Physical Qualities and Match Demands of Female Australian Football

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This thesis is submitted in accordance with the requirements of The Graduate Research Office, Australian Catholic University for the degree of Doctor of Philosophy by Georgia Black.

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Declaration

This thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma. No parts of this thesis have been submitted towards the award of any other degree or diploma in any other tertiary institution. No other person's work has been used without due acknowledgment in the main text of the thesis. All research procedures reported in the thesis received the approval of the relevant Ethics/Safety Committees (where required).

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Author	Roles	Contribution
Georgia Black	Conceived and designed experiments Performed experiments Analysed data Preparation of initial draft of manuscript	65%
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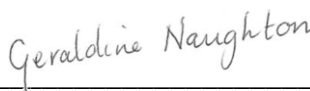| Author	Roles	Contribution
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Abstract

Australian football (AF) is arguably the most popular sport in Australia, with over one million people participating in domestic AF annually. As participation rates have continued to rise, it is the growth of female AF that has drawn further attention to the sport in the last two years. Despite the introduction of the national women's Australian football competition (AFLW) in 2017 and the 400,000 females who participate in recreational AF Australia-wide, there is currently no research to inform training practices. Although the physical match demands of elite male AF have been well established, the differences in physical qualities between male and female athletes emphasises the need to explore the demands of the female game.

Athletes from intermittent team sports are required to train multiple physical qualities in order to improve on-field performances. While certain physical qualities have shown to influence activity profiles in a number of sports, little is understood about how these qualities affect running performance in female AF players. Determining physical tests that are able to (1) discriminate between selected and non-selected players and (2) influence running performance are important for future athletic development. In addition, a number of contextual factors may also influence running performances in games, such as match outcome, opposition ranking and positional differences. Despite previous research focusing on male AF, it is now necessary to explore female AF player responses to potentially key influences on performance.

The overall aim of this thesis was to establish the physical quality profile of female AF and explore factors influencing match activities. The thesis contains 5 individual, but linked studies that investigated the aforementioned aims targeting female AF. Study 1

examined the influence of physical qualities on team selection as well as the relationship between physical qualities and match running performances. Results showed selected players were faster over 30 m and covered greater high-intensity intermittent fitness (Yo-Yo Intermittent Recovery Test Level 1, Yo-Yo IR1) distances than unselected players. Furthermore, these physical qualities were associated with greater distances covered at high-speed during match-play in selected compared with unselected players.

Study 2 determined whether better performances on the high-intensity intermittent running test, were associated with greater distances covered during peak, as well as subsequent and mean periods of running during matches. The results suggested the development of aerobic fitness and high-intensity running ability in female AF players is important to enable greater peak period performances and to improve players' abilities to maintain a greater average running match intensity.

Study 3 investigated the influence of high-intensity running ability and player rotations (interchanges) on match running performance. Higher Yo-Yo performers covered greater distances during their rotation bouts than the lower Yo-Yo group. In addition, short (4-6 minutes) and moderate (6-12 minutes) on-field bouts resulted in greater relative total and high-speed distances compared with longer (12-18 minutes) on-field bouts and whole-quarter efforts (> 18 minutes). Collectively, these findings highlight the development of high-intensity intermittent running ability and the use of short-to-moderate length rotation bouts to promote greater running performances during female AF match-play.

Match activity profiles were further explored in Study 4, which investigated the influence of match quarter, game outcome, and opposition ranking on running demands. The findings demonstrated that match running performances declined during the second half of female AF, irrespective of playing position. Defensive players were required to work at greater match intensities during losses and against higher quality opposition. These data indicate that rotations could be utilised more frequently both early in the match and during the second half to minimise the effects of fatigue and increase running intensity.

Finally, Study 5 investigated the skills important for success in the AFLW competition. Despite the early stages of "elite" female competition, the results revealed that skill performance remains central to success. Furthermore, results show the ratio between inside 50 entries and goals scored and uncontested possessions are the greatest predictors of match success in female football.

Collectively, this program of research highlighted the importance of physical qualities to success in Women's AF and provided initial benchmark intensities that can be used to develop training programs that prepare these athletes for the physical demands of the game. For the first time, these results showed that high-intensity running ability appeared to have the capacity to increase or sustain the intensity of match activity in females. Nonetheless, other factors, such as skill efficiency, uncontested possessions, contested marks and effective 'inside 50' entries also influenced overall performance. Results from this thesis can be used to inform existing coaching practices and more

rigorously support the next wave of research that should focus on the longevity of women in football codes.

Table of Contents

List of Tables

Table 9.2. A comparison of physical variables between female and male AF players

Table 9.3. A comparison of physical variables between female AF and soccer players

List of Figures

List of Abbreviations

=	equal
≥	greater than or equal to
≤	less than or equal to
%	percent
±	plus/minus
AF	Australian football
AFL	Australian Football League
AFLW	Women's Australian Football League
CI	Confidence interval
cm	Centimetre
CMJ	Countermovement jump
CV	Coefficient of variation
ES	Effect size
GPS	Global positioning system
HS	High-speed
kg	Kilogram
$km.hr^{-1}$	Kilometres per hour
LS	Low-speed
m	Metres

m.min^{-1} Metres per minute

m.sec^{-1} Metres per second

MAS   Maximal aerobic speed

MS   Moderate-speed

MSFT   Multi-stage fitness test

n   Number

p   Probability

RL   Rugby league

SD   Standard deviation

sec   Second

SWC   Smallest worthwhile change

TD   Total distance

TE   Typical error

VJ   Vertical jump

VO$_{2\,max}$ Maximal aerobic power

W.kg^{-1} Watts per kilogram

Yo-Yo IR1   Yo-Yo intermittent recovery test Level 1

Yo-Yo IR2   Yo-Yo intermittent recovery test Level 2

VJ   Vertical jump

Navigation of thesis

Understanding the demands of match-play is important for the development of sport-specific training. The work presented in this thesis highlights the gaps in the current literature, as discussed in the introduction, and also builds on the understanding of female Australian football match demands.

All of the studies in this thesis are inherently linked as the first three studies investigate the influence of physical qualities on average match demands, intense periods of match-play and on-field rotation bouts. The first study examined the influence of lower-body power, acceleration, speed and high-intensity running ability on team selection and activity profiles in female AF. The effect of high-intensity running ability on running performance during intense periods of match activity and the physical responses to intense periods of play were explored in study 2. The third study investigated the differences in running intensity between whole-quarter and rotated players during match quarters. The influences of high-intensity running ability on pacing strategies during an on-field bout were also considered. The final component of study 3 sought to understand changes in pacing strategies throughout an on-field bout during short (4-6 minutes), moderate (7-12 minutes) and long (12-18 minutes) bouts.

The fourth study addressed the limitations of the first three studies and identified the influence of contextual factors such as, match quarter, match outcome and opposition ranking on running performance. The final study in the thesis explored the skill profile of the national female AF competition (AFLW) to gain an understanding of the skill involvements required for match success. Additionally, the influence of score margin,

and the relationship between ladder position and skill involvements in female AF were also explored. The rationale for each study included in this thesis is explained in the following general introduction.

Chapter 1: General Introduction

1.1 Overview

Australian football (AF) is an invasive team sport which requires players to move the ball down the field using either foot (kicking) or hand (handball) skills. The objective of the game is to kick the ball through the goal posts and score more points than the opposing team. Australian football teams consist of 18 individual players situated at both ends of the field that compete against the opposing teams in a player-on-player format. Australian football is a popular team sport for both club supporters and domestic participants in Australia. The total attendance for the Australian Football League (AFL) matches exceeded 6.3 million and domestic participation was recorded at 1.4 million in 2016 [1].

Female sport has seen a monumental shift in popularity over the past 5 years with large sponsorship and television deals supporting female netball, soccer, rugby league and rugby sevens competitions both nationally and internationally. However, with this rapid expansion, increasing investment and subsequent interest from the general public, little attention is given to understanding the demands of female competitions and the preparation of players. The inaugural women's Australian football league (AFLW), launched in 2017 with eight teams competing for the first premiership title. A crowd of 25,000 attended the opening match of the season and a further 1.4 million watched via the television broadcast [1]. Despite the support and media attention, it is important to note that these women progressed from recreational, community level players to semi-elite athletes over a period of only eight weeks. Additionally, although these semi-elite players may have had access to knowledgeable coaching and conditioning practitioners during the short preseason (8 weeks) and in-season (8 weeks) phases, these players were

still required to play in the state-based recreational competition without this practitioner support. It has been well-established that understanding match demands is important for the development of game-specific training [2-4] and currently there is limited research available to assist in this training prescription.

The demands and activity profiles of male field-based team sports have been extensively examined [5-8]. Investigations have not only included the average demands of sports [5, 7] but also differences in positional activity profiles [9, 10], running performance across playing standards [11-13], the influence of match-related fatigue [14, 15] and identified intense passages of match-play and responses to these peak periods [16, 17]. To date, results from research has allowed practitioners to develop game-specific, position-specific and "worst-case-scenario" drills in an attempt to expose male athletes to possible match-day situations. The importance of developing physical fitness qualities to improve performance is well established among male football players. Studies of elite level male players have shown that superior high-intensity intermittent running ability contributes to greater high-speed distances covered during soccer match-play [18]. In addition, greater intermittent fitness has been shown to slow the rate of fatigue across competition [19]. Similarly, greater sprint speed among elite level male athletes has been associated with greater match distances covered [12] and a greater attacking ability [20] in team sports. Although a plethora of literature supports male field-based team sports, little is understood about the influence of physical qualities on activity profiles in female match-play, particularly within the sport of AF.

Although the physiological demands imposed on team sport athletes are comparable across genders [21], on average female athletes cover less relative distances than their male counterparts [22]. A number of studies have published information surrounding the average demands of female soccer [23, 24], rugby sevens [25, 26] and hockey [27, 28] match-play. While associations have been made between high-intensity intermittent running ability and distances covered during matches [22], to date, no other physical fitness qualities have been associated with match running performances in female athletes. To support professional quality of performance and promote the broader possibilities of females in team sports, an urgent need exists to investigate the influence of physical qualities on activity profiles in female athletes, specifically in the newly emerging population of female AF players.

Running performances of male AF players are known to decline as matches progress [29]. More specifically, running performance declines across match halves [29], quarters [29, 30] and following intense periods of match-play [16]. While some aspects of results are conflicting, consistent reductions in distances covered are reported, either at low- [31] or high-speeds [32], as a consequence of match-related fatigue.

Researchers in female soccer have reported 3 to 8% reductions in distances covered between the first and second halves [24, 33]. Similarly, monitoring of both national and international competitions showed 14 to 17% reductions in relative distances covered in the second half of women's rugby sevens matches, respectively [34]. Although percentage decrement in work rates are not consistent across published research in women's sport, the limited information available suggests that running performances

decline across a match regardless of competition level or sport.

Collectively the literature supports the notion that declines in performance are inevitable across matches; however, research has also linked these decrements in running intensity to self-selected pacing strategies [31, 35, 36]. The majority of evidence suggests that, as matches progress, players adopt a self-selected pacing strategy in which they reduce low-speed activity (<15 km.hr^{-1}) in an attempt to maintain high-speed ($\geq$15 km.hr^{-1}) activities [31, 37].

Moreover, a number of contextual factors are postulated to influence the pacing strategies adopted during team sport matches. For example, interchanged rugby league players set a higher pacing strategy than whole-match players [36], suggesting greater intensities are possible when they are exerted over shorter match periods compared with longer match periods. In addition, winning rugby league teams tend to adopt a higher intensity pacing strategy, covering greater distances than losing teams [35]. Superior high-intensity running ability has also been associated with higher pacing strategies than those with a lower high-intensity running ability [19]. However, the influence of contextual factors and pacing strategies within rotations in AF players is not well understood and as such, investigations are warranted.

Although understanding match running demands are important for implementing appropriate training programs, arguably the more important component for match success is skill proficiency. Skill involvements have been consistently associated with

success in male AF [38, 39]. In contrast, the skill involvements that determine success in female football remain speculative and thus, research is required to understand skill performance in female AF.

Participation in female Australian football has increased markedly in the last 5 years and is continuing to increase with competitions expanding nationwide. With limited research available and, the development of the national women's competition in 2017 it is possible players are under prepared for performance or at risk of overtraining and injury. It has been acknowledged that excessive and rapid increases in training loads may increase the risk of non-contact, soft tissue injuries [40]. Intuitively, the opportunities available to female athletes who are new to professional sport require a stronger evidence base to ensure appropriate training and sports development

1.2 Aims

The overall aim of the current research was to determine the influence of physical qualities on activity profiles in female AF match-play. Furthermore, the research aimed to investigate the influence of rotations, opposition rank and match outcome on match running performance in female footballers. Additionally, the skill involvements important for match success were also explored. Results from this research will help to inform coaches and practitioners on the match demands of football and provide a basic understanding of the physical qualities important for current and future success.

To assist in the development and understanding of female AF, five studies were conducted (Figure 1.1) to fill existing gaps in the literature. Study 1 compared differences in physical qualities and activity profiles of players selected into the Queensland Academy team with players from the same squad who were not selected. This study further aimed to explore the relationships between physical qualities and match activity profiles in state-league female footballers. Study 2 aimed to advance the understanding of how the physical fitness of players influenced peak match running periods. Study 3 examined the role of rotations on running performance during quarters and further investigated the influence of fitness on running demands during rotation bouts. Study 4 explored changes in pacing strategies across matches in state-league female AF players. Study 4 also sought to understand changes in pacing strategies based on match outcome and opposition ranking. The final study aimed to identify the skill profile of winning and losing teams from the national competition (AFLW). Additionally, Study 5 investigated the relationship between ladder position and skill profiles. This is the first research to investigate the activity profiles of female AF matches and to examine the influence of physical qualities on running performances. Sports scientists are yet to understand the average demands of competition and the importance of physical fitness in the female AF population. Furthermore, identifying skills that are important for success in the highest tier of competitive female AF will further aid in the development of both the female footballers and the level of competition in the sport.

Thesis Title

Physical qualities and match demands of female Australian football

Literature Review

Study 1

Influence of physical qualities on activity profiles

Study 2

Physical fitness and intense exercise periods

Study 3

Physical fitness on running performance during rotation bouts in midfielders

Study 4

Contextual factors on running performance during match play

Study 5

A skill profile of female AF and importance for competition success

Figure 1.1 Schematic overview of the studies that comprise this thesis.

1.3 Research Questions and Alternative Hypotheses

Table 1.1 outlines the research questions and alternative hypotheses posed within this program of research.

Table 1.1. Thesis research questions and alternative hypotheses

	Research Questions		Alternative Hypotheses
Study 1	Do physical qualities (lower body power, speed and high-intensity running ability) discriminate between selected and non-selected female AF players?	-	*Selected players will possess superior power, speed and high-intensity running ability than non-selected players*
	What is the relationship between physical qualities and activity profiles?	-	*Speed, power and high-intensity running ability will be associated with greater distances covered at high-speed*
	Do activity profiles differ across positional groups?	-	*Midfielders will cover greater distances than the other positional groups*
Study 2	Are there positional differences in peak periods of match running?	-	*Midfielders will cover greater distances during peak periods than half-line players*
	Does high-intensity intermittent running ability influence peak running intensities and the responses to peak periods of match-play?	-	*Higher fitness players will exhibit greater activity profiles during the peak, subsequent and mean periods*
Study 3	How do pacing strategies differ between rotated and whole-quarter players during matches?	-	*Rotated players will possess a higher match intensity across all stages of their on-field bout compared to whole-quarter players*
	Does high-intensity running ability influence running performance during rotation bouts?	-	*Players with superior high-intensity intermittent running abilities will perform at a higher match intensity than lower fitness players across on-field bouts*
	How do pacing strategies change across short, moderate and long rotation bouts?	-	*Shorter on-field bouts will elicit greater running intensities than longer bouts*

Table 1.1. Continued

	Research Question		Alternative Hypotheses
Study 4	Do pacing strategies differ across positional groups?	-	*Half-backs will exhibit a higher pacing strategy when losing than winning and half-forwards will exhibit a higher pacing strategy when winning than losing*
	What influence does match outcome and opposition ranking have on changes in running performance across matches?	-	*Winning teams will have a lower activity profile than their losing counterparts*
		-	*Bottom 4 teams will have to complete more total- and high-speed running than Top 4 teams*
Study 5	What are the greatest skill predictors of match success in female football?	-	*Winning teams will perform a greater number of skill involvements, at a greater efficiency than losing teams, however disposal efficiency and 'inside 50's' will be the greater predictors of match outcome*
	What is the influence of winning margin on the skill profile in female football?	-	*Smaller winning margins will be associated with greater disposal efficiency*
	What is the relationship between ladder position and skill profiles?	-	*Higher ladder position will be associated with a greater number of skill involvements and a lower ratio between 'inside 50's' and goals scored*

Chapter 2: Literature Review

2.1 Introduction

Global positioning system (GPS) technology is now widely used in the Australian Football League (AFL) for both game and training analyses. Data from GPS provides detailed descriptions of players' movements and hence their activity profiles during matches. Despite the match demands of Australian Football (AF) being extensively researched, the activity profiles of female AF players are yet to be investigated. It is well established that individualized training programs are based on the physical qualities and the demands of the sport offer the greatest training benefit [41]. Furthermore, while it is globally accepted that high-speed running ability is paramount for performance in high-intensity, intermittent team sports [15], conflicting evidence surrounds the influence of high-intensity activity on match success [39, 42, 43]. Finally, a multitude of research has highlighted a range of physical fitness qualities important for success in a number of field-based team sports [22, 44-46]. Understanding the match demands and the physical qualities required for success in sports allows coaches to prescribe training that appropriately prepares players for competition. The following literature review traces the origins of time-motion analysis, demands of team sports, and the influence of physical qualities on performance.

