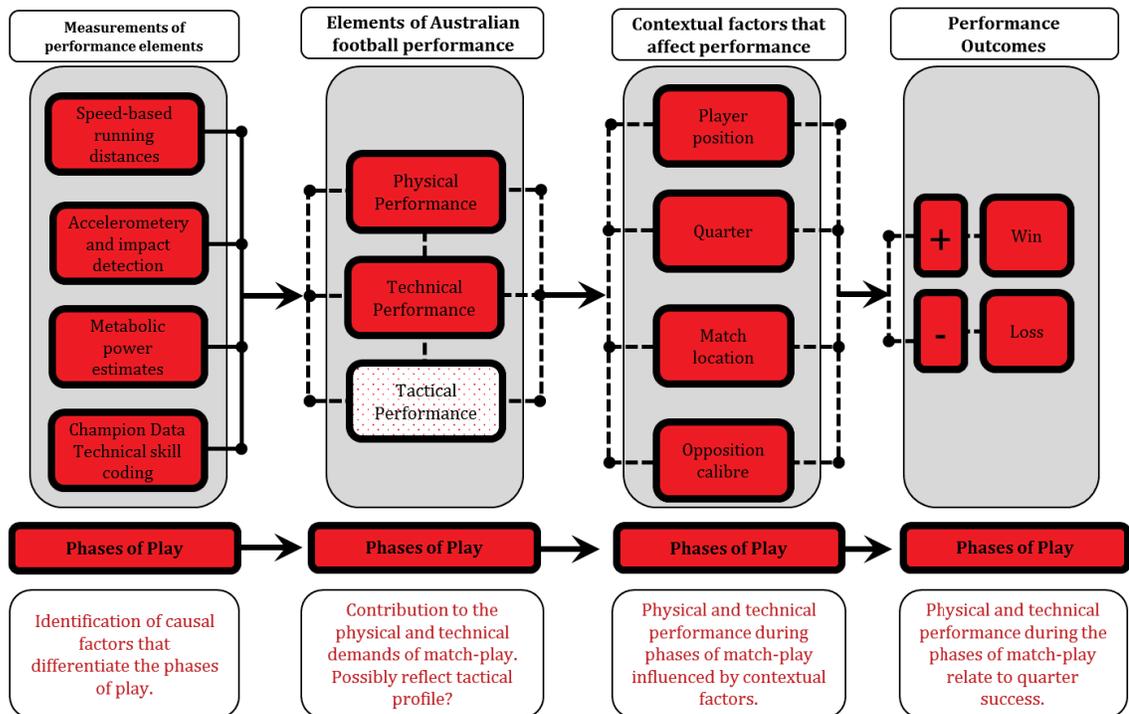


Figure 7.1: Contribution of the present thesis to a conceptual model of Australian Football performance highlighted in red.

The first study in this thesis revealed that the phases of match-play can be coded with an acceptable level of precision for match-analysis research. These findings permitted the physical and technical analysis of the phases of play that are important improving the depth of knowledge about the intermittent demands of competition. Without this reliability assessment, doubt could be cast over the repeatability of measuring these phases of play according to the operation definitions provided. As such, other performance analysts can utilise the specific methodology provided in *study one* to investigate the phases of match-play. Given the research in this thesis involved a single AFL club, further research studies from a variety of AFL clubs is required to validate the results presented in this case-series of research.

The intermittent nature of Australian match-play has been well described. However, this study illustrated fluctuations in intensity from a match context perspective. The nature of the game, rules

and regulations are likely to contribute to the stop/start nature of play. While previous research identifying total and average match demands of full matches and quarters, the phase of play information may be more relevant for the design of specific training drills. Furthermore, the time spent in phases of match-play underpin player opportunity to perform activity and technical skills. As such, it is recommended that physical and technical performance information be analysed with consideration to the time spent in the phases of play. A simple example may be the number of tackles made in an AFL match. A higher number of tackles may be perceived to be a good indicator of defensive pressure; however, a high number of tackles may also indicate a large amount of time spent defending. Possibly a more appropriate measure may be the number of tackles during time in defence. This level of analysis may provide further detail about performance indicators in future Australian Football research that are specific to the phases in play. Furthermore, *study three* has identified some important limitations relating to previous work in Australian Football that has analysed the incidence of match-related fatigue. The findings highlight the importance of considering stoppage time when conducting research about match-related fatigue. It is important to consider the match context in future research to ensure that reductions in physical performance and technical skill are simply not related to stoppages in match-play that often follow periods of very high intensity activity, such as immediately after a goal being scored.

An emerging theme in this research was the importance of considering the contested element of Australian Football match-play. Studies two, three and four showed that the highest proportion of game time was contested. Additionally, contested play involved the most distance covered, accelerations, decelerations and tackles. Several technical skills are performed during contested scenarios indicating that players are required to execute skills under pressure conditions. As such, an appropriate proportion of training should be dedicated to performance in this area. It was also clear that the metabolic demands of contested play were significantly higher than other elements of match-play. *Study four* showed that when considering quarter success and opposition calibre, there were

numerous reductions in physical and technical performance during contested play. These findings may be important for talent identification purposes, player development, training periodisation and performance analysis. In addition, the collective findings from studies one, two three and four highlights the myriad of performance qualities that are important for team performance in Australian Football. Some players may be more proficient during contested elements of match-play due to muscle mass, shorter stature and aggressive personality profile while the high-speed running demands during offence and defence would clearly suit players who are leaner and possess stronger running abilities. It is evident that while each player requires a variety of different skill sets, players with specific physical and technical qualities that relate to the phases in play are likely to be essential for team success.

An important consideration of performance analysis research is to determine whether causal measures of performance relate to match success (or team ranking when multi-team datasets are available). An important finding in this thesis is that both physical and technical measures associated with the phases of match-play are related to the outcome of a quarter. These findings add a degree of construct validity to the measurement of the phases of match-play. Nevertheless, the work in this thesis has some inherent limitations (discussed in the introduction) including the use of GPS microtechnology to derive physical performance measures, technical skill data provided by a commercial statistics provider and potential error associated with coding the phases of play. Additionally, given the associated link to quarter success, it is hoped that this research encourages other performance analysts to adopt similar research methodologies to validate the results presented in this thesis.

CHANGES EMBEDDED INTO INDUSTRY

From an applied perspective, this thesis and findings from the four studies contributed to several positive changes at the Australian Football club involved in this research. The phases of match-play are now analysed during each match and during training drills that involve game-specific scenarios.

Physical and technical skills are analysed using similar methodology to those utilised in *study two*. Several of the current findings and the practical applications presented herein have been adopted by the club's coaching and fitness staff. Specifically, contested play elements of training have been implemented throughout the pre-season in a periodised manner that reflects progressions in accelerations, decelerations, tackling and performance of skills in contested scenarios. Training periodisation during the pre-season involves strategic implementation of the various characteristics of the phases of play. For example, while high-speed running is progressed via conditioning bouts in the initial stages of a pre-season, high-speed running is gradually implemented into skills sessions via the progression of offensive and defensive training drills. In addition, accelerations, decelerations, tackling and the performance of technical skills under pressure is developed with the gradual integration of contested elements of training. Finally, repeat high-intensity efforts are performed using the phases of play as the context for the drills. The practical recommendations listed in the following section (7.4) are not simply recommendations, they also include examples of how the findings in the four studies have been applied in a professional Australian Football club. The real-world implementation of these findings highlights the applied nature of this research.