2.2 History of Time-Motion Analysis

Optimising physical fitness has become an essential component of player and team preparation [47]. Consequently, time-motion analysis has been used extensively to determine the movement patterns and physical demands of high-intensity intermittent team sports. Player tracking during competition was originally established using manual video-based motion analysis [48], which included notational analysis of key

sport-specific 'events'. Video footage was then coded, analysed and interpreted [49]. These original techniques were not only labour-intensive, but also required considerable training, time and precision from the game analysts. Furthermore, these attributes of manual time-motion analysis also made it difficult for analysts to track multiple players simultaneously and limited the efficiency of real-time tracking [47]. Few video analysis systems had the ability to track multiple players throughout a match simultaneously.

In the past two decades, computer-based tracking systems have been widely used to analyse the match demands of field-based sports [50-52]. The AMISCO Pro system was the first system developed to achieve concurrent analysis of the work rate of every player in a team throughout an entire soccer match [51]. Using a video analysis system, AMISCO Pro provided an activity profile of each player throughout the match with detailed analyses of player and ball movements up to 25 times per second [51]. More recently, Prozone® has provided another video-based system that tracks players' movement patterns within each 0.1 sec trajectory, with the average velocity across the 0.5 s period computed from the distance covered over time. Independent testing of the Prozone® system showed a valid measure of soccer activity profiles [52]. The average velocity recorded by the Prozone® system has shown an excellent correlation with timing gates [52] when athletes performed maximal curved sprints ranging from 15 to 60 m. While these systems have reported acceptable reliability for reporting match demands, most video tracking systems used in elite soccer lack real-time analysis; with the data generally available within 24 to 36 hours post-match [47]. Further to this, computer-based tracking systems are expensive and are extremely labour intensive;

resulting in practitioners searching for alternative methods to monitor player performance.

Table 2.1 describes the advantages and disadvantages of time-motion analysis techniques. The use of GPS technology is preferred by researchers and practitioners and is regularly applied in the team sport environment. As GPS technology has the ability to track multiple players simultaneously, and requires no permanent installation of cameras, it has become increasingly popular in intermittent team sports, such as AF, soccer, field hockey, rugby union, and rugby league. Advantages of GPS devices include the provision of quantitative information on the position, displacement, velocity, and acceleration of field sport athletes that could not be previously reported from video time-motion analysis [53]. Other advantages of GPS units for monitoring on-field performances include; i) their ability to collect live data and inform the timing of player rotations/interchanges; ii) their light-weight and relatively low cost compared with other sophisticated devices; and iii) their portability.

Over the past 10 years, GPS application has grown in popularity and began with team sports first using 1 Hz units [50] to gain a better understanding of the training and match activity profiles of their athletes. However, researchers quickly identified the inability of these units to detect rapid changes in velocity that are commonplace in team sport athletes [8, 54]. The sampling rate of the GPS units has since been improved to 10 Hz and units are now regularly applied in fast-paced team sports, such as AF, hockey and rugby league [8]. The use of GPS units has allowed coaches to understand the activity profiles of their respective sports, including knowledge of distances covered in different

speed bands. Furthermore, GPS units have also been applied to compare positional activity profiles [9], understand differences in running performance across playing standards [10], detect match-related fatigue [15, 55], and identify peak periods of match-play [14, 16, 17].

Table 2.1. A summary of previously reviewed advantages and disadvantages of time-motion analysis techniques

Example authors	Time-motion analysis method	Advantages	Disadvantages
Gabbett & Mulvey [3]	Notational and video-based analysis	✓ Provide information on the physical and technical demands ✓ Reliable and valid measure of match demands	✗ Manual labour ✗ Skilled operator to collect and analyse data ✗ No real-time feedback ✗ Can only track one player at one time
Edgecomb & Norton [50]	Computer-based tracking	✓ Multiple player tracking ✓ No player instrumentation	✗ No real-time feedback ✗ Expensive ✗ Multiple camera installation ✗ Skilled operator to collect and analyse data
Varley et al [56]	Global Positioning Systems	✓ Multiple player tracking ✓ Real-time feedback ✓ User-friendly	✗ Players must be equipped with a GPS on the upper thoracic region ✗ No information on the technical demands

2.2.1 Validity and Reliability of Global Positioning Systems

Multiple researchers have reported GPS devices to be a valid and reliable method for tracking total distance [50]. However, GPS for assessment of short, high-speed running and change of direction activities [57] has shown poor validity and reliability. Conversely, increasing the sampling rate of the GPS unit from 1 Hz to 5 Hz corresponded with higher reliability and validity when reporting velocity and acceleration, especially over shorter distances [56, 57]. The 5 Hz MinimaxX GPS units now have acceptable validity and reliability for estimating longer distances at walking through to striding speeds [58, 59]. Short, intermittent spurts of high-intensity exercise are characteristic of most running-based team sports, therefore valid and reliable measurements are vital to the accuracy of game demands.

It is widely accepted that increasing the GPS sampling frequency to 10 Hz offers even greater reliability and validity than 5 Hz units (Table 2.2) [56]. Indeed the 10 Hz MinimaxX GPS devices are associated with a six-fold better reliability than the 5 Hz units for measuring instantaneous velocity during tasks completed at a range of velocities [56]. The inter-device reliability of these 10 Hz units has also been investigated, with the results indicating an inter-device coefficient of variation (CV) of 1.3% and 0.7% for sprints over 15 m and 30 m, respectively [60]. Moreover, the 10 Hz units have reported acceptable reliability for detecting changes in physical activity during team sport matches [61].

Validity of GPS units in team sports is vital to understanding match demands and subsequent training prescription. During intermittent shuttle running over a distance of

70 m, acceptable validity of measures were reported for total distance and high-speed running distance from multiple 10 Hz GPS units (CV = 1.9% and CV = 4.7%, respectively) [62]. When comparing 10 Hz and 15 Hz units (5 Hz interpolated to 15 Hz), the 15 Hz GPS units reported a lower validity for total distance and average peak speed than 10 Hz units [63]. However, irrespective of sampling rate, as the speed of movement increases and the distance decreases, the validity of GPS units decline [63]. Thus, the high-intensity and sports-specific precision of GPS devices remains a work in progress. Nonetheless, results of studies support the use of 10 Hz units and are often interpreted within the limitations of these devices.

Table 2.2. Reliability of the 1 Hz, 5 Hz and 10 Hz Catapult GPS units during walking and sprinting over a range of distances

Author	Sampling Frequency	Movement	Distance	CV (%)	SWC (%)
Jennings et al [57]	1 Hz	Walking	10 m	30.8	5.4
			20 m	20.4	6.8
			40 m	7.0	7.2
		Sprinting	10 m	77.2	6.4
			20 m	44.9	8.8
			40 m	11.5	9.0
Jennings et al [57]	5 Hz	Walking	10 m	23.3	5.4
			20 m	21.2	6.4
			40 m	6.6	7.2
		Sprinting	10 m	39.5	5.6
			20 m	23.0	6.8
			40 m	9.2	8.4
Varley et al [56]	10 Hz	Walking	< 100 m	5.3	6.6
		Sprinting	< 100 m	2.0	1.9

CV = Coefficient of Variation; SWC = Smallest Worthwhile Change

2.2.2 Speed Thresholds

Despite recommendations for reporting GPS data, a range of reporting methods is observed in the scientific literature [26, 64, 65]. For example, to date, no standardised methods exist for reporting velocity 'zones', and several definitions of what constitutes an 'effort' [37, 44, 53]. There is a lack of consistency in classifying speed zones in team sports with some researchers using two zones [10] and others reporting six velocity bands [18, 29].

The application of arbitrary speed zones across different sporting codes is unlikely to accurately represent the specific demands of each sport [66]. Furthermore, it is well accepted that activity profiles differ across different positional groups [9, 67]. For example, in Australian Football, midfielders covered greater total distance, spent less time on the field, and completed more high-intensity running at >5 m.sec^{-1} than forwards and defenders [9].

In female sports, researchers originally transposed men's speed thresholds on studies to describe activity profiles. Using a high-speed running band of >5 m.sec^{-1}, researchers found that elite female soccer players only covered 1.53 km of high-intensity activity during a match [68], compared with ~2.8 km for male athletes [69]. Women's rugby sevens researchers found no meaningful relationship between velocity at $VO_{2\,max}$ and distances covered above 5 m.sec^{-1} [26]. These findings support the notion that the use of men's speed thresholds does not accurately reflect the physical ability of female athletes [65]. It has been recommended that speeds of 4 to 4.5 m.sec^{-1} should be used to define high-speed running in female team sports [65]. The use of relative-speed zones

(based on the maximal speed of individual players) [70], may allow comparisons in percentage of time spent and distance covered in speed zones across genders. However, as match speeds are not dictated by the slowest team player, the individualisation of speed bands seems only appropriate for monitoring individual player workload.

2.3 Physical Demands of Team Sports

The physical demands of field-based team sport, such as hockey, soccer, rugby league, rugby union and Australian football have been examined and total distance has been a common metric used to identify match demands. However, it is well accepted that relative distance (i.e. metres per minute of play) [8] is a more appropriate measure of contributed effort as it takes into account individual playing time. Furthermore, by sub-dividing running data into low-, moderate- and high-speed zones, it is possible to gain an improved understanding of the activity profiles of running-based match performance.

Activity profiles have been extensively studied in a range of team sports, but it has not always been possible to directly compare the physical demands of different sport types [5]. Despite this, when match activity profiles of elite footballers from AF, rugby league and soccer were compared [5], results showed that AF players covered greater distances per minute at low, high and sprinting speeds than rugby league and soccer players, using the same zones for intensity. The relative distances covered were 129, 97, and 104 m.min^{-1} for AF, rugby league, and soccer matches, respectively. High-speed distances accounted for ~15% of the total distances covered by AF players compared

with ~6% in RL and soccer players. Furthermore, AF players were more likely to have a shorter recovery period between high-intensity efforts than the other sports [5]. Within the limited comparative data available, AF appears to impose relatively high running demands on elite level players, yet the running demands of females in the same sport remain unknown.

2.3.1 Activity Profiles of Women's Team Sports

Despite the availability of average distances for different codes of football, large variability is noted within the match demands of high-intensity intermittent team sports. Until recently, limited data were available from women's field sports [71]. Furthermore, although the physiological demands of team sports is comparable across genders [21], on average, female soccer players covered ~30% lower high-speed running distance than their male counterparts [22]. Average match demands of female sports were examined in elite female field hockey players who reportedly covered between 94 and 115 m.min^{-1} during match-play [27, 28, 72]. Similarly, relative match distances ranged between 100 and 118 m.min^{-1} in elite female soccer players [23, 24]. Among female rugby seven players, work rates between 86 and 111 m.min^{-1} were reported [25, 34, 46]. In line with research in males, a large portion of distances covered during match-play were at low-speeds. For example, female hockey players covered an average of 6.6 km (but up to 9.5 km) during match-play, with 97.3% of the total match running occurring at low and moderate speeds [72]. Similarly, elite female soccer players covered an average total distance of 10.3 km during competition, with high-intensity running accounting for 1.31 km of that distance [22]. Additional analyses showed the female soccer players performed high-intensity running efforts on 125

occasions across a match, for an average duration of 2.3 s [22].

Comparisons of high-speed running in female sports is difficult to quantify given the varied definitions of high-speed activities across sports. Using curves of best fit based on velocity from match data, researchers proposed a generic threshold for high-speed running of >12.2 $km.hr^{-1}$ (i.e. >3.4 $m.sec^{-1}$) [53]. However, irrespective of this well considered recommended threshold, high-intensity velocity zones still vary considerably in the literature (Table 2.3). Recently, researchers have investigated using high-speed thresholds based on physical tests [26, 65]. Rugby sevens practitioners used speed at the second ventilatory threshold ($\dot{V}$T2 speed) during a maximal aerobic capacity ($\dot{V}O_{2\,max}$) running test to define high-intensity running [26]. However, as field-based tests are more readily available to conditioning coaches than laboratory prerequisites for identifying ventilatory breakpoints, other researchers have suggested using 80% of maximal aerobic speed to estimate high-speed zones in female athletes [65].

Table 2.3. Relative intensities and varying speed zones used in female team sports

Sport	Total Distance (m)	Relative Distance (m.min⁻¹)	Speed Zone Band 1	Speed Zone Band 2	Speed Zone Band 3	Speed Zone Band 4	Speed Zone Band 5
Soccer							
Vescovi et al [24]	9141 – 10982	92 – 114	0 – 6 km.hr⁻¹ *"walking"*	6.1 - 8.0 km.hr⁻¹ *"jogging"*	8.1 – 12 km.hr⁻¹ *"low-intensity"*	12.1-15 km.hr⁻¹ *"moderate-intensity"*	15.1 – 20 km.hr⁻¹ *"high-speed running"*
Hewitt et al [73]	8759-10150	97-112	0 – 6 km.hr⁻¹ *"walking"*	6.1 – 12 km.hr⁻¹ *"jogging"*	12 – 19 km.hr⁻¹ *"running"*	>19 km.hr⁻¹ *"sprinting"*	
McCormack et al [23]	7918 – 9988	88 – 110	0 – 13 km.hr⁻¹ *"low-intensity"*	>13 km.hr⁻¹ *"high-intensity"*	>22 km.hr⁻¹ *"sprinting"*		
Field hockey							
Gabbett [72]	3400 – 9500	N/A	0 – 1 m.sec⁻¹ *"low-intensity"*	1.1 – 5 m.sec⁻¹ *"moderate-intensity"*	>5 m.sec⁻¹ *"high-intensity"*		
Vescovi & Frayne [27]	5438 – 7294	92 – 115	0 – 8 km.hr⁻¹ *"low-intensity"*	8.1 – 16 km.hr⁻¹ *"moderate-intensity"*	16.1 – 20 km.hr⁻¹ *"high-intensity"*	>20.1 km.hr⁻¹ *maximal intensity"*	
Macutkiewicz et al [28]	4700 – 6170	110 – 123	0 – 6 km.hr⁻¹ *"low-intensity"*	6.1 – 15 km.hr⁻¹ *"moderate-intensity"*	15.1 – 29.5 km.hr⁻¹ *"high-intensity"*		

Table 2.3. Continued

Sport	Total Distance (m)	Relative Distance (m.min^{-1})	Speed Zone Band 1	Speed Zone Band 2	Speed Zone Band 3	Speed Zone Band 4	Speed Zone Band 5
Rugby Sevens							
Clarke et al [46]	916 – 1120	107 – 116	0 – 2 m.sec^{-1} *"low-speed"*	2.1 – speed @ VT *"moderate-speed"*	>speed @ VT *"high-speed"*	>3.5 m.sec^{-1} *"high-speed"*	>5 m.sec^{-1} *"high-speed"*
Portillo et al [34]	1363 – 1642	86 – 100	0 – 6 km.hr^{-1} *"walking"*	6.1 – 12 km.hr^{-1} *"jogging"*	12.1 – 14 km.hr^{-1} *"cruising"*	14.1 - 18 km.hr^{-1} *"striding"*	18.1 – 20 km.hr^{-1} *"high-intensity"*
Suarez et al [25]	1364 – 1724	97 – 123	0 – 6 km.hr^{-1} *"walking"*	6.1 – 12 km.hr^{-1} *"jogging"*	12.1 – 14 km.hr^{-1} *"cruising"*	14.1 - 18 km.hr^{-1} *"striding"*	18.1 – 20 km.hr^{-1} *"high-intensity"*

VT = ventilatory threshold

As no study has investigated the demands of female AF; it is possible that conditioning coaches are developing training drills based on male data. This raises the issue of specificity as it is well established that female and male match demands vary considerably in team sports [22, 55, 68]. More recently, female soccer players were shown to cover lower total- and high-speed distances than their male counterparts [74]. The same researchers showed greater differences in high-speed distances (>15 km.hr^{-1}) as female players spent a greater portion of matches at speeds <12 km.hr^{-1} than male players. Considering the clear difference in match demands between genders and the commencement of an Australian-wide competition for female AF in 2017, research is necessary to highlight the running demands of the game. Currently, coaches are unable to develop appropriate training based around the match running activity profiles.

2.3.2 Physical Demands of Australian Football

The sport of AF is highly intermittent, requiring athletes to perform multiple accelerations throughout the match with repeated bouts of high-intensity running interspersed with lower intensity activity [9, 29, 37]. Results from AF GPS match analysis indicated that the average total distance covered by players was 12,300 ± 1,900 m, with the average relative match speed of players being 124.2 ± 19.2 m.min^{-1} [9]. Other studies in AF have reported similar values for total distance covered (12,311 ± 1,729 m, 12,939 ± 1,145 m) with one study reporting a relatively higher average speed (128 ± 12 m.min^{-1}) [75] and the other a lower average speed (109 ± 15 m.min^{-1}) [29] than previously reported. Despite the discrepancies in the reporting of average speeds in matches, it is clear that professional AF players cover considerable distances during matches; with substantial demands for running at high speeds. Additional profiles of

AF movement demands show that players performed 28.6 ± 8.1 sprint efforts in a match and spent approximately 11% of total match time running above 14.4 km.hr^{-1} [29]. As matches progress, players can regulate the amount of low-intensity activity undertaken to preserve the important high-intensity components of running during matches [37]. Additionally, researchers have consistently shown that the demands of competition dictate continued engagement in high-intensity exercise; specifically evident in reductions in the volume and intensity of low-intensity activity rather than high-intensity activity [31].