In summary, the understanding of the physical and technical demands of Australian Football match-play are imperative for the design of evidence-based training programs that lead to improvements in athletic performance. The information provided in this thesis supports the notion that Australian Football is a highly intermittent game, characterised by frequent changes in the current phase of play. Additionally, the phases of play contribute to the undulating intensity of the game and the opportunity to perform technical skills. Coaches and conditioning staff can use this data to design position-specific training programs that contextualise match running performance and the practice of technical skills.

7.3 RESEARCH LIMITATIONS

The research studies that comprise this thesis were primarily designed to impact on current practice by:

- i. Improving knowledge about the interpretation of physical and technical Australian Football match data,
- ii. Contextualising the physical and technical components of match-play that leads to improved training specificity,
- iii. Identifying performance indicators that relate to the phases of play and, d) developing further evidence-based information that ultimately contributes to improvements in professional AFL player performance.

It also aimed to develop a methodological framework to direct future research studies that lead to continual development in the Australian Football sport science community. While some of these objectives may have been realised within the immediate football club, the ability to transfer these results to other footballs clubs and different levels of competition requires caution due to some inherent limitations associated with this research.

The series of research studies incorporated into this thesis involved the participation of a single Australian Football club. The results are likely to be influenced by the tactics employed by the reference team, home ground field dimensions, physical and technical ability of the participating players, opposition team influence, contextual factors and environmental factors inherent in one season sample of AFL matches. While the coding of the phases of play did consider the opposition to a large degree, all physical and technical data were related to the reference team. It is probable that 'successful' match profiles vary between teams. In other words, because teams use different strategies that depend on the qualities of their players, match tactics are likely to vary and thus, not every team achieves a successful match outcome in the same way. Given that the research was performed under

professional match conditions and the physical and technical data came from a high calibre team (finished 1st at the conclusion of the regular season), the findings of the present research possesses high levels of ecological validity.

In *study four* teams were dichotomised according to whether they competed in the final series or not. This may have been an unfair classification system as some teams could have missed out on the finals by a small margin and perhaps been ranked inside the top eight teams for majority of the season. Further studies should aim to investigate the opposition team's ranking at the time of the match and consider their current form. For example, a win/loss ratio for previous four matches may be a useful approach to illustrate a team's 'form' and be a better indicator of current team calibre.

Currently, physical performance data (GPS) is not freely available between clubs in the AFL. In contrast, technical skill data from every club from each match is collected by a commercial statistics provider and available for all clubs to access, hence the prevalence of research studies comparing the technical profiles from various clubs (Robertson et al., 2016; Woods et al., 2017). Clearly, the possibility of overcoming this limitation is either by collaboration between clubs (see Kempton et al., 2017 as an example) that have a shared and equal interest in the research, or if match GPS data is made available to all clubs. At this stage, the latter appears less likely. Thus, collaborative research is clearly required for the present research in this thesis to somewhat achieve a degree of proof of concept. Arguably, this research could be carried out by a discipline group of academic researchers who are independent to football clubs to ease concerns about data confidentiality. This type of research would be valuable for different levels of competition, different teams in the AFL and possibly contribute to the evolution of the game.

The findings from the collection of studies were primarily observational, longitudinal, descriptive studies. Thus, some criticisms of the work presented here may be that the set of studies lack generalisability or experimental control that provides objective data. Transferring quantifiable

training outcomes into identifiable changes in match performance remains the biggest challenge in team sports (Bishop, 2008; Carling, 2013). Ideally, experimental training studies that lead to performance improvements in competitive matches would be ideal to provide proof of concept. For example, does high-speed running performance during contested play in competition change following a 6-week training intervention that specifically focuses on this element of match-play? Or is it simply that high-speed running ability improves? There is an absence of research in professional Australian Football in which the effects of controlled interventions on actual competitive performance have been definitively shown. There are clearly a number of logistical issues that may contribute to difficulties executing these types of training interventions in a professional setting. Other recent studies have shown that performance during training can be used to predict performance during competitive matches (Graham et al., 2017). Potentially, this method can be used to determine whether individual improvements in player fitness or skill from training lead to performance improvements in competition.

One practical limitation of the work presented here may be the time-consuming nature of integrating the three different datasets (phases of play [Sportscode® video analysis], physical data [GPS data] and technical skill data [Champion Data® coding]). Indeed, a dataset from a single season using the present methodology represented approximately 250,000 lines of contextual, physical and technical skill information at the phase of play level. This limitation may be less problematic for the research scientists who represent the slow-thinking conscience that is crucially responsible for sound decision-making, establishing evidence to support proof of concept and are skilled at handling large datasets. At the commencement of this thesis the vision was for this level of analysis to be available in real-time for coaches and performance analysts to make decisions that ultimately influence performance. Coaches and applied sport-scientists work in a fast-paced environment where delivering timely information relies on efficient processes and is easily interpreted on match-day or during training (Coutts, 2016; Kahneman, 2011). As such, the time-consuming nature of the data collection and

processing may limit real-time applications within a football club under current technological constraints. In the following chapter, under ‘Recommendations for Future Research’, some suggestions are made that may lead to an automation of this process and thus enable an increase in the data availability for real-time decision-making. At the conclusion of this thesis, it is clear that future research is warranted to validate the results identified using this common case-study approach. The hope is that future research expands on the findings reported here to enhance current understanding of the physical and technical demands in the context of the phases of match-play in professional Australian Football.

7.4 PRACTICAL APPLICATIONS

The four studies that comprise this thesis have resulted in a number of practical findings that are useful to sport scientists, performance analysts and coaching staff in professional Australian Football. These practical applications relate to the physical, technical and tactical constructs of Australian Football performance and include:

- A trained researcher can code the phases of match-play with an acceptable level of precision. Nevertheless, the typical error should be considered when interpreting phase of play information in Australian Football. Additionally, coding stoppages (umpire stoppages, set shots and goal resets) is slightly more reliable than coding active elements of match-play (offence, defence and contested play).
- The intermittent nature of Australian Football match-play is underpinned by frequent changes in the phase of play. Coaching staff can use this descriptive information to design training drills and manage work including the recovery cycles that reflect the contextual nature of match-play.
- *Study two* showed that each phase differed with respect to several physical and technical performance variables, suggesting that each phase involved diverse movement profiles. As

such, the intermittent match-running demands and opportunity to perform technical skills during Australian Football competition are underpinned by the phases of play. Coaching and conditioning staff should aim to contextualise physical and technical performance during training to optimally prepare players for the individual demands of the phases of match-play.

- Sport scientists should be pragmatic when determining whether to include stoppage data in the analysis of the physical demands of Australian Football. Including these stoppage periods in the analysis may underestimate transient match intensities by ~27%. In contrast, excluding these stoppage periods would result in an underestimation of total and high-speed running distance by 25% and 13% respectively. The analysis of specific elements of match-play may be more important for the design of training drills that reflect the demands of match-play, while a global analysis may be more relevant for load monitoring purposes.
- The physical demands of 'active' elements of match-play far exceed the demands placed on players during stoppage periods. Conditioning and performance staff could monitor the time spent in active elements of match-play and time in stoppages as the game context can contribute to the physical demands. Table 7.1 provides a simple illustration of two different rotation bouts of ~10 minutes within the same match for the same player. These observations suggest that rotations based simply on field time may impede a team's ability to maintain a high collective match intensity.

Table 7.1: Example of two different rotation bouts of equal duration with different physical profiles due to the proportion of time spent in the phases of play.