The influence of a team's score on their activity profiles and skill performance has previously been investigated in professional AF [39]. Skill involvements (total disposals per minute, long kicks per minute, marks per minute, running bounces per minute and player rank per minute) are greater in winning than losing quarters [39]. Yet, the players' high-speed running distance per minute, sprints per minute and peak speed are higher in losing compared with winning quarters [39]. Subsequently, AF players may demonstrate an increased physical activity profile and decreased skill proficiency when their team is less successful.

Although understanding the average match demands of elite AF is important for coaching and conditioning staff, the elite population only comprises a small portion of the total participants in the sport. The activity profiles of lower recreational divisions of male AF have been examined [12]. The relative distances covered by division 1, 2 and 3 players were 129.8 ± 10.2, 106.5 ± 13.4 and 101.6 ± 16.5 m.min^{-1}, respectively. Furthermore, division 1 players covered 35 m.min^{-1} of running at >4.0 m.sec^{-1}

compared with about 21 m.min^{-1} at this velocity for the lower divison players [12]. An analysis of the running demands of female AF warrants investigation to ensure players are developed and adequately prepared for competition.

2.3.3 Differences in Game Demands among Australian Football Positions

Australian football teams consist of 18 players and a number of positional groups (Figure 2.1).
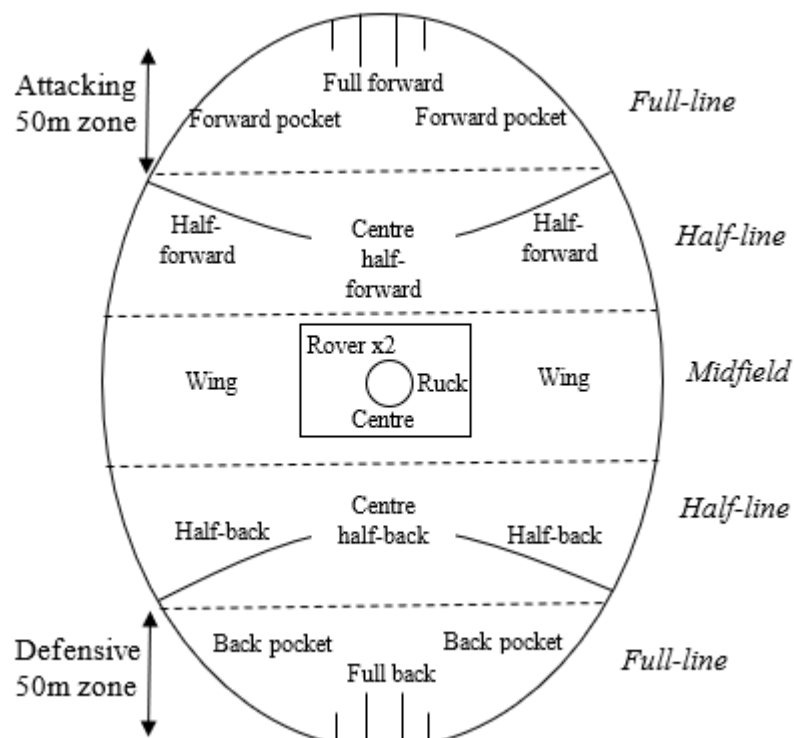
Figure 2.1. Australian football playing field and positional groups

Activity profiles are known to differ across positional groups in AF match-play. An early study found positional variations in total distances covered during matches in elite and semi-elite AF players [75]. The small forwards/backs covered 12,963 ± 1575 m at 127 ± 9 m.min^{-1}, midfielders covered the greatest distance (12,637 ± 1637 m; 135 ± 12

m.min^{-1}) and rucks covered the least distance (10,811 ± 1995 m; 123 ± 9 m.min^{-1}) [75]. In addition, midfield players covered greater distances and recored a higher average speed than other positional groups. The total distance covered and relative high-speed running distance across all positions have been reported, at 12,939 ± 1145 m and 3,880 ± 663 m [29]. The position of full forward/full back differs most from the other positions, as they were involved in more low-speed activity (e.g. standing and jogging) and less high-speed running [67]. For all positional groups, players recorded more than 150 high-intensity movements in the game, but these accounted for only 4 to 6% of total movement time [67]. Midfielders had greater physical demands than fixed (centre-halves and full) forwards and backs [67, 75]. It is important to consider differences in positional match activity profiles when programming training and recovery.

2.3.4 Differences in Performance among Competitions

A key discriminator of elite and sub-elite team sport athletes is the amount of high-speed running performed during match-play [76]. Physical match performance can be superior in elite athletes than their sub-elite peers [15]; with elite players generally covering greater high-intensity distances than sub-elite athletes. Elite soccer players covered 2.43 km at high-intensity running speeds compared with 1.90 km for sub-elite players over the same period of game time. Similarly, international male hockey players performed greater total distances, low-speed distances and high-speed distances than their sub-elite peers [11] for all positional groups. International hockey strikers, midfielders and defenders covered 10%, 12.1%, and 13.8% greater total distances, respectively compared with their sub-elite counterparts. Strikers (19.9%), midfielders (32.1%), and defenders (30.3%) also covered greater high-speed distances at an

international than national level [11].

Similarly, international female soccer players covered greater high-speed and sprinting distances than domestic players [68]. In partial agreement with the soccer-based research, international female rugby sevens players covered greater high-speed distances than national players [10]. However, national competition players covered a greater relative total distance than their international counterparts [10].

Research comparing elite junior and elite senior rugby league players demonstrated that the majority of physical demands of competition were similar between both groups [13]. In contrast, a higher playing intensity was reported for elite senior AF players than elite junior athletes in the same sport [77]. Senior AF matches were associated with greater relative distances and a greater proportion of time spent sprinting than junior matches. Female rugby sevens revealed similar trends with senior players covering greater total and high-speed distances during matches than junior sevens players [10]. Similarly, investigations into differences between elite and sub-elite AF male players showed that, on average, elite players had a significantly lower playing time than their sub-elite competitors [75]. Although sub-elite players covered a higher total distance (13,174 m) than elite AF players (11,705 m), the intensity of elite match-play (128 m.min^{-1}) was greater than sub-elite match-play (117 m.min^{-1}) [75].

The influence of playing standard on match running performance has also been assessed in recreational AF players and findings highlighted that division 1 players covered

greater relative total, moderate- and high-speed running distances than their division 2 and 3 counterparts [12]. These findings lend support to the need for research into the variations that may exist in match running performance in a number of AF leagues and divisions around Australia.

2.4 Player Rotations in Australian football

Given the large distances covered in AF match-play, rotations or interchanges are implemented regularly across match quarters. Male AF matches are currently limited to 90 rotations per team. However, female football teams are not restricted to the same rules as their male counterparts. Player rotations are an integral component of AF as they provide players with passive recovery periods throughout different match stages. Previous research highlighted that a greater number of rotations throughout a game significantly influenced running performances during the second half of AF matches [78]. Specifically, this research highlighted that a greater number of rotations resulted in greater relative and high-speed distances covered during the third and fourth quarters in rotated players than players who were rotated less regularly. However, separate research has presented conflicting evidence concerning changes in running performance between rotation periods in match quarters [37, 79]. In an earlier study, no change in relative distances covered was reported across rotations [37]. However, more recently, longer rotation durations and rotations that occurred later in a quarter have been related to reductions in total and high-speed distances covered [79]. Further research is required to explore running demands in rotation periods across matches.

Since a reduction in running performance is likely as matches progress [29], midfielders should be regularly rotated throughout match quarters, to slow the influence of match-related fatigue. Recommendations include coaches rotating the midfielders no less than 6 times per match, with on-field bouts of approximately 5 minutes [80]. Although it has been established that rotations are important for maintaining a higher match running intensity, running changes within a rotation bout remain unknown. If coaches had a greater understanding of when the peaks and troughs within an on-field bout occur, it could better inform the tactical implementation of rotations. Nonetheless, it appears that the rotation strategy employed may alter the intensity of the match and individual performances.

2.5 Pacing in Team Sports

Pacing has been described as the pattern of energy used during competition to achieve optimal performance [81]. To reach the endpoint of exercise in the fastest time possible, athletes can become competent in adjusting running performance to prevent premature fatigue [82]. Pacing has long been apparent in individual, self-paced sports. However, more recently pacing based strategies have become evident in team sports [86, 87]. Nonetheless, based on the intermittent, upredicatable and chaotic nature of team sports, specific and controlled pacing strategies can be difficult to implement [19]. Although individual pacing strategies may differ across competitions, four distinct strategies have been previously described. The first strategy has been defined as an all-out pacing strategy, in which athletes begin competition at the maximal possible pace and attempt to continue this pace until the exercise endpoint. Although the athletes adopting this strategy may be integral to a team's performance in the early to mid stages of a match,

running intensity often declines towards the end of the event. The second pacing strategy has been described as a slow-start strategy, in which athletes start the event at a lower intensity and increase pace as the competition progress. The third strategy is described as an even-paced strategy, in which intensity is maintained across the entire event. The last strategy is a variable pacing strategy, in which athletes begin the event at a maximal intensity, reduce intensity during the middle of the event and exhibit an end-spurt towards the end of the competiton [82].

Conflicting evidence exists in AF; with some studies reporting a reduction in low-speed activity as matches progress to maintain high-intensity movements [31, 32], and others showing no change in low-speed distances throughout match-play [37]. Notwithstanding, research has consistently shown that a number of factors influence pacing strategies in self-paced activities [19, 35, 36]. For example, research in AF has shown running intensity is reduced when the score margin is increased [39]. Additionally, recent evidence has suggested physical fitness levels influence pacing strategies during rugby league tournaments [19]. Specifically, compared with less aerobically fit players, players with greater high speed running capacity adopted a higher playing intensity and were able to better maintain the intensity across the competitive tournament. The even paced strategy was maintained albeit with reduced high-speed activity across matches in the high fitness group. In contrast, the lower fitness players used an all-out pacing strategy and subsequently reduced running performance across the tournament [19]. Although these findings provided a link between physical fitness levels and the implementation of pacing strategies across matches, there is a need for more extensive research to determine how players pace

themselves during matches.

The initial research on pacing during interchanges was conducted in rugby league players [36]. Specfically, when the match was sub-divided into eight parts of equal length (i.e. octiles), players interchanged during the first half of rugby league exhibited a greater work rate during the first match octile than whole-game players and those interchanged during the second match half [36]. Following the initial octile, running intensity declined progressively over the subsequent octiles in the interchanged players [36]. In contrast, and consistent with previous research [35], players interchanged into the match for the first time during the second match half showed an "end-spurt" during the final match octile that was not evident in the whole-game players [36].

While it is clear that interchanged players have the ability to produce greater running-based activity profiles, the influence of prior knowledge of exercise duration on pacing strategies (knowing how long they are likely to be on the field) has also been investigated [85]. Players competing in small-sided games for an unknown amount of time covered a greater proportion of their total distances at lower speeds than players who had knowledge of their game's endpoint [83]. These findings highlight that during game-based activities, athletes alter their pacing strategy based on the anticipated endpoint of the exercise bout. Investigating pacing profiles during female AF is yet to occur and could offer a point of significance to coaches and conditioning staff striving to improve strategic development and match success.

2.5.1 Transient Reduction in Running Performance in Team Sports

The ability of athletes to maintain playing intensity over the course of a match has been explored in a number of male team sports [18, 37, 84], but has not previously been investigated in female team sport athletes. Declines in match running can occur during three distinct stages of match-play [47]: (1) between halves or quarters, (2) after short-term intense periods during different match stages [16], and (3) towards the end of a match [15]. Soccer players have decreased in total distance [18], moderate- [84] and high-intensity running activity [18] between halves. Moreover, AF players showed greater reductions in total distances and high-intensity running during the second (-7.3%), third (-5.5%), and fourth (-10.7%) quarters than the first quarter; suggesting that fatigue occurs during AF match-play [29]. Nevertheless, AF players can maintain low-intensity activity (89 m.min^{-1}) over the course of the game [37].

Comparisons of elite male and female soccer players have returned conflicting outcomes relating to the extent of decrement in running capacity throughout a competitive match. For example, in one study female athletes were observed to have a greater decrement in high-speed running during the second half of match-play than their male counterparts [74]. However, in an earlier report, researchers reported no reduction in high-speed activity across match halves in elite female soccer players [85]. Collectively these inconsistent findings highlight a need for research to further investigate changes in running performance across matches in female athletes.

The greatest distance covered in a peak intensity 5-minute running period and the distances covered in the subsequent period have also been used as an indication of transient reduction in running performance [15, 86, 87]. Elite male soccer players reduced high-speed running by 50% to distances below the match average, following the most intense 5-min period [87]. Similarly, following the peak 5-minute period of high-intensity running, performance was reduced by 12% in the following 5 minutes compared with the game average [15]. Despite reductions in performance following the peak 5-minute period in rugby league matches, no differences existed between the subsequent 5-minute period and the average match demands [17]. Given that the use of peak periods has the potential to over- or under-estimate distances covered [87, 88], the potential utility of rolling time scales (distance covered at every point for the next 5-minute period) have also been explored [88].

Using 3-minute rolling time periods, observations in AF showed linear decreases in running intensity within each individual quarter following intense passages of play [16]. Additionally, running intensities during the subsequent periods were reduced below the average match demands; suggesting peak periods cause transient reductions in the performances of AF players. Large amounts of low-speed activity during team sport matches and less time spent at high-speeds are frequently reported after periods of match-play involving extended bouts of high-intensity running [37, 72, 89]. However, given evidence that high-speed activity occurs at critical moments of the game [89, 90], further investigation into individual responses to intense periods of match-play may provide vital conditioning information. Furthermore, while the response to peak periods of match running have been explored, recent research has highlighted 3- to 5-minute

epochs are not true maximal periods of match-play [91, 92]. Therefore, the physical response to varying duration peak periods warrants investigation to increase training specificity.

2.6 Skill Performance in Male Australian Football

Technical performance is arguably the most important aspect of success in AF matches [39]. For example, skill involvements are greater in winning than losing quarters [93] and matches [77] in male AF matches. Furthermore, skill involvements seem to influence coaches' perceptions of performance to a greater extent than running performances [94]. Interestingly, a recent study in elite AF players disagreed with previous research and reported a positive relationship between the total number of disposals and distances covered during on-field bouts [79]. However, the team used in this research had a win/loss record of 4 wins and 11 losses and the research was limited to one team. Therefore, it is possible that better performing teams would report differing results.

A recent study using chi-squared automatic interaction detection (CHAID) classification trees found higher team kick and goal conversion values relative to the opposition were the two most important performance indicators in successful match outcomes in elite AF [95]. Additionally, inside 50's, marks inside 50, marks and contested possessions were also significant contributors to match outcome [95]. In junior AF, a player's ability to be involved in more contested possessions and inside 50 entries has been associated with earlier draft picks into the AFL [96]. Despite the

number of skill involvements remaining relatively constant through playing standards, differences may lie in the efficiency of disposals [97]. Currently, the majority of research highlights that skill efficiency is important for both career longevity and match success in AF.

2.7 Physical Qualities in Team Sports

Physical qualities or characteristics are terms often used interchangeably to describe athlete fitness levels. A number of physical testing batteries are used across team sports to assess qualities such as aerobic fitness, speed, power and strength. Physical qualities can denote differences between playing standards and have also been associated with increased running performances in a number of team sports. Based on the physical demands of running-based team sports, a range of fitness qualities are required for success.

2.7.1 Physical Qualities, Playing Standards and Team Selection

Multiple studies have established the importance of well-developed physical qualities on team selection and differentiating playing standards [45, 64, 98-100]. Moreover, the ability of players in team sports to repeatedly perform and recover from intense exercise has also been considered [101]. The Yo-Yo Intermittent Recovery test (Yo-Yo IR) is among the most cited physical quality tests for high-intensity running ability in team sports [101, 102]. There are two versions of the Yo-Yo IR test; (i) the Yo-Yo Intermittent Recovery Level 1 (Yo-Yo IR1) and, (ii) the Yo-Yo Intermittent Recovery Level 2 test (Yo-Yo IR2) [103]. Both versions of the Yo-Yo IR test are deemed a highly

reproducible and valid measure of performance in soccer players [101]. Multiple studies have since reported the Yo-Yo IR test's ability to discriminate between playing standards in a number of team sports [45, 104]. Table 2.1 shows the results of comparisons of the Yo-Yo Intermittent Recovery 1 (IR1) test among elite junior AF players, sub-elite junior AF players, and non-athletic healthy males [104]. The results demonstrated the ability of the test to separate the three groups; revealing the elite individuals covered a greater distance in the Yo-Yo IR1 than the other groups [104].

Although the Yo-Yo IR test is prevalent in testing batteries in a number of sports, the Multi-Stage Fitness Test (MSFT) has also been assessed [99, 100]. Using the MSFT, junior state representative AF players ran longer distances than their non-representative counterparts. The MSFT has also been used to predict draft selection in elite junior AF players and to explore differences between starters and non-starters in an elite AF club [105]. The starting players covered significantly greater distances in the MSFT than the non-starters [105]. Despite their apparent similarities, the Yo-Yo IR test and the MSFT possess a number of key differences that are used to guide selection of the most appropriate test for a specific athlete population. For example, the Yo-Yo IR tests were initially developed to evaluate the high-speed distances covered by athletes during field-based team sports [15, 101] and, hence, assesses a player's ability to repeatedly perform and recover from high-speed running [101]. In contrast, the MSFT assesses aerobic power [106] and, despite its demonstrated capacity to discriminate between players of different standards and relationship with high-speed running in soccer players [107], provides little insight into an athlete's capacity to perform the repeated

high-intensity intermittent running bouts that are common in sports, such as Australian Football.

Fitness testing batteries in team sports often include multiple physical qualities. In addition to prolonged high-intensity intermittent running, superior lower-body and upper-body strength have also been associated with team selection at a semi-elite level in rugby league [45]. As strength is deemed important for performance, tests of power have also been thoroughly investigated. Lower body power is frequently assessed in team sport athletes and, until recently, the vertical jump, using a Yardstick, has been the most common tool used to discriminate between different playing levels in rugby league [64] and team selection in AF [105]. However, the validity of the Yardstick has since been questioned [108]. The vertical jump, using the Yardstick, offers a measurement of jumping skill due to the need to coordinate a number of body segments. On the contrary, the countermovement jump (CMJ), with no arm swing, is a lower-body specific measure of explosive power. In a comparison of elite and sub-elite AF players, lower body power measures assessed via a CMJ were shown to differentiate athletes of different playing standards, despite the groups exhibiting similar lower body strength [109]. These findings were also supported by elite AF players producing more power during a CMJ than sub-elite senior and elite junior players [110].

Sprinting speed over distances of 10 to 40 m has also been shown to differentiate selected players from non-selected players and higher performing male athletes from lower performing male athletes in a number of team sports [64, 100, 111-113]. In AF, players drafted into the AFL were faster over 5 to 20 metres than players not drafted

[112] (Table 2.4). Furthermore, players selected to start on-field during AF matches were faster over both 10 metres and flying 30 metres than non-starters [105]. Similarly, repeated sprint performance, which is influenced by maximum speed [114], has also been shown to discriminate between selected and non-selected players in elite AF [115]. Greater lower body strength (front squat; r = -0.60) [116] and power (CMJ; r = -0.62) [117] have also been shown to have strong relationships with speed in male AF players. Collectively, these findings suggest that increasing lower body strength and power qualities may improve maximum speed and repeated sprint ability, and could be important for performance in AF.

Table 2.4. Physical qualities of AF players by playing standard

	Yo-Yo IR1 (m)	Yo-Yo IR2 (m)	10 m time (s)	20 m time (s)	30 m time (s)	40 m time (s)	CMJ (cm)
Elite	1910 [a]	1029 to 1060	1.70 to 1.89	2.94 to 3.13	4.08 to 4.10	5.40	62.8
Sub-Elite	1438 [a]	880	1.83	3.05 to 3.09	4.34	5.50	55.0

Data presented as means; *a* denotes data from junior players; IR1= intermittent recovery test 1; IR2 = intermittent recovery test 2; VJ=vertical jump height using Vertec. Data extracted from multiple sources [12, 30, 78, 104, 105, 112]

Table 2.5. Physical qualities of senior female field-based team sport athletes

	Yo-Yo IR1 (m)	10 m time (s)	20 m time (s)	30 m time(s)	40 m time (s)	CMJ (cm)
Soccer	1051 to 1455	1.95 to 2.31	3.17 to 3.53	4.35 to 4.43	5.64 to 5.75	30.5 to 35.0
Rugby League	610 to 728	1.94 to 2.04	3.44 to 3.60	4.85	6.13 to 6.59	35.1 to 35.7
Rugby Sevens	1058 to 1702	1.95 to 2.31	-	4.28 to 4.50	5.50 to 5.79	47.4 to 49.6
Rugby Union	-	1.90 to 2.08	-	-	5.66 to 6.51	32.9 to 44.4
Hockey	1147 to 1419	-	-	-	-	-

Data presented as mean ranges; IR1= intermittent recovery test 1; CMJ= jump height during a countermovement jump with arm swing. Data extracted from multiple studies [22, 46, 89, 113, 118-123]

A number of studies have examined the physical qualities of female athletes in field-based team sports (Table 2.5). However, a number of gaps are evident in the literature relating to the importance of physicality in these athletes. Several studies have used different tests of physical qualities and differences between playing standards are inconsistently reported. Some evidence on female soccer players has shown differences between playing standards for CMJ performances [122], while others reported no differences in CMJ height between junior and senior female soccer players [113]. Further research is required to investigate the importance of lower body power in female athletes.

Comparisons of female sporting performance standards demonstrate some similar trends with male athletes. Specifically, senior soccer players have been shown to cover ~33% greater distances during the Yo-Yo IR1 test than junior athletes, independent of gender [122]. Furthermore, in agreement with research derived from men's sport, maximal running speed has also been shown to have the ability to distinguish between female athletes selected to play professional soccer and non-selected female players [123]. With the exception of the flying 5 metre sprint, selected players were faster over all distances up to and including 35 metres compared with their non-selected counterparts [123]. Similar results were reported in a comparison of the sprinting abilities of female soccer players, where it was shown that elite players were faster over 10 to 40 metre distances than both the first and second division players [113]. A comprehensive analysis of physical differences between women's rugby sevens high and low playing-minute players revealed aerobic fitness and upper-body strength differentiated groups [118]. Although this study found no differences between lower body strength and power between groups [118], this research provided scope to continue to assess and develop all physical qualities in emerging female sports.

2.7.2 Physical Qualities and Match Performance

Well-developed physical qualities have been associated with superior match performance in a number of team sports. Considering the variances in activity profiles across sports, the importance of certain physical qualities also differs in relation to game demands. In sports of a highly intermittent nature, high-intensity running ability is often assessed. Anecdotally, the 2-kilometre time trial is a common practice in AF teams to evaluate an athlete's maximum aerobic speed (MAS). Athletes' MAS is known to be positively related to distances covered during matches, but MAS also negatively impacted player skill ratings [79].

Research consistently highlights positive associations between the Yo-Yo IR tests and team sport performance. For example, a significant correlation was reported between the distances covered at high speed in soccer match-play and the Yo-Yo IR1 results [18]. Other researchers have investigated the influence of playing standard and physical fitness, assessed using a Yo-Yo IR1 test, on pacing strategies across a youth rugby league tournament [17]. Regardless of playing standard, low-fitness players exhibited decreased playing intensity as the tournament progressed; suggesting superior performance on the Yo-Yo IR1 may reflect an athlete's capacity to maintain a high level of performance during competition [19]. Results from the Yo-Yo IR1 test have also been shown to discriminate selected semi-professional rugby league players from non-selected players [95]. Interestingly, this study showed intermittent-running ability was not a significant predictor of match running performance [45]. In contrast, results from both male and female soccer players have shown strong correlations (r > 0.70) between Yo-Yo IR1 distance and high-speed distances covered during matches [22, 68, 74]. Despite this similarity, male athletes consistently performed a greater amount of high-intensity activity

than their female counterparts [22, 68, 74]. While a plethora of research exists on the influence of Yo-Yo IR test performance on activity profiles in soccer, investigations into other female sports have been largely neglected.

The relationship between intermittent running ability and match running performance in male AF players is well documented [30, 78]. Superior Yo-Yo IR2 performance is linked to greater relative distances and high-speed distances across elite AF match-play [78]. Previous AF research has also demonstrated relationships between high-speed running, number of disposals, and Yo-Yo IR2 performance [30]. The validity of the Yo-Yo IR2 has been further supported in recreational AF players with large associations reported between Yo-Yo IR2 performances and the relative and high-speed distances covered during match-play [12].

Other physical qualities and their relationship with performance have also been investigated. Well-developed physical qualities have improved rugby sevens match performance [20]. Specifically, associations include greater attacking ability and superior sprint times, as well as, defensive performances linking with greater sprint, CMJ and repeated sprint performances [20]. Researchers have recently reported associations between physical qualities and skill performance during elite AF match-play [124]. Results demonstrated that upper body strength was a significant predictor of Champion Data© ranking (game analysis statistics provided for the public domain) in AF midfielders [124]. Research involving semi-elite and recreational AF players highlighted strong correlations between maximum velocity during a 40 metre sprint and the relative, moderate- and high-speed running distances covered by the athlete [12]. Similarly, rugby league research identified a relationship between well-developed lower body strength and match distances covered at low and high-speeds [45]. No associations were

reported between lower body power and match running performance in semi-elite rugby league players [45]. The AF research has shown moderate correlations between vertical jump height and relative and high-speed distances covered during recreational matches [12]. Furthermore, sprinting and jumping activities, more specifically straight line sprinting, remain the most dominant actions performed prior to goals scored during soccer matches [125]. Despite limited evidence suggesting that lower body power influences match running performance, superior sprinting ability has been consistently associated with greater lower body power production [126]. Considering the associations between sprint speed and activity profiles, it is reasonable to suggest that superior lower body power may result in greater running distances. However, research is required to determine the specific influence of lower body power on match activities. Collectively, the existing literature presents equivocal evidence regarding the importance of physical qualities on match performance; emphasising the need for further studies that aim to explore the influence of multiple physical fitness variables on performance.

2.8 Opposition Quality and Match Outcome on Performance in Team Sports

Intuitively, a link exists between winning team performance and players' ability to maintain a high playing intensity throughout a match compared with less successful teams. Early research demonstrated greater distances covered, more accelerations and repeated high-intensity effort bouts performed in rugby league matches when games were won rather than lost [43]. Additionally, elite rugby league players covered greater high-speed distances when playing against "Bottom 4" teams than when competing against "Top 4" teams [43]. In contrast, more successful rugby league teams showed they did not cover greater total or high-speed distances than less successful teams [42]. Similarly, rugby sevens research has found greater high-speed running demands against higher than lower quality opposition [127]. Although some research suggests that the trend is for playing intensity to increase as the playing standard increases [15,

76], additional research has reported a reduction in playing intensity as playing standards increase [128]. Others suggested [69] that independent of their prior success, teams covered greater total and high-intensity distances when playing higher quality competition. Further research showed that the higher ranked teams covered greater distances at low-speeds [129] and lower ranked teams performed greater high-intensity running activity [128]. Comparisons of the activity profiles of successful and less successful soccer teams showed that the most successful teams covered greater total distances with the ball, and more high-intensity and very high-intensity running with the ball [128, 130]. A major difference between less successful and most successful teams existed in the high-intensity distances covered without the ball [130]. Greater high-intensity distances were covered by lower placed teams, which may occur as a consequence of their attempts to regain possession of the ball [128]. The influence of opposition ranking on running performance remains unclear in AF players.

Results from research into elite soccer reported a 50% decrease in high-intensity activity in winning than losing matches [129]. Furthermore, elite AF research demonstrated that in losing matches, players increased the high-speed running distances covered and sprints completed per minute [39]. In contrast, skill involvements and skill efficiency were greater in quarters won [39]. Collectively, these results suggest that professional AF team success is more likely dependent on skill efficiency than an increase in physical activity profiles [39]. In a study in which AF coaches' subjectively rated their players' match performance (out of 20), higher calibre players (scored >15/20) spent more time performing low-speed running, had more kicks and disposals per minute and covered less distance per kick and disposal than lower rated players (score <9/20) [131]. This study also found that high-calibre players covered less distance, spent a lower percentage of time at high-speeds, and performed fewer high-speed running efforts per minute than lower rated players. Consistent with these findings, a more

recent investigation has shown that increased physical activity (sprinting distance per minute and peak speed) through the match negatively impacted player rank in AF [38]. Conflicting and more recent research shows higher rated players covered more distance and spent more time running at high-speed per minute than lower rated players [6]. Additionally, the higher rated players had more involvements with the ball across matches than the lower rated players [6]. Therefore, further studies are required to better understand the importance of physical activity profiles and their relationship with competitive success.

2.9 Gaps in the Literature

The literature review highlights a complex relationship between physical qualities and match performance in field-based team sports. Well-developed speed and high-intensity running ability (Yo-Yo) positively influence the distances covered during match-play. However, the influence of lower-body power on activity profiles is less understood. More specifically, there is no evidence to support the identification of the physical tests that are most important for performance in female AF players.

Australian football is a high-intensity intermittent team sport requiring players to cover greater distances than other field-based sports. The knowledge of average and intense passages of match-play is important for training development, but remains unknown in female AF. Furthermore, factors such as rotations, match outcome, and opposition quality have been shown to influence activity profiles in other team sport athletes; hence, understanding how specific contextual factors affect running performance may also inform coaching practices and game-day strategies in female AF.

Chapter 3: Methodology Overview

3.1 Introduction

To complete an ethical and rigorous thesis, a number of important processes were followed. Initially, a thorough ethics application was submitted, which included a detailed information letter for potential participants and obtaining written informed consent. The methods used to recruit participants into this study were designed to ensure voluntary involvement in the research.

3.2 Recruitment

The recruitment process involved a sequence of phases before the current research was discussed with the participant population. The first phase involved discussions with the Queensland Women's Australia football manager to obtain agreement on the need for research to enable an understanding of the match demands and training development. The manager then approached six clubs competing in the Queensland Women's Australian Football League (QWAFL) to discuss the proposed research and the subsequent benefits of their individual club's involvement. Three of the six clubs approached expressed an interest in the research. The researchers then visited these teams to discuss the nature of the projects with their players. All players competing in the Division 1 competition were invited to participate in the research and, from this cohort, 49 participants provided written informed consent. The participant population were all aged over 18 years and were injury-free at the time of testing. Furthermore, of the 49 recruited players, 22 were selected into the QLD state academy team and formed the "selected" group in Study 1; permitting comparisons with the 27 "non-selected" players.

3.3 Ethical Considerations

The program of research in this thesis was granted ethics approval by the Australian Catholic University's Human Ethics Review Board (2016-27H). The overarching aims, requirements and potential benefits were verbally presented to potential participants. Following the initial presentation, the coaches distributed an information letter and consent form to potential participants who expressed interest in the project. The participation in the research was entirely voluntary and no pressures were placed on players to be involved. The information letter described the physical fitness tests and the requirement to wear a GPS unit during a number of matches in the competitive season.

Although participants were unaccustomed to the majority of the physical testing procedures, detailed instructions and familiarisation protocols preceded each test. Specifically, as players were unfamiliar with the Yo-Yo IR1 test the first two levels were incorporated into their warm-up**.**

While the majority of players were unaccustomed to wearing GPS units there were no reports of discomfort experienced during match-play. As descriptive statistics were used for the analyses, data were de-identified post collection using a coding system. This process ensured the identity of any participant would not be disclosed to anyone other than the researchers.

3.4 The Dependent Variables

3.4.1 Off-Field Performance

The testing procedures and reliability of each dependent variable assessed in this thesis are explained within individual chapters.

Table 3.1. Chapter location of off-field dependent variable procedures

Dependant variable	Chapter location
Countermovement Jump	Chapter 4
30m speed	Chapter 4
Yo-Yo Intermittent Recovery Test (Level 1)	Chapter 4 to 7

3.4.2 Running Performance: Global Positioning Systems

On-field running performance was determined using 10 Hz GPS units (Optimeye, S5, Catapult Sports, VIC, Australia). The reliability of the 10 Hz units for measuring activity profiles in team sports has previously reported acceptable values (Table 2.2). The GPS units provided information on the running covered during match-play in four of the five studies that formulated this program of research. Participants were required to wear the units in a customised vest with the unit positioned between the shoulder blades. Although the reliability of the units was not assessed in this body of research, a number of studies have published evidence to support the use of 10 Hz units to monitor activity profiles in team sports. A strong body of evidence has reported acceptable reliability when assessing linear sprints over a range of distances (TE=1.2 to 11.7%) [56, 58, 60]. Furthermore, researchers have assessed the inter-unit reliability of 10 Hz GPS units and found good levels of repeatability for distances covered, time spent, and number of efforts performed at low and high-speeds [63]. However, it has been established that as the speed of movement increases and the distance decreases, the validity of

GPS units declines [132]. Nonetheless, no significant differences have been reported from comparisons with criterion measures when assessing short, multi-directional accelerative sprints, over distances as short as 2 metres [132].

3.5 Conclusion of Selected Measures

The recruitment process allowed participant involvement to be entirely voluntary. Furthermore, ethical considerations ensured all players understood, volunteered willingly, and acknowledged their requirements. The selected off-field and on-field measures in this research were supported with reliable and mostly concurrently valid measures of performance in the sample size investigated. Furthermore, although the reliability of the Yo-Yo IR1 and GPS units were not assessed within the targeted population, previous research offers support for their use in this thesis. Finally, in each study of this program of research, broad speed bands were used to determine movements, in an effort to reduce the associated limitations of GPS technology [56].

3.6 Sample Size Calculations

For chapters 4 to 7 a sample size of at least 20 players per group was predicted to enable the detection of a significant differences if the mean of key performance metrics in one group was at least 0.75 to 1.00 standard deviations higher than the other group (power = 80%, significance $p = 0.05$) [133]. Although some comparisons involved fewer numbers, and the exploration may be slightly underpowered, the results still provide hypothesis generating evidence for future research.