	Phase of Play	Time (min:ss)	Total Distance (m)	HSR (m)	Active match-play (min:ss)	Stoppages (min:ss)
Rotation 1	Offence	2:58	598	298		
	Defence	2:48	524	215	9:22	
	Contested Play	3:36	359	182		
	Umpire Stoppage	0:35	51	12		
	Set Shot	0:00	0	0		0:35
	Goal Reset	0:00	0	0		
	TOTAL	9:57	1532	707	6:18	3:39
Rotation 2	Offence	1:45	201	68		
	Defence	1:35	223	51	5:56	
	Contested Play	2:36	329	21		
	Umpire Stoppage	0:49	95	10		
	Set Shot	0:52	52	0		3:58
	Goal Reset	2:17	159	0		
	TOTAL	9:54	1059	150	4:58	4:56

- The activity and recovery cycle information presented in *study two* can be utilised by coaching staff to design training programs that reflect the normative work and rest periods in Australian Football. Additionally, the findings from *study one* and *study two* can be integrated by other coaches and fitness staff working in Australian Football, permitting the individual design of training drills depending on the purpose of specific teams.
- The highest proportion of Australian Football competition comprised contested play. This phase also involved the highest proportion of total distance, accelerations, decelerations and tackles. The metabolic demands of this phase were also higher than all other phases. Furthermore, playing against higher calibre opposition involved marked increases in contested play. Taken together, coaches and conditioning staff should implement elements of contested play into their training program to adequately prepare players for the demands

of this phase. Contested elements of training could be implemented in a periodised manner to minimise the possible injury risk associated with contested training.

- Stoppages during competitive matches (umpire stoppages, set shots and goal resets) are not considered as complete cessations during match-play. There are important physical and tactical elements during these phases of play and performance during these phases should be practiced during training.
- Metabolic power estimates may be useful for practitioners to assess contested play scenarios during match-play and possibly during training. This method may account for the spatial constraints associated with contested play scenarios and capture the metabolically demanding nature of this phase.
- Sport scientists should consider the time spent in the various phases of match-play when assessing physical and technical profiles, positional demands and match-related fatigue as they influence opportunity to perform activity and contribute to the undulating intensities of Australian Football.

CHAPTER EIGHT

SUMMARY & RECOMMENDATIONS

8.1 SUMMARY

This thesis contains four original research studies (Chapters Three to Six) that contribute to the performance model of Australian Football that incorporates physical, technical and tactical constructs. The first study developed a set of operation definitions of the phases of match-play and the methods for coding these phases were assessed for intra-observer reliability. Additionally, a descriptive analysis of the phases of match-play were provided. Studies two and three provided new information about the physical and technical demands of the phases of match-play with specific consideration to activity and recovery cycles, quarter of the match and player position. The final study described the influence of quarter outcome, opposition calibre and match location on a myriad of physical and technical performance measures during the phases of match-play. Collectively, this series of research studies provide new insight into the physical and technical demands of professional Australian Football match-play by introducing a new methodology of considering the phases of match-play.

8.2 DIRECTIONS FOR FUTURE RESEARCH

Throughout the development of this thesis there have been several research questions that have formed from the results, discussion with coaching staff and current developments in team sport research. The four research studies contribute to a specific element of the conceptual model identified in the introduction to the thesis and therefore future studies should aim to expand on these findings and contribute to the global performance model of Australian Football.

- The analysis of the phases of match-play identified in *study one* presents a potential methodology for other clubs to assess performance during specific elements of match-play. Historically, Australian Football research has been limited to case-study approaches because opposition physical performance data is not freely available between clubs. Future studies

should aim to integrate the physical and technical performance data during the phases of match-play from multiple teams in the AFL to confirm the findings presented in studies two, three and four. Clearly, a collaborative approach is necessary for this type of research to occur. Nevertheless, the methodology presented here can be easily adopted by other clubs and it is hoped that other research is produced that analyses match-play using a phasic approach to further elaborate on the work presented in this thesis.

- Future research should aim to determine the inter-observer reliability of coding the phases of match-play in Australian Football. This data would be useful for multiple clubs to determine the reliability of the methodology used in this research.
- The coding of the phases of match-play in the studies that encompass this thesis was a relatively time-consuming process. Therefore, the analysis of physical and technical performance during these phases of match-play in real-time during competitive match-play may be problematic. Indeed, practitioners and coaches alike require information quickly during matches so tactical changes can be made to negate deleterious factors that lead to unsuccessful match outcomes. Several technical skill measures and coding by the AFL statistics provider are indicative of the current phase of match-play. As such, it may be possible to incorporate this coding to simultaneously derive the current phase of match-play. This research would contribute to the validity of the phases of match-play identified in this thesis and automate the process of deriving the phases of match-play.
- Match-related fatigue appears to be isolated to elements of offence, defence and contested play. These findings are specific to cumulative fatigue over the entirety of a match and as such, future studies should examine transient fatigue responses with consideration to the time spent in the different phases of match-play that are most useful for practitioners to make real-time decisions during matches. Additionally, this research only considered the use of external load measures. Future research should integrate both external and internal load measures to

provide a more accurate assessment of cumulative and transient fatigue during the phases of match-play in Australian Football.

- The three match analysis studies raise questions about the value of assessing match-related fatigue when the opposition is not considered. Future studies should aim to investigate whether reductions in physical and technical performance during the phases of match-play differ between successful and unsuccessful teams during the same match. Conceptually, match-induced fatigue is virtually a guaranteed occurrence in a high-intensity, intermittent team sport that lasts for approximately 120 minutes. If the rate of decline in physical output is greater in unsuccessful teams compared to successful teams during match-play, then match-induced fatigue research is highly pertinent to performance. It is likely that Australian Football research will continue to be confined to case-study approaches without collaboration between clubs. This approach will permit large-scale studies and assessment of the causal indicators of the different constructs that influence match outcomes in professional Australian Football. Additionally, future studies should determine whether reductions in physical output during the phases of match-play are related to reductions in technical skill performance.
- *Study three* dichotomised players into nomadic, key and ruck position players. Other studies that have assessed physical performance of different position groups in professional Australian Football have utilised more specific positional categories compared to those used in *study three*. Future studies could assess the physical and technical demands of fixed forwards, fixed defenders, small forwards, small defenders and midfield players to elucidate more specific information pertaining to player position. Indeed, Figure 8.1 shows that while the majority of players analysed in this study perform higher running intensities during offence, there are a select few that perform the converse. Future studies could assess the factors that explain individual player variance in match running performance during the phases of match-play.

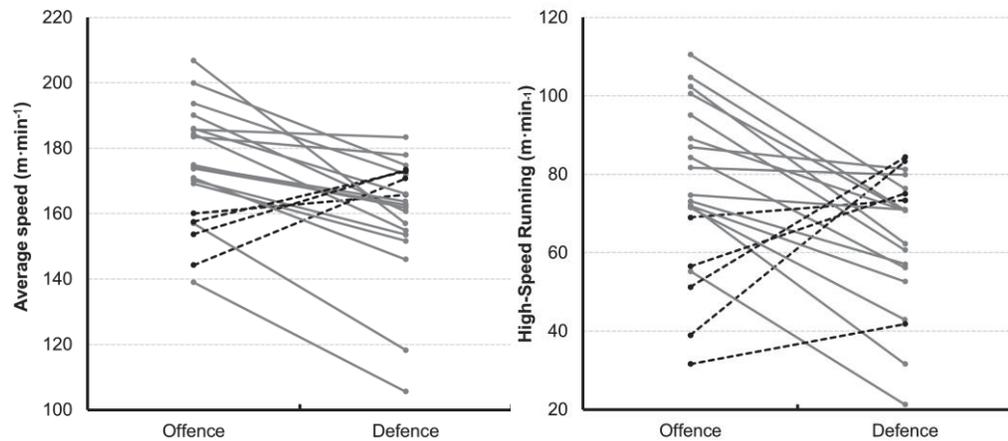


Figure 8.1: Example of offensive and defensive running intensities measured by average speed and HSR ($\text{m}\cdot\text{min}^{-1}$) for each player (22 players). Grey lines indicate higher offensive running intensities and black dotted lines indicate higher defensive running intensities.