3.7 Generic Statistical Analyses

Linear mixed models with fixed effects for team selection, positional group and playing period and a random effect for individual player identity were used throughout the thesis. As repeated measures ANOVAs consider every data point unique, the linear mixed model was used in this thesis, with the random effect for player identity, to account for the dependence arising from repeated measurements of running performance variables from individual participants. Statistical Package for the Social Sciences (SPSS), Version 19, was the statistical software used in this research. Cohen effect sizes and 90% confidence intervals, and magnitude-based inferences were also used to determine differences between groups. Effect sizes of ≤ 0.2, 0.21–0.6, 0.61–1.2, 1.21–2.0, and >2.0 were considered trivial, small, moderate, large, and very large, respectively. Magnitude-based inferences provide a practical approach of analyses which are simple to convey to non-analysts.

Chapter 4: The influence of physical qualities on activity profiles in female Australian football match-play

Physical qualities have demonstrated an ability to influence team selection and activity profiles in a number of team sports [45, 115, 118]. With the current development of female Australian football, research is yet to highlight which, if any, physical qualities contribute to team selection and running demands during female AF match-play. Therefore, the first study of this dissertation aimed to investigate the importance of physicality to better understand its role in female Australian football.

This study has been accepted for publication in the International Journal of Sports Physiology and Performance. Full reference details:

4.1 Introduction

Australian football (AF) is a high-intensity intermittent team sport that involves a combination of physical and technical components. Physical testing batteries are used to monitor the physical attributes of players throughout the season and have been used to discriminate high standard players from low standard players within multiple team sports [64, 100]. Despite the importance of one's physical qualities to their playing standard, physical fitness tests also have the ability to predict team selection [64, 105]. Compared with non-selected players, selected junior rugby league players were faster over 10-40 metres and demonstrated superior vertical jump and maximal aerobic power [64]. Similarly, individuals selected to play in elite men's AF teams covered greater distances on the Yo-Yo intermittent recovery test compared to non-selected players [105]. Furthermore, elite senior AF players selected for the first competitive game of the season were older and more experienced than the non-selected players [105]. In contrast, physical attributes are suggested to be less important for discriminating starters and non-starters in junior volleyball squads, while sport-specific skill qualities have been shown to be more important to a player's selection [98]. Collectively, these findings demonstrate that physical qualities are important to selection in most team sports, but it appears that the specific qualities contributing to team selection differs across sports.

Physical qualities of team sport athletes are known to be related to match running performance [44, 45, 134]. For example, maximum sprint velocity has been strongly linked to the amount of moderate- and high-speed running performed by semi-elite and recreational AF players [12]. Furthermore, separate studies have reported associations between intermittent-running ability and both high-speed and total distances covered during elite AF match-play [30, 78]. While these studies provide some insight into the influence of different physical qualities on physical match performance, they have largely involved elite and sub-elite playing groups. Given these

populations encompass only a small proportion of participants in sport, a need exists to further explore the demands of recreational team sports. Furthermore, despite growing evidence in support of the use of physical quality tests for discriminating selected male athletes from their non-selected counterparts, the evidence for the use of such assessments for female playing groups is far less substantive. Given the vast differences in physical preparation between male and female AF environments, there is a need to explore the influence of physical qualities on female AF team selection, and gain an understanding of which, if any, qualities require further development.

In accordance with research involving male athletes [104], prolonged high-intensity running ability was associated with greater total and high-speed running distances in female soccer players [22]. Additionally, a small number of studies have reported positive relationships between the playing standard of female soccer players and their sprinting [113] and jumping [122] performance. Furthermore, it has been shown that female soccer players with faster sprints perform at a lower proportion (77%) of their maximal speed during matches than players with slower speed (84%) [135], which would likely have implications for the fatigability of these athletes. However, in contrast to the reported relationships between running ability and playing standard in female athletes, separate research [105] has reported similar countermovement jump performance for female soccer players competing at different levels. Although a number of physical qualities have been linked to performance in female team sports, to date, the research concerning the relationships between physical attributes and playing standards in female team sport athletes has been largely restricted to women's soccer. Additionally, the majority of AF research has focussed on male AF which is largely represented by a homogenous group of elite senior athletes. With the inaugural season of the National Women's Australian Football League commencement in 2017, there is a clear need for research

investigating the differences in physicality between selected and non-selected players and the importance of different physical qualities on match running performance in female Australian footballers. An understanding of the physical qualities important to team selection may substantially advance current practice in the National Women's League and other female football codes. Additionally, identifying the activity profiles of different positional groups should aid in the development of sport-specific training programs. Given the recent development of the National Women's League, the aims of this study are to (1) highlight the physical qualities that discriminate selected and non-selected female AF players, (2) investigate activity profiles of female AF players, and (3) gain an understanding of the influence of physical qualities on running performance in a state-level female AF competition.

4.2 Methods

4.2.1 Subjects

Twenty-two selected players (mean ± SD age, 23.2 ± 4.5 years; playing experience, 4.0 ± 2.8 years) and 27 non-selected players (mean ± SD age, 23.4 ± 4.9 years; playing experience, 2.1 ± 1.6 years) participated in this study. Three teams competing in the top division of the six team Queensland Women's Football League were recruited. Players selected into the state academy represented the "selected" group, while players who were not selected for the state academy formed the "non-selected" group. The state academy coaches had no knowledge of the results of the physical tests reported in this study prior to selection. The state academy participants competed for their individual Queensland Women's Australian Football League teams in the same competition as "non-selected" players when not on state representative duties. Before the study, all players provided written consent and the study was approved by the University's Human Ethics Review Board (2016-27H).

4.2.2 Design

An observational cohort study was used to investigate the influence of physical qualities on running demands in female AF players. Initial physical quality testing was completed at the end of preseason and activity profiles were measured using Global Positioning System (GPS) units during 14 matches. All participants completed two field sessions per week with their respective clubs during the preseason. This project was completed in three phases. Firstly, the sample was separated into selected and non-selected players, for the Queensland State Academy group. Secondly, the match activity profiles were obtained for three positional groups (midfielders n = 22 players; N = 97 match files, half-line players n= 16 players; N = 81 match files, and full-line players n = 11 players; N = 54 match files). Half-line players represented centre half-backs/forwards and half-backs/forwards. Full-line players represented full-backs/forwards and back/forward pockets. Finally, the relationship between physical qualities and activity profiles were determined using partial correlations, controlling for playing position.

4.2.3 Methodology

As part of preseason training for the competitive season, participants completed physical tests that included the: (1) countermovement jump (CMJ), (2) 30-metre sprint and (3) Yo-Yo Intermittent Recovery Test (level 1 [Yo-Yo IR1]). Testing was completed over two separate days, with the CMJ and the 30-metre sprint tests completed during the initial session and the Yo-Yo IR1 completed during a session scheduled two days later. Participants wore football boots and their normal training clothes. To limit the potential influence of diurnal factors, all testing was completed outdoors on a grass playing field at the same time of day (~1900 hours); players were asked to avoid any exercise and to maintain their normal diet between testing sessions.

The CMJ was included to assess lower body power and was performed on a force platform [136] (Fitness Technology, 400 Series, Australia) interfaced with a laptop (Dell Latitude E7450, Dell, USA) running manufacturer designed software (Ballistic Measurement System, Australia). Before the assessment, players were familiarised with the procedures and performed a standardised warm-up consisting of dynamic stretches and plyometric exercises for the lower body. Players were instructed to keep their hands on their hips for the entire trial and to jump as high as possible. The players received no instruction as to the depth of the countermovement. Players performed 3 jumps separated by 60-seconds rest and the best performance was recorded as relative peak power (watts.kg^{-1}). The typical error of measurement (TE) for the CMJ peak power measure was 4.1% for this population.

The 30-metre sprint test was performed cross-wind using dual-beam electronic timing gates (Swift Performance Equipment, New South Wales, Australia, TE=0.04s) and provided an assessment of running speed [112]. The starting gate was positioned 30 cm from the participant's front foot, with further gates then positioned at 5, 20 and 30 metres. The fastest of three 30 metre sprints was recorded. A three-minute recovery was allowed between sprints. Acceleration was calculated from the 0 to 5-metre timing gates and peak velocity was noted between the 20 and 30 metre timing gates.

To assess prolonged high-intensity running ability, each player completed the Yo-Yo IR1. This test required players to perform 2 x 20-metre shuttles at progressively increasing speeds, controlled by a series of audible signals. Players were required to keep in time with the audible signal for as long as possible. Each 20-metre return run was interspersed with a 10-second active recovery, consisting of jogging around a cone placed 5 metres from the start/finish line.

When players were unable to keep in time with 2 consecutive signals, they were removed from the test, the total distance covered was recorded as the Yo-Yo IR1 score. As players were unfamiliar with the test the first two levels were incorporated into the warm-up. The typical error of measurement for the Yo-Yo IR1 has been reported as 4.9% [101].

Following the physical assessments, activity profiles were recorded for each participant using global positioning system (GPS) units during at least 4 competitive season matches (mean ± SD: 5.1 ± 0.6; range: 4 to 6; total GPS files: 232) played throughout the 2016 competitive season. Match activity profiles were obtained for three positional groups. Half-line players represented centre half-backs/forwards and half-backs/forwards. Full-line players represented full-backs/forwards and back/forward pockets. Prior to the match warm-up, players were fitted with a GPS unit sampling at 10Hz, which was placed in a pouch in the rear of a manufacturer designed vest positioned between the shoulder blades. The GPS units (S5, Optimeye, Catapult Sports, Docklands, VIC, Australia) used in this study have previously reported acceptable reliability (coefficient of variation [CV] = 3.1-8.3%) and validity (CV = 2.0-5.3%) [56]. Data were downloaded to a laptop and analysed using software provided by the manufacturer (Sprint 5.1.7, Catapult Sports, Docklands, VIC, Australia). Player movement profiles were determined by sub-dividing movements into low-speed (0-2.78 m.sec^{-1}), moderate-speed (2.79-4.15 m.sec^{-1}), and high-speed (>4.15 m.sec^{-1}) movement bands [16]. Data were further divided by individual playing time and expressed as relative distances to give an indication of overall player work rate. Only active field time was included in the analysis; data were removed for the time period players were rotated or interchanged off the field.

4.2.4 Statistical Analyses

Differences in physical qualities between selected and non-selected players were compared for null-hypothesis testing (SPSS 19.0, SPSS Inc, Chicago, IL, USA). Data were first tested for normality using a Shapiro Wilk test. Differences between groups were investigated using independent t-tests (normal data) or a Mann-Whitney U test (non-normal data). Statistically significant ($p<0.05$) physical quality variables were included in a linear discriminant analysis that aimed to determine which of the physical attributes contributed to selected or non-selected group classification. A regression equation was created that was used to predict whether a player would be included in the selected or non-selected group. A linear mixed model with a fixed effect for team selection and a random effect for individual player identity was used to examine each GPS variable. The random effect for player identity was included to account for the dependence arising from repeated measurements of running performance variables from individual participants. Differences were further compared using Cohen's effect sizes (ES)[21] and 90% confidence intervals (CI). Effect sizes of ≤0.2, 0.21–0.6, 0.61–1.2, 1.21–2.0, and >2.0 were considered trivial, small, moderate, large, and very large, respectively [137]. Magnitudes of differences between the two groups were classified as substantially greater or lesser when there was a ≥75% likelihood of the effect being equal to or greater than the smallest worthwhile change, estimated as 0.2 x between-subjects SD (small ES). A custom Excel spreadsheet was used to determine ES and confidence intervals [138]. Finally, partial correlations (controlling for playing position) were used to assess the association between the tests of physical qualities and activity profiles. Correlations of 0.0-0.1, 0.1-0.3, 0.3-0.5, 0.5-0.7, 0.7-0.9, 0.9-0.99, and 1.0 were considered trivial, small, moderate, large, very large, nearly perfect, and perfect, respectively [138].

4.3 Results

Table 4.1 shows the descriptive characteristics for the selected and non-selected players. Selected players had more playing experience (ES=0.78 [90%CI: 0.23-1.33]; Likelihood = very likely, 96%; p=0.02), superior 30-metre sprint time (ES=0.57 [90%CI: 0.10-1.03]; Likelihood = likely probable, 90%; p=0.04), recorded a higher peak velocity between the 20-30m timing gates (ES=0.65 [90%CI: 0.19-1.11]; Likelihood = likely probable, 95%; p=0.03) and covered greater distances during the Yo-Yo IR1 (ES=1.09 [90%CI: 0.63-1.55]; Likelihood = almost certainly, 100%; p<0.001) than the non-selected players. No significant differences were recorded for the other physical qualities (ES≤0.37 [90%CI: -0.36-0.95]; p≥0.330).

Table 4.1. Physical qualities of selected and non-selected female AF players.

	Selected	Non-selected	Difference	p-value	ES ± 90% CI
Physical Characteristics					
Age (yr)	23.2 ± 4.5	23.4 ± 4.9	-0.20	0.759	0.10 ± 1.64
Height (cm)	167.2 ± 5.0	167.9 ± 5.0	-0.40	0.746	0.07 ± 0.22
Body mass (kg)	67.8 ± 8.1	65.4 ± 9.0	2.40	0.330	0.20 ± 0.35
Playing experience (years)	4.0 ± 2.8	2.1 ± 1.6	1.9	0.022*	0.78 ± 0.55
Performance					
Lower body power (watts.kg^{-1})	44.0 ± 7.1	41.6 ± 6.2	2.34	0.164	0.35 ± 0.51
5-metre sprint time (s)	1.19 ± 0.15	1.20 ± 1.26	-0.01	0.559	0.09 ± 3.14
30-metre sprint time (s)	4.85 ± 0.31	5.06 ± 0.32	0.21	0.044*	0.57 ± 0.47
20-30-metre velocity (m.sec^{-1}) [a]	7.17 ± 0.51	6.81 ± 0.49	0.36	0.032*	0.65 ± 0.46
Yo-Yo IR1 distance (m) [a]	712 ± 251	495 ± 252	216.5	<0.001*	1.09 ± 0.46

denotes significant difference between selected and non-selected groups

The average squared canonical correlation of 0.521 showed that 2 variables accounted for 52.1% of the overall discrepancy between selected and non-selected players. The discriminant analysis correctly predicted 63.6% (14 of 22) of selected players and 81.5 % (22 of 27) of non-selected players, with an overall accuracy of 73.4% (36 of 49) for all athletes. The discriminant analysis equation is shown below:

$(0.181 \times \text{peak velocity}) + (0.004 \times \text{Yo-Yo IR1 distance}) -3.738.$

Comparisons of the activity profiles of selected and non-selected midfielders, half-line and full-line players are shown in Table 4.2. Selected midfielders spent 7.8% more time on the field (ES=0.85 [90%CI: 0.29-1.41]; Likelihood = likely, probable, 93%; p=0.004) and covered 6.1% greater total match distances (ES=0.73 [90%CI: 0.21-1.25], Likelihood = likely, probable, 92%; p=0.009) than non-selected midfielders. No other differences were found between midfield groups. There were no meaningful differences between selected and non-selected half- and full-line players (ES<0.44 [90%CI: -0.24-0.86]; p≥0.08).

Table 4.2. Match activity profiles of selected and non-selected female AF players

	Selected	Non-selected	Difference (%)	p-value	ES ± 90% CI
Midfielders					
Field Time (minutes)	74.9 ± 5.7	69.1 ± 12.1	7.8	0.004*	0.85 ± 0.56
Total Distance (metres)	8018.1 ± 832.3	7532.3 ± 1240.1	6.1	0.009*	0.73 ± 0.52
Relative Distance (m.min^{-1})	107.9 ± 9.6	108.9 ± 9.3	-0.9	0.950	0.07 ± 0.44
Low-speed Distance (m.min^{-1})	58.5 ± 4.8	57.6 ± 3.5	0.1	0.867	0.19 ± 0.38
Moderate-speed Distance (m.min^{-1})	35.5 ± 8.7	36.5 ± 9.4	-0.2	0.769	0.04 ± 0.46
High Speed Distance (m.min^{-1})	13.9 ± 5.2	14.8 ± 4.8	-0.7	0.948	0.06 ± 0.42
Half Back/Forward Line					
Field Time (minutes)	77.4 ± 4.3	75 ± 6 [m]	3.1	0.558	0.54 ± 0.43
Total Distance (metres)	7249.7 ± 1085.1 [m]	6792.3 ± 1353.7	6.3	0.695	0.25 ± 0.44
Relative Distance (m.min^{-1})	92.7 ± 11.9 [m]	90.9 ± 15.5 [m]	2.2	0.252	0.09 ± 0.44
Low-speed Distance (m.min^{-1})	55.0 ± 4.6 [m]	54.7 ± 7.8	1.8	0.767	0.15 ± 0.45
Moderate-speed Distance (m.min^{-1})	25.0 ± 7.0 [m]	24.9 ± 7.9 [m]	4.0	0.452	0.22 ± 0.44
High Speed Distance (m.min^{-1})	12.7 ± 5.3	11.3 ± 4.6 [m]	8.3	0.954	0.31 ± 0.43
Full Back/Forward Line					
Field Time (minutes)	69.8 ± 6.4	68.0 ± 15 [h]	2.5	0.135	0.27 ± 0.53
Total Distance (metres)	5484.6 ± 1017.7 [m h]	4909.8 ± 1523.5 [m h]	10.4	0.256	0.56 ± 0.75
Relative Distance (m.min^{-1})	78.2 ± 15.9 [m h]	72.7 ± 17.8 [m h]	7.6	0.827	0.34 ± 0.90
Low-speed Distance (m.min^{-1})	46.3 ± 8.7 [m h]	46.2 ± 9.5 [m h]	0.0	0.636	0.39 ± 0.96
Moderate-speed Distance (m.min^{-1})	20.8 ± 6.3 [m]	18.7 ± 7.2 [m h]	10.0	0.862	0.18 ± 0.84
High Speed Distance (m.min^{-1})	12.8 ± 3.6	7.8 ± 4.5 [m h]	41.7	0.851	0.30 ± 0.93

denotes significant difference between selected and non-selected groups; "m" denotes difference compared with midfielders; "h" denotes difference compared with half-line players

Both selected and non-selected midfielders covered greater relative- (ES≥1.13 [90%CI: 0.74-3.28]; Likelihood = almost certainly, 100%; p≤0.03) and moderate-speed (ES≥1.06 [90%CI: 0.62-2.32]; Likelihood = almost certainly, 100%; p<0.001) distances than half- and full-line players. There were no differences in high-speed running across positions in selected players (ES≤0.33 [90%CI: 0.04-0.69]; p≥0.924). Non-selected midfielders covered greater high-speed distances than non-selected half-line (ES=0.79 [90%CI: 0.30-1.27]; Likelihood = very likely, 98%; p=0.01) and full-line players (ES=1.21 [90%CI: 0.80-1.63]; Likelihood = almost certainly, 100%; p<0.001). Selected half-line players covered 15% greater relative- (ES=1.40 [90%CI: 0.50-2.30], Likelihood = very likely, 98%; p<0.001) and 16% greater low-speed (ES=1.28 [90%CI: 0.03-2.54]; Likelihood = likely, probable, 93%; p<0.001) distances than selected full-line players. Non-selected half-line players covered greater distances at all speeds than non-selected full-line players (ES≥0.85 [90%CI: 0.40-1.90]; Likelihood ≥ 99%; p<0.03).

The relationship between tests of physical qualities and match activity profiles, controlling for playing position, is shown in Table 4.3. High-speed distance covered during matches was related to faster 5-m (r = -0.612; p=0.012) and 30-m times (r = -0.807; p<0.001), as well as greater peak velocity (r = 0.775; p<0.001) and Yo-Yo IR1 performance (r = 0.489, p=0.05). Players who were faster over 30-metres (r = -0.496; p=0.05) covered greater relative match distances. No meaningful associations were found among any other physical quality and activity profiles (Table 4.3).

Table 4.3. Relationships between physical qualities and running performance variables (controlling for position) in female AF players, with 90% Confidence Intervals *[Lower limit, Upper limit]*.

	RelDist	LowSpDist	ModSpDist	HighSpDist
Lower Body Power	0.362	-0.107	0.389	0.393
	[-0.273, 0.584]	*[-0.468, 0.128]*	*[-0.306, 0.331]*	*[-0.182, 0.599]*
5-m Time	0.161	-0.263	0.124	-0.612†
	[-0.167, 0.384]	*[-0.467, 0.136]*	*[-0.220, 0.574]*	*[0.228, 0.735]*
20 to 30-m Velocity	0.474	-0.156	0.379	0.775*
	[-0.032, 0.586]	*[-0.514, 0.186]*	*[-0.220, 0.574]*	*[0.496, 0.863]*
30-m Time	-0.496†	0.182	-0.415	-0.807*
	[-0.570, 0.065]	*[-0.218, 0.537]*	*[-0.540, 0.274]*	*[-0.848, -0.487]*
Yo-Yo IR1	0.194	-0.106	0.096	0.489†
	[-0.215, 0.317]	*[-0.390, 0.233]*	*[-0.388, 0.259]*	*[0.154, 0.690]*

*Δ RelDist= relative distance; LowSpDist = relative low-speed distance; ModSpDist = relative moderate-speed distance; HighSpDist = relative high-speed distance; * denotes significance at p <0.01; †denotes significance at p <0.05.*

4.4 Discussion

This study investigated (1) the physical qualities that discriminate selected and non-selected female AF players, (2) the activity profiles of female AF players, and (3) the influence of physical qualities on running performance in female AF match-play. Consistent with research on junior elite male AF players [100, 104], selected female AF players were faster over 30 metres, had a higher peak velocity and superior prolonged high-intensity running ability. The greater prolonged high-intensity running ability and speed would likely enable selected players to place themselves in more advantageous positions to receive the ball during match-play. In partial agreement with previous research in elite senior male AF players [105], the selected players were more experienced, however age did not influence team selection in this group. Acceleration, peak running speed and high-intensity running ability were all associated with greater high-speed running distances during match-play, suggesting that such physical

attributes may influence team selection and match activity profiles in female AF players. Support for this notion was provided by the discriminant analysis, which showed that a combination of speed and high-intensity running ability are important in team selection of female AF players. However, it is worth considering that the presented discriminant model was more successful at classifying players who were not selected in the Academy squad, suggesting that other factors, such as skill performance, may be better predictors of team selection in female AF players [98]. With this in mind, the inclusion of skill-based testing in future team selection processes warrants investigation.

The associations between speed and high-speed running distances during matches support the importance of running speed to a player's performance during female AF match-play, but the lack of relationships between lower body power and match running performances was unexpected. For male team sport athletes, both lower body power [109] and acceleration [105] have been shown to discriminate higher standard athletes from lower standard athletes and starting players from non-starting players. The absence of relationships between lower body power, acceleration and running performances in female AF players may have been influenced by the lack of access to training facilities and limited exposure to systematic strength and power training; potentially limiting their capacity to specifically focus on strength and power development [139, 140]. These findings appear to highlight the importance of more sport-specific training, as further development of these attributes may influence the players' peak running speed [140] and, in turn, match running performances.

Consistent with elite male AF research [75], the positional activity profiles of female AF match-play varied considerably. Midfielders covered greater total, relative, low-, moderate-, and high-speed distances than both half-line and full-line players. Furthermore, activity profiles

were greater for half-line players than full-line players. High-speed running distances were similar across the three positions in the selected group. Conversely, non-selected midfielders covered more high-speed running distance than other non-selected players. In agreement with previous research [101], the distances covered at high-speed were closely related to performance on the Yo-Yo test. The selected midfielders covered greater total distances than non-selected players as a direct result of greater playing time. Although there were no differences in overall work rate between groups, it is likely that the superior Yo-Yo IR1 scores allowed selected players to remain on-field for extended periods of time while still matching the intensity of non-selected players. However, to increase work rate, coaching staff should seek to rotate selected players more regularly to better utilise these higher-skilled players throughout the match.

Finally, although total relative distances reported in this study are comparable with elite junior AF competition (range: 45-126 m.min^{-1} and 68-134 m.min^{-1} for females and elite junior males [7], respectively), male footballers cover up to 70% greater high-speed distances than female players (range: 4-30 m.min^{-1} and 13-45 m.min^{-1} for female and elite junior males [7], respectively). It is likely that the arbitrary speed thresholds used in this study will favour males to cover greater high-speed distances than female AF players. Notwithstanding, to aid in the advancement of female AF, players should be exposed to greater amounts of high-intensity running in training.

4.5 Conclusion

This is the first study to investigate the influence of physical qualities on team selection and activity profiles in female AF match-play. The findings demonstrated that players who are faster and have greater intermittent running ability are more likely to be selected to a State

Academy program and that midfielders perform more activity during match-play than half-line and full-line players. These results provide important information that can be used to establish appropriate preseason training programs to maximise the preparedness of the entire playing group competing in the National Women's AF competition. Future research should extend upon these findings by investigating differences in the activity and skill profiles of players competing in the National competition and by recruiting players from a wider range of female football academies.

4.6 Practical Applications

The assessment of speed and high-intensity running ability is vital for female AF players as these qualities can influence both team selection and activity profiles. The reported average match intensities should be used as a starting point for training programs; however preseason training should aim to expose these players to increasing intensities. Specifically, coaching and conditioning staff may choose to incorporate high-intensity work rates of elite junior male AF competition and use those intensities as benchmarks for future training. Physical fitness should be assessed early in the preseason to identify deficiencies and facilitate targeted approaches for improvement.

Despite the novelty of the reported findings, the relatively small sample size and the restriction of player recruitment from only one Australian State competition are both limitations that should be taken into consideration when interpreting the results. Additionally, extra individual training sessions were not accounted for and if performed, these would likely influence the physical qualities of individual players. Nevertheless, it is important to emphasise that there is a paucity of research evaluating the game and positional demands of female AF players competing at different levels. Given the National Women's AF competition will be introduced

in 2017, the results presented in this study have the potential to make a significant contribution to this area of research, despite these potential shortcomings.

Chapter 5: Physical fitness and peak running periods during female Australian football match-play

The findings of Study 1 demonstrated that Yo-Yo IR1 performance was associated with greater average distances covered during female AF match-play. However, this study did not explore fluctuations in activity profiles during the match. As research has shown that running performance declines following short, intense periods of play [16, 17], Study 2 sought to understand how these periods influence the activity of female Australian footballers. An improved understanding of the influence of fitness on peak and subsequent running performance may provide further support for the use of the Yo-Yo IR1 for female footballers.

This study has been accepted for publication in Science and Medicine in Football:

5.1 Introduction

Understanding the demands of match-play has been central to training prescription in team sport athletes [2]. Research commonly reports the average distances covered during matches [5, 67]. However, given the stochastic nature of team sports, it is important to understand the fluctuations in running demands that regularly occur during match-play. The use of global positioning system (GPS) technology has allowed scientists to detect transient reductions in running performance during team sport match-play [8, 9, 29]. Specifically, research has recently shown female AF midfielders and half-line players reduce overall running intensity and high-speed distances across match halves [141]. Despite the importance of understanding variations in running performance over the course of a match, knowledge of peak running periods [92] is of equal importance to optimise player preparedness for possible match situations.

To identify intense passages of play, studies have used rolling time scales to identify peak periods of high-intensity running throughout match-play [16, 88]. Using rolling periods, research has reported reductions in running performance following the most intense match periods in a number of team sports [16, 17, 142]. To measure transient reductions in team sports, with the exception of one study [16], 5-minute peak periods for total distance are compared with the subsequent 5-minute period and the average match running intensity [14, 15, 17]. However, recent research investigating duration-specific peak running periods in male AF and rugby league found increases in running intensity as the duration of the rolling period decreased [91, 92]. These findings show that 5-minute epochs are not representative of true maximal match intensity in team sports [91, 92]. Furthermore, although researchers have provided insight peak exercise periods and player response to within match fatigue, studies have not taken into account how physical fitness may influence this response.

Several studies of team sport athletes have identified a relationship between physical fitness and match running performance. In AF [30] and soccer [22], Yo-Yo Intermittent recovery test scores have been associated with greater total- and high-speed running distances during match-play. Therefore, in order to understand the influence physical fitness on peak periods, and responses to peak periods of match-play, this study aimed to (1) identify peak periods of varying durations in female football and (2) determine whether better performance on the Yo-Yo IR1 was associated with greater distances covered during peak and subsequent periods of varying durations in female AF match-play.

5.2 Methods

5.2.1 Participants

Forty-three players (age 24.3 ± 5.5 years, height 167.4 ± 4.3 cm, body mass 66.5 ± 9.3 kg) from 3 Queensland Women's Australian Football League teams were recruited into this study. Two positional groups were analysed in this study and were further separated into high or low fitness groups based on their Yo-Yo IR1 score; midfielders (high fitness n= 10; Yo-Yo IR1 distance 950 ± 62 m, low fitness n = 12; Yo-Yo IR1 distance 670 ± 165 m) and half-line players (high fitness n= 10; Yo-Yo IR1 distance 800 ± 95 m, low fitness n = 11; Yo-Yo IR1 distance 410 ± 80 m). All participants completed two field sessions per week with their respective clubs during the preseason. However, extra individual training sessions were not accounted for and if performed, these would likely influence the physical fitness of individual players. Due to the small number of the half-backs and half-forwards these positions were pooled [75] to represent the half-line group. Prior to data collection, participants received an information sheet outlining

the risks and benefits of the study and written consent was obtained. The study was approved by the Australian Catholic University's Human Research Ethics Committee (2016-27H).

5.2.2 Procedures

An observational cohort study was used to investigate the influence of physical fitness on the response to intense exercise periods in female AF match-play. Physical fitness was assessed using the Yo-Yo IR1 test and match running performances were measured using Global Positioning System (GPS) units worn across one competitive season. Each positional group were divided into two subsets based on their final Yo-Yo score. Each match was analysed in rolling periods in order to compare the "peak", "subsequent" and "mean" periods during match-play for players with high and low fitness.

During the final two weeks of preseason, players were required to complete the Yo-Yo IR1 to assess physical fitness, with the total distance covered recorded as the Yo-Yo IR1 score. Players were separated into four groups based on their positional groups and Yo-Yo IR1 performance. Specifically, following the test both the midfield and half-line players were further divided into two subsets according to their Yo-Yo IR1 performance using a median split (high/low fitness midfielders, high/low fitness half-liners). During testing, participants wore football boots and their normal training clothes; given that some players were unfamiliar with the Yo-Yo IR1 test, the first two levels were incorporated into the warm-up. The typical error of measurement for the Yo-Yo IR1 has been reported as 4.9% [101].

Each player's match activity profiles were recorded for each quarter during at least 4 (mean ± SD: 5.1 ± 0.6; range: 4-6; total GPS files: 180) competitive matches during the 2016

competitive season. Player movement was recorded using a S5 GPS unit (S5, Optimeye, Catapult Sports, Docklands, VIC, Australia) sampling at 10 Hz worn in a customised vest positioned between the shoulder blades. These 10 Hz GPS units have reported greater validity and inter-unit reliability than 1 Hz, 5 Hz and 15 Hz units [63]. Data were downloaded onto a laptop and analysed using software provided by the manufacturer (Sprint 5.1.7, Catapult Sports, Docklands, VIC, Australia). All matches were played at the same time of day (~1600 hours). Activity profiles were determined by dividing movements into low-speed (0-4.15 $m.sec^{-1}$), and high-speed (>4.15 $m.sec^{-1}$) bands as it has been recommended that speeds of 15 to 16 $km.hr^{-1}$ should be used to define high-speed running in female team sports [65]. Only active field time was included in analyses; data were removed for the time players were rotated or interchanged off the field.

As has been previously described [16], the physical performance variables were arranged into one-minute rolling periods [88]. Although 5-minute epochs are commonly used to identify peak match periods [15, 142], individual files were separated into peak periods of five different durations (1, 2, 3, 4 and 5-minute). To measure transient reductions in performance, peak periods were identified as the maximum distance covered per minute ($m.min^{-1}$), for each duration interval. This period was then compared with the subsequent duration interval and the average match intensity. Data were removed from the analysis if players were interchanged off the field or the match quarter ended in the subsequent period. A total of 180 match files were included in the analysis (GPS files n =97 midfielders [45 high fitness, 52 low fitness]; GPS files n = 83 half-line players [high 49 fitness, 34 low fitness]). However, 155 peak periods were removed (72 [15%] midfielders, 83 [20%] half-line players) from the analysis as players were interchanged off the field or the match quarter ended in the subsequent period.

5.2.3 Statistical Analyses

Cohen's effect size (ES) statistic ± 90% confidence intervals (CI) were used to determine the magnitude of differences between midfielders and half-line players. Differences between the peak, subsequent and the average match demands were calculated. Furthermore, differences between high and low fitness groups were also compared. The effect sizes were classified as substantially greater or lesser when there was a ≥75% likelihood of the effect being equal to or greater than the smallest worthwhile change estimated as 0.2 x between-subjects SD (small ES). Effect sizes of ≤0.2, 0.21–0.6, 0.61–1.2, 1.21–2.0, and >2.0 were considered trivial, small, moderate, large, and very large, respectively [138]. A custom Excel spreadsheet (Version 16, Microsoft, USA) was used to calculate ES, CI and likelihoods [138].

5.3 Results

Midfielders covered meaningfully greater distances on the Yo-Yo IR1 test than the half-line group (ES = 0.53 ± 0.63; Likelihood = likely probable, 80%). Greater average match relative total- and low-speed distances were covered by the midfielders compared with the half-line players. Table 1 illustrates the peak periods for midfield and half-line positional groups. No differences were reported between playing positions for high-speed distances during peak periods (ES ≤ 0.28; likelihood ≤65%) with the exception of the 1-minute period (ES = 0.38 ± 0.36; Likelihood = likely probable, 80%). As the duration of the peak period increased, running intensity subsequently decreased (ES range = 0.37-1.31; likelihood ≥ 77%).