- No research has examined the influence of time spent in the different phases of match-play on the various factors associated with post-match fatigue and homeostatic disruption. Contested play appears to involve the highest number of accelerations, decelerations and tackles, all of which have been associated with increases in muscle damage following match-play. Further research should examine the influence of time spent in the various elements of match-play and their association with post-match markers of fatigue, muscle damage and soreness. This information would be highly useful for medical staff to identify game-related factors that explain differences in recovery time-courses following matches. Conditioning staff could also design training programs in the preseason that attempt to address the components of match-play that lead to higher levels of fatigue following competition.
- *Study Four* revealed that successful match performance was influenced by physical and technical factors during the different phases of match-play. Therefore, it may be possible that team tactics and individual player strengths and weakness are linked to specific elements of match-play. As such, the success of different teams may be linked to performance during particular phases of match-play. For example, some teams may be highly efficient in offence

by moving the ball quickly and achieving a high level of scoring efficiency. Comparatively, other teams may be more proficient in contested play and score using pressure tactics. This information would be useful for profiling successful and unsuccessful outcomes from different teams to build opposition analysis profiles that can help direct game tactics and improve the chances of successful match outcomes.

- To date, no study has assessed the factors that contribute to periods of high density scoring periods during Australian Football match-play. Identifying whether certain physical or technical performance measures change when a team is scoring heavily or conversely, when the opposition accumulates points quickly, would be highly pertinent to determine the characteristics of “momentum” in Australian Football. The cumulation of these causal factors may be highly useful for coaches in real-time to assist in determining tactical changes during different periods in a match. Furthermore, a greater understanding of this aspect may be achieved if such data is provided at the phase of play level.
- Future research could investigate the context of repeat high-intensity running efforts in professional Australian Football. The GPS software utilised in this research was able to detect the number of repeat high-intensity efforts using predetermined criteria. Given the mean duration of each active phase in play is approximately 10 seconds, it was rare to observe three high-intensity efforts being performed in the same phase of play. Therefore, it may be that such efforts are performed in response to changes in the current phase of match-play. This research would be highly valuable for coaching and conditioning staff alike to develop repeat, high-intensity training drills that reflect the phasic nature of Australian Football.

REFERENCE LIST

- Akenhead, R., Hayes, P. R., Thompson, K. G., & French, D. (2013). Diminutions of acceleration and deceleration output during professional football match play. *Journal of Science and Medicine in Sport, 16*(6), 556-561.
- Allen, D. G., Lamb, G. D., & Westerblad, H. (2008). Skeletal muscle fatigue: cellular mechanisms. *Physiology Review, 88*(1), 287-332.
- Appleby, B., & Dawson, B. (2002). Video analysis of selected game activities in Australian Rules Football. *Journal of Science and Medicine in Sport, 5*(2), 129-142.
- Atkinson, G., & Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine, 26*(4), 217-238.
- Aughey, R. J. (2010). Australian football player work rate: evidence of fatigue and pacing? *International Journal of Sports Physiology and Performance, 5*(3), 394-405.
- Aughey, R. J. (2011a). Applications of GPS technologies to field sports. *International Journal of Sports Physiology and Performance, 6*(3), 295-310.
- Aughey, R. J. (2011b). Increased high-intensity activity in elite Australian football finals matches. *International Journal of Sports Physiology and Performance, 6*(3), 367-379.
- Aughey, R. J., Elias, G. P., Esmaili, A., Lazarus, B., & Stewart, A. M. (2016). Does the recent internal load and strain on players affect match outcome in elite Australian football? *Journal of Science and Medicine in Sport, 19*(2), 182-186.
- Austin, D. J., Gabbett, T. J., & Jenkins, D. J. (2011). Repeated high-intensity exercise in a professional rugby league. *Journal of Strength and Conditioning Research, 25*(7), 1898-1904.
- Barris, S., & Button, C. (2008). A review of vision-based motion analysis in sport. *Sports Medicine, 38*(12), 1025-1043.
- Bishop, D. (2008). An applied research model for the sport sciences. *Sports Medicine, 38*(3), 253-263.
- Black, G. M., Gabbett, T. J., Naughton, G. A., & McLean, B. D. (2016). The effect of intense exercise periods on physical and technical performance during elite Australian Football match-play: A comparison of experienced and less experienced players. *Journal of Science and Medicine in Sport, 19*(7), 596-602.
- Boyd, L. J., Ball, K., & Aughey, R. J. (2013). Quantifying external load in Australian football matches and training using accelerometers. *International Journal of Sports Physiology and Performance, 8*(1), 44-51.

- Bradley, P. S., Carling, C., Archer, D., Roberts, J., Dodds, A., et al. (2011). The effect of playing formation on high-intensity running and technical profiles in English FA Premier League soccer matches. *Journal of Sports Sciences*, 29(8), 821-830.
- Bradley, P. S., Lago-Penas, C., Rey, E., & Gomez Diaz, A. (2013). The effect of high and low percentage ball possession on physical and technical profiles in English FA Premier League soccer matches. *Journal of Sports Sciences*, 31(12), 1261-1270.
- Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., et al. (2009). High-intensity running in English FA Premier League soccer matches. *Journal of Sports Sciences*, 27(2), 159-168.
- Brewer, C., Dawson, B., Heasman, J., Stewart, G., & Cormack, S. (2010). Movement pattern comparisons in elite (AFL) and sub-elite (WAFL) Australian football games using GPS. *Journal of Science and Medicine in Sport* 13(6), 618-623.
- Buchheit, M., Lacome, M., Cholley, Y., & Simpson, B. M. (2017). Neuromuscular Responses to Conditioned Soccer Sessions Assessed Via GPS-Embedded Accelerometers: Insights Into Tactical Periodization. *International Journal of Sports Physiology and Performance*, 1-21. doi:10.1123/ijsp.2017-0045
- Buchheit, M., Manouvrier, C., Cassirame, J., & Morin, J. B. (2015). Monitoring Locomotor Load in Soccer: Is Metabolic Power, Powerful? *International Journal of Sports Medicine*, 36(14), 1149-1155. doi:10.1055/s-0035-1555927
- Buchheit, M., & Simpson, B. M. (2017). Player-Tracking Technology: Half-Full or Half-Empty Glass? *International Journal of Sports Physiology and Performance*, 12(Suppl 2), S235-s241. doi:10.1123/ijsp.2016-0499
- Burgess, D., Naughton, G., & Hopkins, W. (2012a). Draft-camp predictors of subsequent career success in the Australian Football League. *Journal of Science and Medicine in Sport*, 15(6), 561-567.
- Burgess, D., Naughton, G., & Norton, K. (2012b). Quantifying the gap between under 18 and senior AFL football: 2003-2009. *International Journal of Sports Physiology and Performance*, 7(1), 53-58.
- Burgess, D. J., Naughton, G., & Norton, K. I. (2006). Profile of movement demands of national football players in Australia. *Journal of Science and Medicine in Sport*, 9(4), 334-341.
- Carling, C. (2010). Analysis of physical activity profiles when running with the ball in a professional soccer team. *Journal of Sports Sciences*, 28(3), 319-326.
- Carling, C. (2013). Interpreting physical performance in professional soccer match-play: should we be more pragmatic in our approach? *Sports Medicine*, 43(8), 655-663.