Table 5.1 Positional comparisons of running demands during competition

	Midfielders	Half-liners	ES CI	Likelihood
Average match demands				
Relative-distance (m.min^{-1})	109 (77-127)	94 (69-109)	1.06 ± 0.28	*Almost certainly*
Low-Speed distance (m.min^{-1})	95 (69-109)	82 (60-105)	1.15 ± 0.26	*Almost certainly*
High-speed distance (m.min^{-1})	14 (7-30)	13 (6-25)	0.19 ± 0.32	*Trivial*
1-minute period				
Relative-distance (m.min^{-1})	178 (148-211)	173 (236-212)	0.33 ± 0.35	*Possible*
Low-Speed distance (m.min^{-1})	132 (59-180)	116 (61-167)	0.60 ± 0.35	*Very likely*
High-speed distance (m.min^{-1})	46 (0-109)	57 (0-130)	-0.38 ± 0.36	*Likely, probable*
2-minute period				
Relative-distance (m.min^{-1})	156 (134-184) ***	148 (120-172) ***	0.64 ± 0.35	*Very likely*
Low-Speed distance (m.min^{-1})	127 (97-167)	114 (83-153)	0.72 ± 0.34	*Almost certainly*
High-speed distance (m.min^{-1})	29 (4-60) **	33 (0-66) **	-0.28 ± 0.37	*Possible*
3-minute period				
Relative-distance (m.min^{-1})	147 (125-176) *	136 (108-155) **	0.81 ± 0.35	*Almost certainly*
Low-Speed distance (m.min^{-1})	122 (90-149)	108 (84-128) *	0.99 ± 0.33	*Almost certainly*
High-speed distance (m.min^{-1})	25 (4-52)	28 (5-57) *	-0.24 ± 0.38	*Possible*
4-minute period				
Relative-distance (m.min^{-1})	141 (121-167) *	130 (102-155) *	0.82 ± 0.36	*Almost certainly*
Low-Speed distance (m.min^{-1})	119 (93-147)	107 (83-141) *	0.87 ± 0.34	*Almost certainly*
High-speed distance (m.min^{-1})	22 (5-43)	23 (4-53)	-0.07 ± 0.38	*Trivial*
5-minute period				
Relative-distance (m.min^{-1})	137 (115-158)	125 (98-156)	0.86 ± 0.37	*Almost certainly*
Low-Speed distance (m.min^{-1})	116 (83-141)	103 (85-140)	0.92 ± 0.35	*Almost certainly*
High-speed distance (m.min^{-1})	21 (5-41)	22 (5-49)	-0.14 ± 0.39	*Trivial*

Data reported as mean (range)

*denotes small ES (0.43-0.47) difference from previous duration-specfic period; **denotes moderate ES (0.68-0.90) difference from previous duration-specfic period; ***denotes large ES (1.21-1.31) difference from previous duration-specfic period

Figures 5.1 and 5.2 illustrate the differences among peak, subsequent and average running intensities for the high and low fitness players. No differences were reported between high and low fitness midfielders, irrespective of period, for low-speed distances covered (ES ≤ 0.37; likelihood ≤74%). Higher fitness midfielders covered greater high-speed distances than the lower fitness players during the subsequent 1-, 2- and 3-minute periods (ES = 0.57 ± 0.61; likelihood ≥ 82%). Higher fitness half-line players covered greater relative total- (ES range = 0.89-1.22; likelihood ≥ 99%) and high-speed (ES range = 0.70-1.16; likelihood ≥ 94%) distances during all peak periods than lower fitness players. Greater relative total (ES ≥ 0.59 ± 0.70; likelihood ≥ 85%) and low-speed (ES ≥ 0.47 ± 0.74; likelihood ≥ 76%) distances were covered by the higher fitness half-liners than the lower fitness players in the subsequent 2-minute, 3-minute and 5-minute periods. Higher fitness half-line players reduced high-speed running below the match average during all subsequent periods (ES ≥ 0.43 ± 0.84; likelihood ≥ 80%).
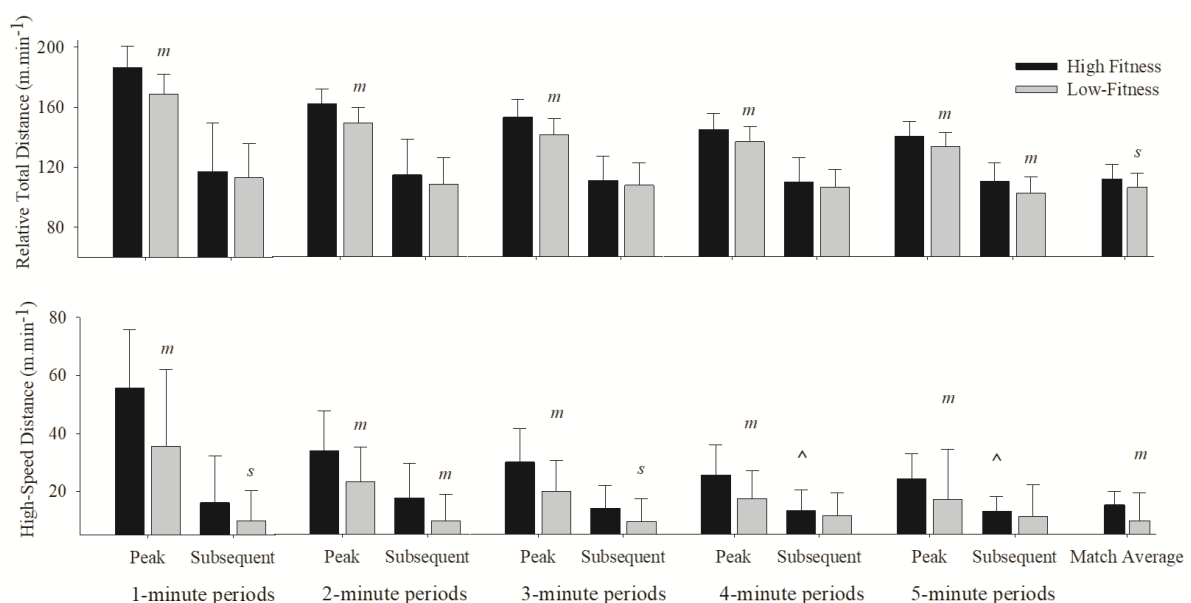
Figure 5.1. *Duration-specific peak and subsequent periods, and match averages for the higher fitness and lower fitness midfielders.*

"m" denotes a moderate effect size (ES=0.61-1.2) difference between high and low fitness midfielders; "s" denotes a small effect size (ES=0.21-0.60) difference between high and low fitness midfielders; ^ denotes meaningful difference (ES=0.50-0.62) between the subsequent period and match average.
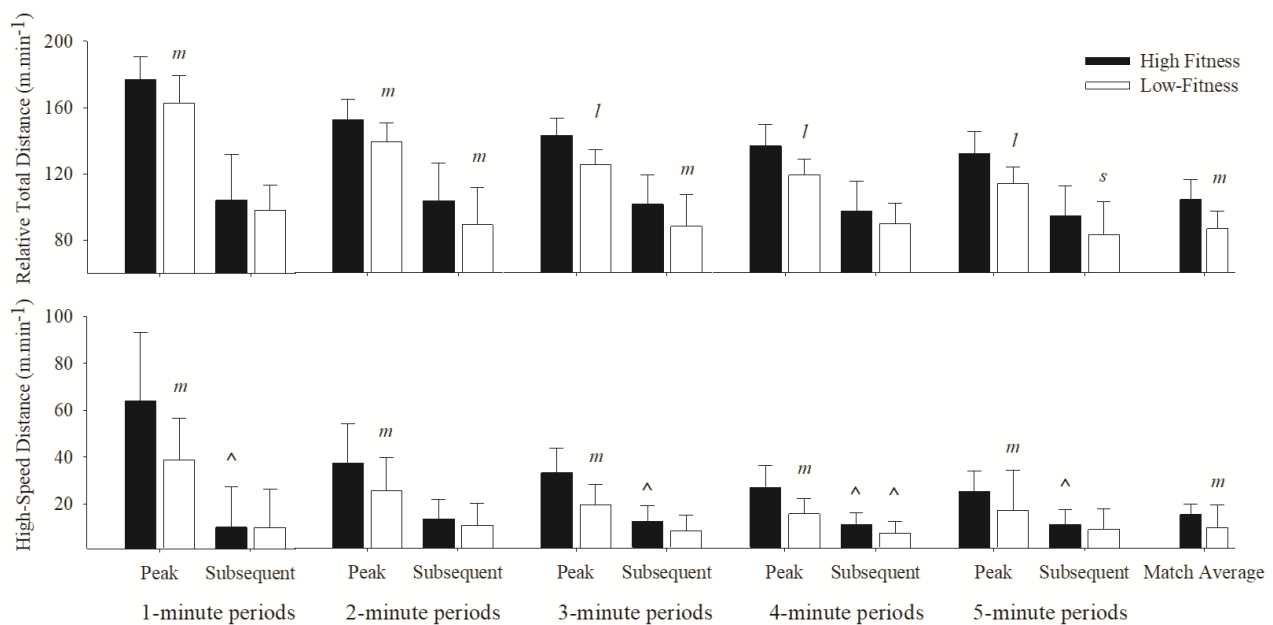
Figure 5.2. *Duration-specific peak and subsequent periods, and match averages for the higher fitness and lower fitness half-line players.*

"l" denotes a large effect size difference (ES=1.21-2.0) between high and low fitness half-line players; "m" denotes a moderate effect size (ES=0.61-1.2) difference between high and low fitness half-line players; "s" denotes a small effect size (ES=0.21-0.60) difference between high and low fitness half-line players; ^ denotes meaningful difference (ES=0.50-0.62) between the subsequent period and match average.

5.4 Discussion

This is the first study to identify true peak periods, of varying durations, on during female AF match-play. Moreover, this study compared the effect of physical fitness on the response to short periods of high-intensity activity. True peak periods, based on maximal distances covered per minute, were identified across a number of duration-specific periods. In contrast to male AF players [92], the current results highlighted midfielders exhibit greater peak periods, irrespective of period duration, than half-line players. Additionally, greater Yo-Yo performers covered greater relative total and high-speed distances in all peak periods than low Yo-Yo performers. The current findings highlight the importance of developing physical fitness and identify intense exercise periods that players will be exposed to during match-play.

95

Our results demonstrated the midfielders covered greater distances during peak periods of play than the half-line players. Furthermore, midfielders reported greater fitness levels and, similar to previous research, average match demands [67] than the half-line players. Collectively, these findings suggest that players with lower fitness levels may be selected for positions that are less physically demanding. Notwithstanding, both positional groups are exposed to intense passages of play during female AF matches (Table 1). Interestingly, as the discrete period duration increased, the difference between midfield and half-line peak running intensities subsequently increased. Moreover, in accordance with previous research [92], half-line players covered greater high-speed distances during the 1-minute peak period than the midfielders. These findings suggest that half-line players should be exposed to shorter duration peak periods (1 to 2 minutes) during training as they may be more representative of match situations. Nevertheless, with the exception of the 1-minute period, high-speed distances were comparable across positional groups, which highlights the ability to increase high-intensity activity during intense match stages is important for female footballers, irrespective of playing position.

While fluctuations in match running intensity across female AF matches have been previously reported [141], our results highlight the most demanding fluctuations of match-play (Table 5.1). The greatest "peak" period of match-play performed by an individual player consisted of 212 m covered, 122 m at low-speed and 90 m covered at high-speed. In agreement with previous research [92], as the period duration increased (~1 minute), running intensity was reduced. Nevertheless, irrespective of the period duration, players are required to exhibit significantly greater running intensities compared with the match average during these short epochs. Therefore, the results demonstrate duration-specific running intensities that can be used

to develop "worst-case scenario" training drills [92, 143] specific to female footballers. While running intensities may be influenced by contextual factors such as game outcome [129], match score [39], opposition rank [42] and playing strategy, these were not accounted for in this study and require further research.

Higher Yo-Yo IR1 performers covered greater relative total and high-speed distances during all peak periods compared with low Yo-Yo performers, irrespective of position. These findings demonstrate that superior fitness enables female footballers to increase high-speed running during intense match periods which, although speculative, may lead to a greater ability to (1) lead for the football, (2) beat their opponent to a contest, or (3) evade their opponent by running to space to become a passing option for their teammate. Furthermore, as research has identified relationships between Yo-Yo performance, high-intensity match running and skill involvements [30]; and peak exercise periods are associated with greater skill involvements in male AF players [16], superior Yo-Yo performance may increase female footballers' ability to gain possession of the football during peak periods.

Figure 5.1 demonstrates that higher fitness midfielders cover greater high-speed distances during the subsequent 1-, 2- and 3-minute periods compared with lower fitness midfielders. Given that the Yo-Yo IR1 is an assessment of high-intensity intermittent running ability [22], it is not surprising the higher Yo-Yo performers were protected from match-related fatigue [17] following the peak match periods. While higher fitness midfielders reduced high-intensity activity below their match average during the subsequent 4- and 5-minute period, high-speed distances were comparable with low fitness players. Given the higher fitness players exhibited greater peak period and match intensities, it is possible these players implemented a self-

preservation strategy [144, 145] during these subsequent periods and performed at the lowest intensity that the match allowed.

On the contrary, half-line covered comparable high-speed distances across fitness groups during the subsequent periods (Figure 5.2). Differences between high and low fitness half-line players were explained by distances covered at low-speed. Although in disagreement with previous research [16, 17], a possible explanation may lie within the positional requirements of the half-line players. Male AF half-line positional players complete less skill involvements than midfielders [67]. Therefore, it is possible following peak periods high-intensity running is not demanded of half-line players as the football has been cleared from the attacking/defending zones.

A limitation of this study is the relatively small number of players (3 teams drawn from one state competition) included in this analysis. Also, due to the small sample size of the full-line positional group (full backs/forwards and back/forward pockets), these data were excluded from the analysis. Future research should aim to identify intense match periods in all teams competing in the national female AF competition. Additionally, there are a number of confounders, such as the player nutrition and match recovery strategies that that were not accounted for and may have influenced running performance. Furthermore, the Yo-Yo IR1 was only assessed once at the end of preseason; as such it is possible that physical fitness may have improved or declined as the season progressed. Finally, work rate does not equate to performance therefore further research investigating the influence of peak periods on match running performance and skill efficiency in elite female AF players is warranted and remains a future challenge.

5.5 Practical Implications

The assessment of high-intensity running ability is important for female Australian football players, as superior Yo-Yo IR1 performance is linked with greater distances covered during peak and subsequent periods, of varying durations, and average match running intensities. Players with poorly developed physical fitness should be identified early to detect individual deficiencies and allow sufficient time for improvements. Additionally, coaches should expose all players to the "worst-case scenarios" during training to increase match preparedness. Small-sided games, using peak running intensities relative to the drill duration, could be used to develop physical fitness and adequately prepare players for competition. However, these distances and intensities should be used as a starting point with training programs progressively increased to greater intensities.

Chapter 6: The influence of rotations on match running performance in female Australian football midfielders

Studies 1 and 2 demonstrated the influence of Yo-Yo IR1 performance on average and peak running demands during female AF competition. During AF rotations are commonly used to manage player fatigue. However, the effect of rotation frequency and timing on running performance has not been investigated. Therefore, Study 3 sought to further understand the influence of Yo-Yo IR1 on running performance during on-field bouts and across rotations. By identifying optimal on-field durations, it may be possible to inform the rotation strategies used on game day.

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Black G, Gabbett T, Johnston R, Cole M, Naughton G, Dawson B. The influence of rotations on match running performance in female Australian football midfielders. *International Journal Sports Physiology and Performance,* doi: 10.1123/ijspp.2017-0175

6.1 Introduction

Australian football (AF) is an intermittent team sport, involving repeated bouts of high-intensity activity interspersed with lower-intensity movement [9]. The high-intensity intermittent nature of the sport is particularly evident in the midfield positional group, with elite male AF players covering 135 m.min^{-1} and performing approximately 300 high-intensity efforts over the duration of a match [9]. Due to these match demands and the positional requirements of midfielders to cover a larger proportion of the field than other positional groups, these players are regularly rotated on and off the field [80]. Based on the high-intensity nature of AF, it is accepted that rotations are most commonly used to delay the onset of fatigue [80]. Not surprisingly, a positive association has been reported between running intensity and number of interchanges across match-play in elite male footballers [78]. Moreover, these researchers demonstrated that in combination with increased rotations, players who performed better on the Yo-Yo intermittent recovery 2 test completed the match at a greater running intensity than players with lower scores [78]. Collectively, this information suggests that by improving the physical fitness of their players [78] and strategically rotating players on and off the field, coaches can manipulate the intensity of the match and potentially gain a competitive edge over the opposition by maintaining player work rate as a result of short recovery periods on the bench [80]. However, while rotations may slow the rate of cumulative fatigue, it is well accepted that irrespective of rotations, player work rate declines across the four match quarters [29].

Given the inevitable decline in running performance across AF matches, the effectiveness of on-field playing time per rotation has recently been investigated [80]. Specifically, following 5 minutes, relative distances declined and continued in this pattern until the 9-minute mark of

a playing period [80]. However, the influence of rotations on running intensity has only been investigated in male players; how rotations affect activity profiles in female AF players is yet to be explored. The relatively recent introduction of females into national and state leagues of AF requires a stronger evidence base for the planning of playing strategies than currently exists. Furthermore, while this research provides insight into the optimal rotation duration, little is understood of the player activity profiles during on-field bouts between rotations. While there is a paucity of information on the changes in running performance during on-field bouts in AF players, differences in running intensities and pacing strategies between whole-game and interchanged rugby league players have been investigated. When analysed as quartiles, players interchanged during the first half of rugby league exhibited a greater work rate during the first match quartile compared with whole-game players and those interchanged during the second half [36]. Following the initial quartile, running intensity declined progressively over the subsequent quartiles in the interchanged players [36]. On the contrary, consistent with previous research [35], players interchanged during the second half exhibited an "end-spurt" during the final match quartile in comparison to whole-game players [36]. Given the tactical importance and number of rotations completed during AF matches, player pacing strategies within an on-field bout between rotations warrant investigation. Furthermore, the majority of research investigating pacing strategies and changes in running intensity during rotation bouts is restricted to male athletes; the evidence of strategies implemented in female team sports is not yet understood. Therefore, the aim of this longitudinal study in female AF players across competitive matches was three-fold; (1) to compare activity profiles of on-field bouts between rotated and whole-quarter player performances; (2) to identify the changes in running performance during different on-field bout durations; and (3) to investigate the influence of Yo-Yo intermittent recovery 1 performance on activity profiles.