- Carling, C., Bloomfield, J., Nelsen, L., & Reilly, T. (2008). The role of motion analysis in elite soccer: contemporary performance measurement techniques and work rate data. *Sports Medicine*, 38(10), 839-862.
- Carling, C., Bradley, P., McCall, A., & Dupont, G. (2016). Match-to-match variability in high-speed running activity in a professional soccer team. *Journal of Sports Sciences*, 34(24), 2215-2223.
- Carling, C., Wright, C., Nelson, L. J., & Bradley, P. S. (2014). Comment on 'Performance analysis in football: a critical review and implications for future research'. *Journal of Sports Sciences*, 32(1), 2-7.
- Casal, C. A., Maneiro, R., Ardá, T., Mari, F. J., & Losada, J. L. (2017). Possession Zone as a Performance Indicator in Football. The Game of the Best Teams. *Frontiers in Psychology*, 8, 1176.
- Castellano, J., Casamichana, D., & Lago, C. (2012). The Use of Match Statistics that Discriminate Between Successful and Unsuccessful Soccer Teams. *Journal Human Kinetics*, 31, 139-147.
- Chambers, R., Gabbett, T. J., Cole, M. H., & Beard, A. (2015). The Use of Wearable Microsensors to Quantify Sport-Specific Movements. *Sports Medicine*, 45(7), 1065-1081.
- Clarke, S. R. (2005). Home advantage in the Australian Football League. *Journal of Sports Sciences*, 23(4), 375-385.
- Cleophas, T. J., & Zwinderman, A. H. (2012). *Statistics applied to clinical studies*: Springer Science & Business Media.
- Collet, C. (2013). The possession game? A comparative analysis of ball retention and team success in European and international football, 2007–2010. *Journal of Sports Sciences*, 31(2), 123-136.
- Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *International Journal of Sports Physiology and Performance*, 3(2), 131-144.
- Coutts, A. J., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport*, 13(1), 133-135.
- Coutts, A. J., Kempton, T., Sullivan, C., Bilsborough, J., Cordy, J., et al. (2015). Metabolic power and energetic costs of professional Australian Football match-play. *Journal of Science and Medicine in Sport*, 18(2), 219-224.

- Coutts, A. J., Kempton, T., & Vaeyens, R. (2014). Relative age effects in Australian Football League National Draftees. *Journal of Sports Sciences*, 32(7), 623-628.
- Coutts, A. J., Quinn, J., Hocking, J., Castagna, C., & Rampinini, E. (2010). Match running performance in elite Australian Rules Football. *Journal of Science and Medicine in Sport*, 13(5), 543-548.
- Cummins, C., Orr, R., O'Connor, H., & West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports Medicine*, 43(10), 1025-1042.
- Dawson, B., Hopkinson, R., Appleby, B., Stewart, G., & Roberts, C. (2004). Player movement patterns and game activities in the Australian Football League. *Journal of Science and Medicine in Sport*, 7(3), 278-291.
- Delaney, J. A., Thornton, H. R., Burgess, D. J., Dascombe, B. J., & Duthie, G. M. (2017). Duration-specific running intensities of Australian Football match-play. *Journal of Science and Medicine in Sport*, 20(7), 689-694.
- Dellal, A., Chamari, K., Wong, d. P., Ahmaidi, S., Keller, D., et al. (2011). Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. *European Journal of Sport Science*, 11(1), 51-59.
- Dennis, J., Dawson, B., Heasman, J., Rogalski, B., & Robey, E. (2016). Sleep patterns and injury occurrence in elite Australian footballers. *Journal of Science and Medicine in Sport*, 19(2), 113-116. doi:10.1016/j.jsams.2015.02.003
- di Prampero, P. E., Fusi, S., Sepulcri, L., Morin, J. B., Belli, A., et al. (2005). Sprint running: a new energetic approach. *Journal of Experimental Biology*, 208(Pt 14), 2809-2816.
- Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of high intensity activity in Premier League soccer. *International Journal of Sports Medicine*, 30(3), 205-212.
- Dillon, P. A., Kempton, T., Ryan, S., Hocking, J., & Coutts, A. J. (2017). Interchange rotation factors and player characteristics influence physical and technical performance in professional Australian Rules football. *Journal of Science and Medicine in Sport*. doi:10.1016/j.jsams.2017.06.008
- Dogramaci, S. N., & Watsford, M. L. (2006). A comparison of two different methods for time-motion analysis in team sports. *International Journal of Performance Analysis in Sport*, 6(1), 73-83.
- Downward, P., & Jones, M. (2007). Effects of crowd size on referee decisions: analysis of the FA Cup. *Journal of Sports Sciences*, 25(14), 1541-1545.

- Duffield, R., Coutts, A. J., & Quinn, J. (2009). Core temperature responses and match running performance during intermittent-sprint exercise competition in warm conditions. *Journal of Strength and Conditioning Research*, 23(4), 1238-1244.
- Dumholdt, E. (2000). *Physical therapy research: principles and applications*.: WB Saunders Company.
- Duthie, G., Pyne, D., & Hooper, S. (2005). Time motion analysis of 2001 and 2002 super 12 rugby. *Journal of Sports Sciences*, 23(5), 523-530.
- Duthie, G., Pyne, D. B., & Hooper, S. (2003). The reliability of video based time motion analysis. *Journal of Human Movement Studies*, 44, 259-272.
- Ebert, T. R. (2000). Nutrition for the Australian Rules football player. *Journal of Science and Medicine in Sport*, 3(4), 369-382.
- Edgecomb, S. J., & Norton, K. I. (2006). Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian football. *Journal of Science and Medicine in Sport*, 9(1-2), 25-32.
- Farrow, D., Pyne, D. B., & Gabbett, T. (2008). Skill and Physiological Demands of Open and Closed Training Drills in Australian Football. *International Journal of Sports Science & Coaching*, 3(4), 489-499.
- Fortington, L. V., Berry, J., Buttifant, D., Ullah, S., Diamantopoulou, K., et al. (2016). Shorter time to first injury in first year professional football players: A cross-club comparison in the Australian Football League. *Journal of Science and Medicine in Sport*, 19(1), 18-23.
- Gabbett, T. J. (2012). Activity cycles of National Rugby League and National Youth Competition matches. *Journal of Strength and Conditioning Research*, 26(6), 1517-1523.
- Gabbett, T. J. (2013a). Activity and recovery cycles of National Rugby League matches involving higher and lower ranked teams. *Journal of Strength and Conditioning Research*, 27(6), 1623-1628.
- Gabbett, T. J. (2013b). Influence of the opposing team on the physical demands of elite rugby league match play. *Journal of Strength and Conditioning Research*, 27(6), 1629-1635.
- Gabbett, T. J. (2014). Effects of physical, technical, and tactical factors on final ladder position in semiprofessional rugby league. *International Journal of Sports Physiology and Performance*, 9(4), 680-688.
- Gabbett, T. J. (2015a). Activity and recovery profiles of state-of-origin and national rugby league match-play. *Journal of Strength and Conditioning Research*, 29(3), 708-715.
- Gabbett, T. J. (2015b). Influence of ball-in-play time on the activity profiles of rugby league match-play. *Journal of Strength and Conditioning Research*, 29(3), 716-721.

- Gabbett, T. J., & Hulin, B. T. (2017). Activity and recovery cycles and skill involvements of successful and unsuccessful elite rugby league teams: A longitudinal analysis of evolutionary changes in National Rugby League match-play. *Journal of Sports Sciences*, 1-11. doi:10.1080/02640414.2017.1288918
- Gabbett, T. J., Jenkins, D. G., & Abernethy, B. (2011). Physical collisions and injury in professional rugby league match-play. *Journal of Science and Medicine in Sport*, 14(3), 210-215.
- Gabbett, T. J., Polley, C., Dwyer, D. B., Kearney, S., & Corvo, A. (2014). Influence of field position and phase of play on the physical demands of match-play in professional rugby league forwards. *Journal of Science and Medicine in Sport*, 17(5), 556-561.
- Gastin, P. B., McLean, O., Spittle, M., & Breed, R. V. (2013). Quantification of tackling demands in professional Australian football using integrated wearable athlete tracking technology. *Journal of Science and Medicine in Sport*, 16(6), 589-593.
- Gastin, P. B., Mclean, O. C., Breed, R. V., & Spittle, M. (2014). Tackle and impact detection in elite Australian football using wearable microsensor technology. *Journal of Sports Sciences*, 32(10), 947-953.
- Gollnick, P. D., Armstrong, R. B., Saubert, C. W. t., Sembrowich, W. L., Shepherd, R. E., et al. (1973). Glycogen depletion patterns in human skeletal muscle fibers during prolonged work. *Pflügers Archiv*, 344(1), 1-12.
- Gómez, M. A., Gómez-Lopez, M., Lago, C., & Sampaio, J. (2012). Effects of game location and final outcome on game-related statistics in each zone of the pitch in professional football. *European Journal of Sport Science*, 12(5), 393-398.
- Goumas, C. (2014). Home advantage in Australian soccer. *Journal of Science and Medicine in Sport*, 17(1), 119-123.
- Gray, A. J., & Jenkins, D. G. (2010). Match analysis and the physiological demands of Australian football. *Sports Medicine*, 40(4), 347-360.
- Graham, S.R., Cormack, S., Parfitt, G., & Eston, R. Relationships Between Model Predicted and Actual Match Performance in Professional Australian Footballers During an In-Season Training Macrocycle. *International Journal of Sports Physiology and Performance*, doi: <https://doi.org/10.1123/ijsp.2017-0026>
- Gregson, W., Drust, B., Atkinson, G., & Salvo, V. D. (2010). Match-to-match variability of high-speed activities in premier league soccer. *International Journal of Sports Medicine*, 31(4), 237-242.

- Gronow, D., Dawson, B., Heasman, J., Rogalski, B., & Peeling, P. (2014). Team movement patterns with and without ball possession in Australian Football League players. *International Journal of Performance Analysis in Sport, 14*(3), 635-651.
- Hader, K., Mendez-Villanueva, A., Palazzi, D., Ahmaidi, S., & Buchheit, M. (2016). Metabolic Power Requirement of Change of Direction Speed in Young Soccer Players: Not All Is What It Seems. *PLoS One, 11*(3), e0149839. doi:10.1371/journal.pone.0149839
- Hajian-Tilaki, K. (2014). Sample size estimation in diagnostic test studies of biomedical informatics. *Journal of Biomedical Informatics, 48*, 193-204.
- Hill-Haas, S. V., Dawson, B., Impellizzeri, F. M., & Coutts, A. J. (2011). Physiology of small-sided games training in football: a systematic review. *Sports Medicine, 41*(3), 199-220.
- Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine, 30*(1), 1-15.
- Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sport and Exercise, 41*(1), 3-13.
- Hoppe, M. W., Slomka, M., Baumgart, C., Weber, H., & Freiwald, J. (2015). Match Running Performance and Success Across a Season in German Bundesliga Soccer Teams. *International Journal of Sports Medicine, 36*(7), 563-566.
- Hulin, B. T., Gabbett, T. J., Johnston, R. D., & Jenkins, D. G. (2017). Wearable microtechnology can accurately identify collision events during professional rugby league match-play. *Journal of Science and Medicine in Sport, 20*(7), 638-642.
- Iaia, F. M., Perez-Gomez, J., Nordsborg, N., & Bangsbo, J. (2010). Effect of previous exhaustive exercise on metabolism and fatigue development during intense exercise in humans. *Scandinavian Journal of Medicine and Science in Sport, 20*(4), 619-629.
- Impellizzeri, F. M., & Marcora, S. M. (2009). Test validation in sport physiology: lessons learned from clinimetrics. *International Journal of Sports Physiology and Performance, 4*(2), 269-277.
- Jennings, D., Cormack, S., Coutts, A. J., Boyd, L., & Aughey, R. J. (2010). The validity and reliability of GPS units for measuring distance in team sport specific running patterns. *International Journal of Sports Physiology and Performance, 5*(3), 328-341.
- Johnston, R. D., Gabbett, T. J., & Jenkins, D. G. (2014). Applied sport science of rugby league. *Sports Medicine, 44*(8), 1087-1100.

- Johnston, R. J., Watsford, M. L., Austin, D., Pine, M. J., & Spurrs, R. W. (2015a). Player acceleration and deceleration profiles in professional Australian football. *Journal of Sports Medicine and Physical Fitness*, 55(9), 931-939.
- Johnston, R. J., Watsford, M. L., Austin, D. J., Pine, M. J., & Spurrs, R. W. (2015b). Movement Demands and Metabolic Power Comparisons Between Elite and Subelite Australian Footballers. *Journal of Strength and Conditioning Research*, 29(10), 2738-2744.
- Johnston, R. J., Watsford, M. L., Austin, D. J., Pine, M. J., & Spurrs, R. W. (2016). Movement Profiles, Match Events, and Performance in Australian Football. *Journal of Strength and Conditioning Research*, 30(8), 2129-2137.
- Johnston, R. J., Watsford, M. L., Kelly, S. J., Pine, M. J., & Spurrs, R. W. (2014). Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. *Journal of Strength and Conditioning Research*, 28(6), 1649-1655.
- Johnston, R. J., Watsford, M. L., Pine, M. J., Spurrs, R. W., Murphy, A., et al. (2012). Movement demands and match performance in professional Australian football. *International Journal of Sports Medicine*, 33(2), 89-93.
- Jones, P. D., James, N., & Mellalieu, S. D. (2004). Possession as a performance indicator in soccer. *International Journal of Performance Analysis in Sport*, 4(1), 98-102.
- Kelly, S. J., Murphy, A. J., Watsford, M. L., Austin, D., & Rennie, M. (2015). Reliability and validity of sports accelerometers during static and dynamic testing. *International Journal of Sports Physiology and Performance*, 10(1), 106-111.
- Kempton, T., & Coutts, A. J. (2016). Factors affecting exercise intensity in professional rugby league match-play. *Journal of Science and Medicine in Sport*, 19(6), 504-508.
- Kempton, T., Sirotic, A. C., & Coutts, A. J. (2016). A Comparison of Physical and Technical Performance Profiles Between Successful and Less-Successful Professional Rugby League Teams. *International Journal of Sports Physiology and Performance*, 12(4), 520-526.
- Kempton, T., Sirotic, A. C., Rampinini, E., & Coutts, A. J. (2015a). Metabolic power demands of rugby league match play. *International Journal of Sports Physiology and Performance* 10(1), 23-28.
- Kempton, T., Sullivan, C., Bilsborough, J. C., Cordy, J., & Coutts, A. J. (2015b). Match-to-match variation in physical activity and technical skill measures in professional Australian Football. *Journal of Science and Medicine in Sport*, 18(1), 109-113.
- King, T., Jenkins, D., & Gabbett, T. (2009). A time-motion analysis of professional rugby league match-play. *Journal of Sports Sciences*, 27(3), 213-219.

- Lago-Penas, C., & Lago-Ballesteros, J. (2011). Game location and team quality effects on performance profiles in professional soccer. *Journal of Sports Science and Medicine*, *10*(3), 465-471.
- Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *Journal of Sports Sciences*, *27*(13), 1463-1469.
- Lago, C., Casais, L., Dominguez, E., & Sampaio, J. (2010). The effects of situational variables on distance covered at various speeds in elite soccer. *European Journal of Sport Science*, *10*(2), 103-109.
- Lago, C., & Martin, R. (2007). Determinants of possession of the ball in soccer. *Journal of Sports Sciences*, *25*(9), 969-974.
- Link, D., & Hoernig, M. (2017). Individual ball possession in soccer. *PLoS One*, *12*(7), e0179953. doi:10.1371/journal.pone.0179953
- Malone, J. J., Lovell, R., Varley, M. C., & Coutts, A. J. (2016). Unpacking the Black Box: Applications and Considerations for Using GPS Devices in Sport. *International Journal of Sports Physiology and Performance*, *12*(Suppl 2), S2-18-S12-26.
- Manzi, V., Impellizzeri, F., & Castagna, C. (2014). Aerobic fitness ecological validity in elite soccer players: a metabolic power approach. *Journal of Strength and Conditioning Research*, *28*(4), 914-919.
- McKenna, M. J., Bangsbo, J., & Renaud, J. M. (2008). Muscle K⁺, Na⁺, and Cl disturbances and Na⁺-K⁺ pump inactivation: implications for fatigue. *Journal of Applied Physiology*, *104*(1), 288-295.
- McLean, D. A. (1992). Analysis of the physical demands of international rugby union. *Journal of Sports Sciences*, *10*(3), 285-296.
- Mooney, M., O'Brien, B., Cormack, S., Coutts, A., Berry, J., et al. (2011). The relationship between physical capacity and match performance in elite Australian football: a mediation approach. *Journal of Science and Medicine in Sport*, *14*(5), 447-452.
- Mooney, M. G., Cormack, S., O'Brien B, J., Morgan, W. M., & McGuigan, M. (2013). Impact of neuromuscular fatigue on match exercise intensity and performance in elite Australian football. *Journal of Strength and Conditioning Research*, *27*(1), 166-173.
- Murray, N. B., Gabbett, T. J., Townshend, A. D., & Blanch, P. (2017). Calculating acute:chronic workload ratios using exponentially weighted moving averages provides a more sensitive indicator of injury likelihood than rolling averages. *British Journal of Sports Medicine*, *51*(9), 749-754.

- Murray, N. B., Gabbett, T. J., Townshend, A. D., Hulin, B. T., & McLellan, C. P. (2017). Individual and combined effects of acute and chronic running loads on injury risk in elite Australian footballers. *Scandinavian Journal of Medicine and Science in Sports*, 27(9), 990-998.
- O'Shaughnessy, D. M. (2006). Possession Versus Position: Strategic Evaluation in AFL. *Journal of Sports Science and Medicine*, 5(4), 533-540.
- Osgnach, C., Paolini, E., Roberti, V., Vettor, M., & E di Prampero, P. (2016). *Metabolic Power and Oxygen Consumption in Team Sports: A Brief Response to Buchheit et al* (Vol. 37).
- Osgnach, C., Poser, S., Bernardini, R., Rinaldo, R., & di Prampero, P. E. (2010). Energy cost and metabolic power in elite soccer: a new match analysis approach. *Medicine and Science in Sports and Exercise*, 42(1), 170-178.
- Petersen, C., Pyne, D., Portus, M., & Dawson, B. (2009). Validity and reliability of GPS units to monitor cricket-specific movement patterns. *International Journal of Sports Physiology and Performance*, 4(3), 381-393.
- Pollard, R., & Pollard, G. (2005). Long-term trends in home advantage in professional team sports in North America and England (1876-2003). *Journal of Sports Sciences*, 23(4), 337-350.
- Pyne, D., Gardner, A., Sheehan, K., & Hopkins, W. (2006). Positional differences in fitness and anthropometric characteristics in Australian football. *Journal of Science and Medicine in Sport*, 9(1), 143-150.
- Rampinini, E., Coutts, A. J., Castagna, C., Sassi, R., & Impellizzeri, F. M. (2007). Variation in top level soccer match performance. *International Journal of Sports Medicine*, 28(12), 1018-1024.
- Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisloff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *Journal of Science and Medicine in Sport*, 12(1), 227-233.
- Richmond, L. K., Dawson, B., Stewart, G., Cormack, S., Hillman, D. R., et al. (2007). The effect of interstate travel on the sleep patterns and performance of elite Australian Rules footballers. *Journal of Science and Medicine in Sport*, 10(4), 252-258.
- Robertson, S., Back, N., & Bartlett, J. D. (2016). Explaining match outcome in elite Australian Rules football using team performance indicators. *Journal of Sports Sciences*, 34(7), 637-644.
- Robertson, S., Woods, C., & Gatin, P. (2015). Predicting higher selection in elite junior Australian Rules football: The influence of physical performance and anthropometric attributes. *Journal of Science and Medicine in Sport*, 18(5), 601-606.

- Ryan, S., Coutts, A. J., Hocking, J., & Kempton, T. (2017). Factors Affecting Match Running Performance in Professional Australian Football. *International Journal of Sports Physiology and Performance*, 1-19. doi:10.1123/ijsp.2016-0586
- Scott, M. T., Scott, T. J., & Kelly, V. G. (2016). The Validity and Reliability of Global Positioning Systems in Team Sport: A Brief Review. *Journal of Strength and Conditioning Research*, 30(5), 1470-1490.
- Spencer, M., Rechichi, C., Lawrence, S., Dawson, B., Bishop, D., et al. (2005). Time-motion analysis of elite field hockey during several games in succession: a tournament scenario. *Journal of Science and Medicine in Sport*, 8(4), 382-391.
- Stewart, M., Mitchell, H., & Stavros, C. (2007). Moneyball applied: Econometrics and the identification and recruitment of elite Australian footballers. *International Journal of Sport Finance*, 2(4), 231-248.
- Sullivan, C., Bilsborough, J. C., Cianciosi, M., Hocking, J., Cordy, J., et al. (2014a). Match score affects activity profile and skill performance in professional Australian Football players. *Journal of Science and Medicine in Sport*, 17(3), 326-331.
- Sullivan, C., Bilsborough, J. C., Cianciosi, M., Hocking, J., Cordy, J. T., et al. (2014b). Factors affecting match performance in professional Australian football. *International Journal of Sports Physiology and Performance*, 9(3), 561-566.
- Sweeting, A. J., Aughey, R. J., Cormack, S. J., & Morgan, S. (2017). Discovering frequently recurring movement sequences in team-sport athlete spatiotemporal data. *Journal of Sports Sciences*, 35(24), 2439-2445.
- Taylor, J. L., & Gandevia, S. C. (2008). A comparison of central aspects of fatigue in submaximal and maximal voluntary contractions. *Journal Applied Physiology*, 104(2), 542-550.
- Terry, P. C., Walrond, N., & Carron, A. V. (1998). The influence of game location on athletes' psychological states. *Journal of Science and Medicine in Sport*, 1(1), 29-37.
- Varley, M., Jaspers, A., Helsen, W. F., & Malone, J. J. (2017). Methodological Considerations When Quantifying High-Intensity Efforts in Team Sport Using Global Positioning System Technology. *International Journal of Sports Physiology and Performance*, 12(8), 1059-1068.
- Varley, M. C., Gabbett, T., & Aughey, R. J. (2014). Activity profiles of professional soccer, rugby league and Australian football match play. *Journal of Sports Sciences*, 32(20), 1858-1866.
- Waldron, M., Worsfold, P., Twist, C., & Lamb, K. (2011). Concurrent validity and test-retest reliability of a global positioning system (GPS) and timing gates to assess sprint performance variables. *Journal of Sports Sciences*, 29(15), 1613-1619.

- Walter, S. D., Eliasziw, M., & Donner, A. (1998). Sample size and optimal designs for reliability studies. *Statistics in Medicine*, *17*(1), 101-110.
- Walter, S. D., Gafni, A., & Birch, S. (2007). Estimation, power and sample size calculations for stochastic cost and effectiveness analysis. *Pharmacoeconomics*, *25*(6), 455-466.
- Walters, S. J. (2004). Sample size and power estimation for studies with health related quality of life outcomes: a comparison of four methods using the SF-36. *Health and Quality of Life Outcomes*, *2*, 26.
- Walters, S. J., & Campbell, M. J. (2005). The use of bootstrap methods for estimating sample size and analysing health-related quality of life outcomes. *Statistics in Medicine*, *24*(7), 1075-1102.
- Wisbey, B., Montgomery, P. G., Pyne, D. B., & Rattray, B. (2010). Quantifying movement demands of AFL football using GPS tracking. *Journal of Science and Medicine in Sport*, *13*(5), 531-536.
- Woods, C. T., Bruce, L., Veale, J. P., & Robertson, S. (2016). The relationship between game-based performance indicators and developmental level in junior Australian football: Implications for coaching. *Journal of Sports Sciences*, *34*(23), 2165-2169.
- Woods, C. T., Joyce, C., & Robertson, S. (2016). What are talent scouts actually identifying? Investigating the physical and technical skill match activity profiles of drafted and non-drafted U18 Australian footballers. *Journal of Science and Medicine in Sport*, *19*(5), 419-423.
- Woods, C. T., Veale, J. P., Collier, N., & Robertson, S. (2017). The use of player physical and technical skill match activity profiles to predict position in the Australian Football League draft. *Journal of Sports Sciences*, *35*(4), 325-330.
- Young, W. B., Newton, R. U., Doyle, T. L. A., Chapman, D., Cormack, S., et al. (2005). Physiological and anthropometric characteristics of starters and non-starters and playing positions in elite Australian Rules football: a case study. *Journal of Science and Medicine in Sport*, *8*(3), 333-345.
- Youngstedt, S. D., & O'Connor, P. J. (1999). The influence of air travel on athletic performance. *Sports Medicine*, *28*(3), 197-207.

APPENDICES

APPENDIX A: UNIVERSITY ETHICS APPROVAL

Appendix A: University Ethics Approval

Dear Applicant

Thank you for your response to the Committee's comments for your project titled, "The Influence of the Phases of match-play on the Physical, Technical and Tactical Profiles of Professional Australian Football". Your response satisfactorily addresses the concerns and questions raised by the Committee who agreed that the application now meets the requirements of the NHMRC National Statement on Ethical Conduct in Human Research (2007). I am pleased to inform you that ethics approval is now granted.

Your approval number is UTS HREC REF NO. 2014000101

Please note that the ethical conduct of research is an on-going process. The National Statement on Ethical Conduct in Research Involving Humans requires us to obtain a report about the progress of the research, and in particular about any changes to the research which may have ethical implications. This report form must be completed at least annually, and at the end of the project (if it takes more than a year). The Ethics Secretariat will contact you when it is time to complete your first report.

I also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

You should consider this your official letter of approval. If you require a hardcopy please contact Research.Ethics@uts.edu.au.

If you have any queries about your ethics approval, or require any amendments to your research in the future, please do not hesitate to contact Research.Ethics@uts.edu.au.

Yours sincerely,

Professor Marion Haas

Chairperson

UTS Human Research Ethics Committee

C/- Research & Innovation Office

University of Technology, Sydney

APPENDIX B: RESEARCH CONSENT FORM



CONSENT FORM

The Influence of the Phases of match-play on the Physical, Technical and Tactical Profiles of Professional Australian Football

I _____ (*participant's name*) agree to participate in the research project "The Influence of the Phases of match-play on the Physical, Technical and Tactical Profiles of Professional Australian Football" (HREC Approval Number: 2014000101) being conducted by Michael Rennie (Kuring-gai Campus, University of Technology, Sydney, Eton Rd, Lindfield, NSW 2070, 0421770418) of the University of Technology, Sydney for his degree Doctor of Philosophy. No funding has been acquired for this study.

I understand that the purpose of this study is investigate various factors that lead to points being scored and factors that lead to winning performances in professional Australian Football. I understand that game data may provide evidence regarding how goals are scored, and how teams eventually win matches.

I understand that I have been asked to participate in this research because of my expertise and skill as a professional Australian Football Player and that my participation in this study will involve wearing a global positioning systems (GPS) unit during AFL matches. This study does not require any additional time or inconvenience to the participant. Wearing a GPS unit during matches poses a slight risk to participants. The risks to participants have been minimised by designed padded pouches that have been sewn into the players' guernsey. Additionally, the most up-to-date GPS units have been purchased which are small in size and designed to capitulate if forcefully impacted, therefore reducing the risk of injury to players.

I am aware that I can contact Michael or his supervisor Dr Mark Watsford if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish, without consequences, and without giving a reason. In the event that you withdraw from this study, it is guaranteed that your withdrawal will not affect your working relationship with the researchers or the Sydney Swans Football club.

I agree that Michael Rennie has clearly explained the purpose, duration and my involvement in this study. He has also answered all my questions fully and clearly.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

Signature (participant)

____/____/____

Signature (researcher or delegate)

____/____/____

NOTE:

This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: +61 2 9514 9772 Research.Ethics@uts.edu.au) and quote the UTS HREC reference number. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

APPENDIX C: INFORMATION SHEET TO PARTICIPANTS



INFORMATION SHEET

The Influence of the Phases of match-play on the Physical, Technical and Tactical Profiles of Professional Australian Football (UTS HREC APPROVAL: 2014000101)

WHO IS DOING THE RESEARCH?

My name is Michael Rennie and I am a PhD student at UTS. My supervisor is Dr Mark Watsford, a senior lecturer in exercise and sport science at UTS.

WHAT IS THIS RESEARCH ABOUT?

This research is to find out about investigating key performance indicators in professional Australian Football. Specifically, this study aims to determine factors that contribute to goals being scored, as well as factors contributing to wins and losses. GPS, skill and positional data will be analysed following each match of the 2014 season.

IF I SAY YES, WHAT WILL IT INVOLVE?

This study will involve players wearing a GPS unit during AFL matches in the 2014 season. This running data, along with video analysis will be used to analyse various factors that lead to strong team performances. Your participation in this study does not involve anything above and beyond your current involvement as a professional AFL player at the Sydney Swans Football Club.

ARE THERE ANY RISKS/INCONVENIENCE?

Your participation in this research poses very few, if any risks above and beyond the normal rigours of competing in professional AFL matches. Additionally, this research does not involve the collection of data that is not already collected during matches by the football club.

WHY HAVE I BEEN ASKED?

As a professional player in an AFL team, you can provide vital and valuable information about key performance indicators that lead to our team's success. We believe that there are specific factors that contribute to our team scoring points. Additionally, we believe that an improved understanding of the differences between wins and losses will lead to improved performance at our football club.

DO I HAVE TO SAY YES?

You don't have to say yes.

WHAT WILL HAPPEN IF I SAY NO?

Nothing. I will thank you for your time so far and won't contact you about this research again.

IF I SAY YES, CAN I CHANGE MY MIND LATER?

You can change your mind at any time and you don't have to say why. I will thank you for your time so far and won't contact you about this research again.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I, Michael Rennie or my supervisor Dr Mark Watsford can help you with. please feel free to contact me (us) on:

Michael Rennie Mobile:

Mark Watsford: (02) 9514 5195

If you would like to talk to someone who is not connected with the research, you may contact the Research Ethics Officer on 02 9514 9772, and quote this number (2014000101)