6.2 Methods

6.2.1 Subjects

The influence of rotations on running performance was assessed in 22 state-level female AF midfielders (mean ± SD age: 23.3 ± 3.8 years; body mass: 62.5 ± 6.3 kg). The players were recruited from three of the six teams competing in the state-based Queensland Women's Australian Football League. Prior to the study, players received an information sheet regarding the risks and benefits of the study and provided written consent to participate. The Australian Catholic University's human research ethics board provided approval for the research study (2016-27H).

6.2.2 Design

An observational cohort study was used to investigate the influence of rotations and fitness levels on running demands in female AF midfield players. During the final two weeks of preseason, players were required to complete the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) to assess high-intensity running ability. Running performances were measured using Global Positioning System (GPS) units across one competitive season. Matches were comprised 4 x 20-minute quarters with no time-on added to the game clock. The dichotomisation of data was completed into three phases. First, each player's data were categorised into three different sub-groups; (1) whole-quarter (2) on-field rotation bout 1 (3) on-field rotation bout 2 before each on-field bout being further divided into quartiles. The second component of analysis investigated running performance during competitive match-play by comparing high and low Yo-Yo IR1 groups. Finally, short (4-6 minutes), moderate (6-12 minutes) and long (12-18 minutes) on-field bout activity profiles were compared with whole-quarter players. All of the data included and dichotomised into quartiles in this research

is representative of within-quarter analysis. The changes in running performance across different match quarters were not analysed in this study.

6.2.3 Procedures

Following the Yo-Yo IR1 test, the total distance covered during the test was recorded as the Yo-Yo IR1 score. Subsequently, players were divided into two subsets (high fitness or low fitness) from a median split of the Yo-Yo IR1 performances. During testing, participants wore football boots and their normal training clothes; given that some players were unfamiliar with the Yo-Yo IR1 test, the first two levels were incorporated into the warm-up. The typical error of measurement for the Yo-Yo IR1 has been reported as 4.9% [101].

Match activity profiles were analysed during 14 regular matches during the 2016 competitive season [97 GPS files (mean: 4.5 (range: 3-6) files per player); 388 individual quarters, with 40 (10%) individual quarters later removed as players started the match off-field], using 10 Hz global positioning system (GPS) devices (S5, Optimeye, Catapult Sports, Docklands, VIC, Australia). The units have acceptable reliability and validity for measuring activity profiles in team sports [56]. Players wore a customised vest with the GPS unit positioned between the shoulder blades; where possible, players wore the same unit during each game. A total of 25 GPS units were used to collect match activity data across multiple teams. Activity profiles were determined by dividing movements into relative total, low-speed (0 to 2.78 m.sec^{-1}), moderate-speed (2.79 to 4.15 m.sec^{-1}), and high-speed (>4.15 m.sec^{-1}) movement bands [16]. All data is reported as distances covered per minute of play.

Analysis of data occurred in three different stages. First, each player's data were categorised into one of three different sub-groups for rotations. Group one comprised players who completed >18 minutes of the quarter and, represented the whole-quarter players (individual quarters = 159; mean ± SD playing duration: 19.9 ± 0.1 minutes). Players in group two were those individuals who started the quarter on the field but were rotated off the field after a period of time (on-field rotation bout 1 [individual quarters = 189]). The third group consisted of players who were rotated off the field during a quarter (mean ± SD playing duration for bout 1: 7.8 ± 3.0 minutes) but were rotated back onto the field during the same quarter after a period on the bench (on-field rotation bout 2 [individual quarters = 135]). The mean ± SD duration of the on-field bouts were 9.2 ± 3.7 minutes (2.3-minute quartiles) and 7.4 ± 2.4 minutes (1.85-minute quartiles) for playing bout 1 and 2, respectively. Following the division of time-related data, each individual on-field bout was further split into even quartiles. Data were excluded from the analysis if the on-field bout was less than 4 minutes.

For the final component of the analyses, the length of the on-field bouts were divided into (1) short (4 to 6 minutes), (2) moderate (6 to 12 minutes), and (3) long duration (12 to 18 minutes) and subsequently compared with whole-quarter player performances. The average on-field rotation bouts were 5.0 ± 0.9 minutes (individual quarters = 61), 9.8 ± 1.8 minutes (individual quarters = 74) and 15.8 ± 1.5 (individual quarters = 54) minutes for short, moderate and long duration on-field bouts, respectively. Additional exploration of the data occurred when the on-field rotation bouts were further split into even quartiles based on the on-field bout duration.

6.2.4 Statistical Analyses

Log transformation of all data was used to reduce bias and non-uniform error. A linear mixed model with a fixed effect for on-field bout (3 levels; whole-quarter, rotation bout 1 and rotation bout 2) and a random effect for individual player identity was used to assess the influence of rotations on match activity profiles (SPSS 19.0, SPSS Inc, Chicago, IL, USA). A separate linear mixed model with a fixed effect of "quartile" was employed to assess the differences in running performance between quartiles. A further model was used to assess the differences in GPS variables among short-, moderate- and long-duration playing bouts. A final linear mixed model with a fixed effect of "fitness" was used to investigate differences between high and low Yo-Yo IR1 players. The random effect for player identity was included to account for the dependence arising from repeated measurements of running performance variables from individual participants. Cohen's effect size (ES) statistic ± 90% confidence intervals (CI) were also used to determine the magnitude of differences between the two groups. These were classified as substantially greater or lesser when there was a ≥75% likelihood of the effect being equal to or greater than the smallest worthwhile change estimated as 0.2 x between-subjects SD (small ES). Effect sizes of ≤0.2, 0.21–0.6, 0.61–1.2, 1.21–2.0, and >2.0 were considered trivial, small, moderate, large, and very large, respectively [138]. A custom Excel spreadsheet (Version 16, Microsoft, USA) was used to calculate ES and confidence intervals [138].

6.3 Results

6.3.1 Rotated Players vs. Whole-Quarter Players

The rotated players covered greater relative total (ES ≥ 0.45 ± 0.29; likelihood = likely probably ≥91%) and moderate-speed (ES ≥ 0.44 ± 0.33; likelihood = likely probably, ≥90%) distances during quartiles one and four than the whole-quarter players (Figure 6.1). During both on-field

bouts, rotated players covered greater relative high-speed distances (ES $\geq 0.89 \pm 0.45$; likelihood = almost certainly, 100%) than whole-quarter players in quartile four. Greater relative distances were covered by rotated players during quartile one of on-field rotation bout 1 than bout 2 (ES = 0.46 ± 0.27; likelihood = likely probable, 94%). Following quartile one, relative- total (ES = 0.51 ± 0.31; likelihood = almost certainly, 99%) and moderate-speed (ES = 0.50 ± 0.31; likelihood =likely probable, 95%) distances were reduced during on-field rotation bout 1. Relative high-speed distances were increased in quartile four during both rotation bouts in comparison with quartile three (ES ≥ 0.39 [90%CI: 0.07-0.90]; likelihood =likely probably, ≥ 85%). During the third quartile, whole-quarter players showed a more reduced relative-total (ES = 0.36 ± 0.19; likelihood = likely probable, 92%) and moderate-speed (ES = 0.30 ± 0.19; likelihood =likely probable, 81%) activity than during quartile two.
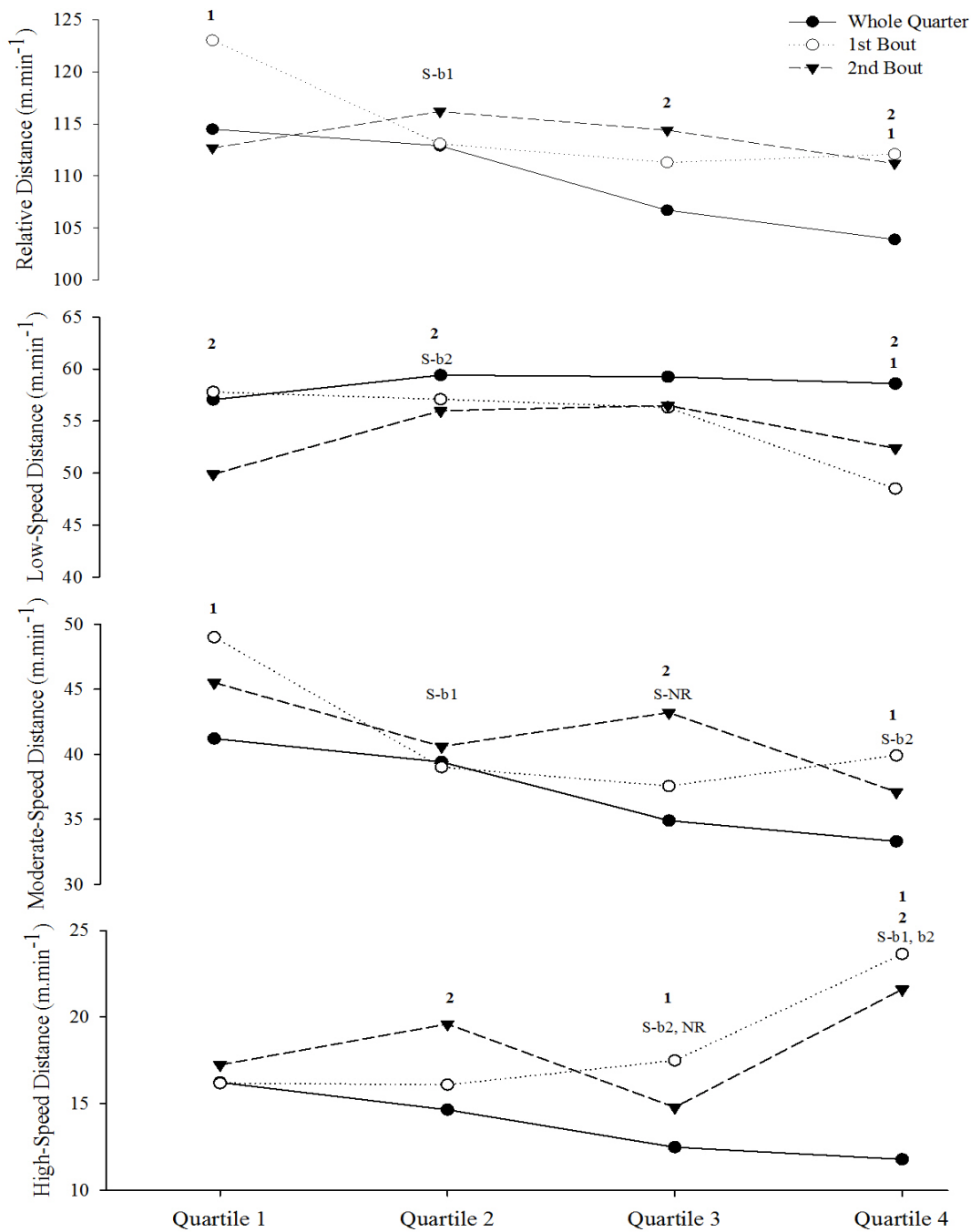
Figure 6.1. *The running demands across quartiles during the first on-field bout, second on-field bout and whole-quarter players.*

"1" denotes difference (ES range = 0.44-1.01) between on-field bout 1 players and whole-quarter players; "2" denotes difference (ES range = 0.40-0.89) between on-field bout 2 players and whole-quarter players; "s-b1" denotes small difference (ES range = 0.21-0.60) from previous quartile in 1st on-field bout; "s-b2" denotes small difference (ES range = 0.21-0.60) from previous quartile in 2nd on-field bout; "s-NR" denotes a small difference (ES range = 0.21-0.60) from previous quartile in whole-quarter players.

NB: *All quarters have been dichotomized into quartiles and collectively analysed. There is no comparative analysis across quarters.*

6.3.2 Influence of Fitness on Activity Profiles

Figure 6.2 demonstrates higher fitness players covered greater relative distances (ES ≥ 0.56 [90%CI: 0.12-1.32]; likelihood ≥97%) during the first on-field bout than lower fitness players, with the exception of quartile one (ES = 0.23; likelihood = 65%). These differences were matched by a greater amount of relative high-speed distance covered by higher fitness players than lower fitness players (ES ≥ 0.57 [90%CI: 0.13-1.19]; likelihood ≥92%). Relative distances were comparable across fitness groups during the second on-field bout (ES ≤ 0.31; likelihood ≤ 71%), with the exception of quartile 2 (ES = 0.76 ± 0.50; likelihood =very likely, 97%). During all four quartiles, higher fitness players covered greater relative high-speed distances than the lower fitness players in the second on-field bout (ES ≥ 0.44 [90%CI: 0.07-1.36]; likelihood ≥80%). Relative distances were comparable across fitness groups in the whole-quarter players (ES ≤0.26; likelihood ≤64%).
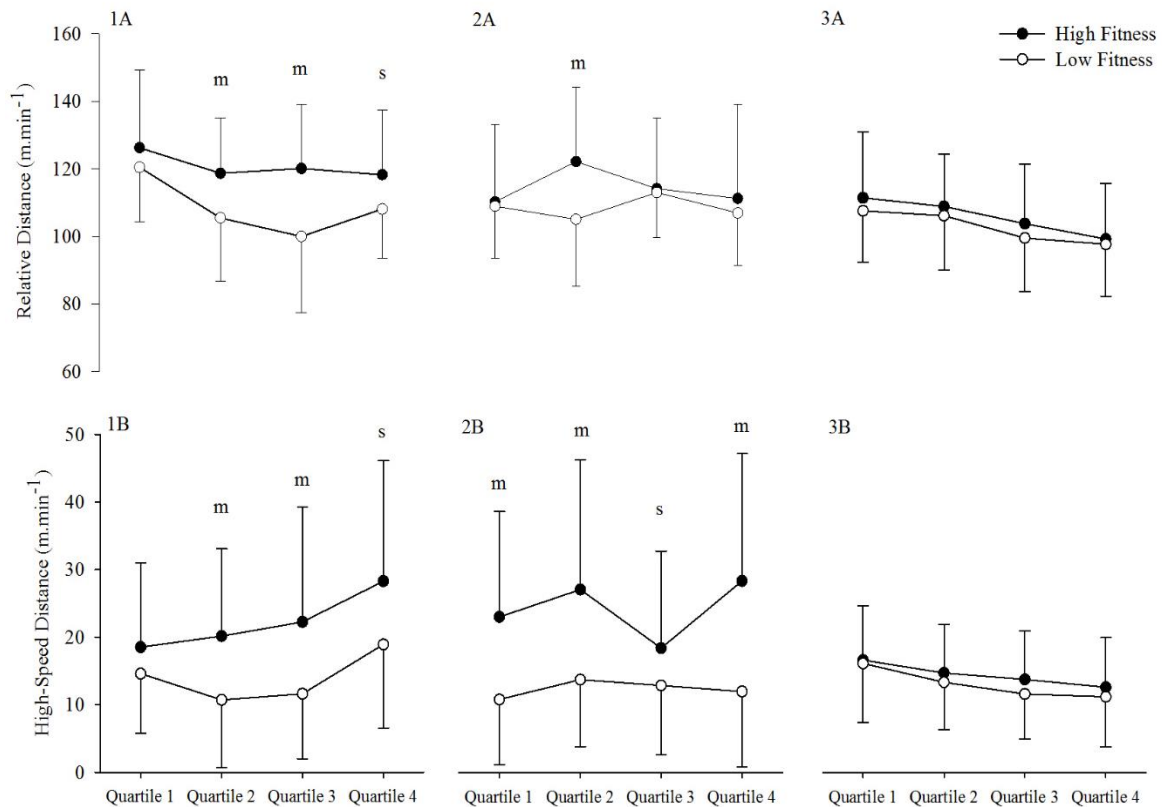
Figure 6.2. *Changes in running performance across quartiles in higher fitness and lower fitness players; (1A) relative distance covered during on-field bout 1; (1B) high-speed distances covered during on-field bout 1; (2A) relative distances covered during on-field bout 2; (2B) high-speed distances covered during on-field bout 2; (3A) relative distances covered by whole-quarter players; (3B) high-speed distances covered by whole-quarter players. "m" denotes a moderate difference (ES range = 0.61-1.2) between high and low fitness players; "s" denotes a small difference (ES range = 0.21-0.6) between high and low fitness players*

6.3.3 Playing Duration

During both short and moderate on-field bout durations, players covered greater relative high-speed distances in quartile two (ES ≥0.37 ± 0.55; likelihood ≥80%) and greater relative moderate-speed distances in quartile three (ES ≥0.33 ± 0.55; likelihood = likely probable, ≥80%) than whole-quarter players (Figure 6.3). Whole-quarter players covered a greater amount of relative low-speed distance in quartile four (ES ≥0.77 ± 0.68; likelihood = almost certainly, 100%) than both short and moderate on-field bout duration players. Greater relative

total (ES $\geq$0.43 $\pm$ 0.46; likelihood = likely probable, $\geq$87%), moderate- (ES $\geq$0.38 $\pm$ 0.47; likelihood =likely probable, $\geq$84%) and high-speed distances (ES $\geq$0.92 $\pm$ 0.66; likelihood = almost certainly, 100%) were covered by short and moderate on-field bout duration players than whole-quarter players. Long on-field bout duration players covered greater relative total distances during quartile 1 (ES = 0.84 $\pm$ 0.49; likelihood = very likely, 98%) and greater relative high-speed distances during quartile four (ES = 0.65 $\pm$ 0.63; likelihood = likely probable, 89%) than whole-quarter players.
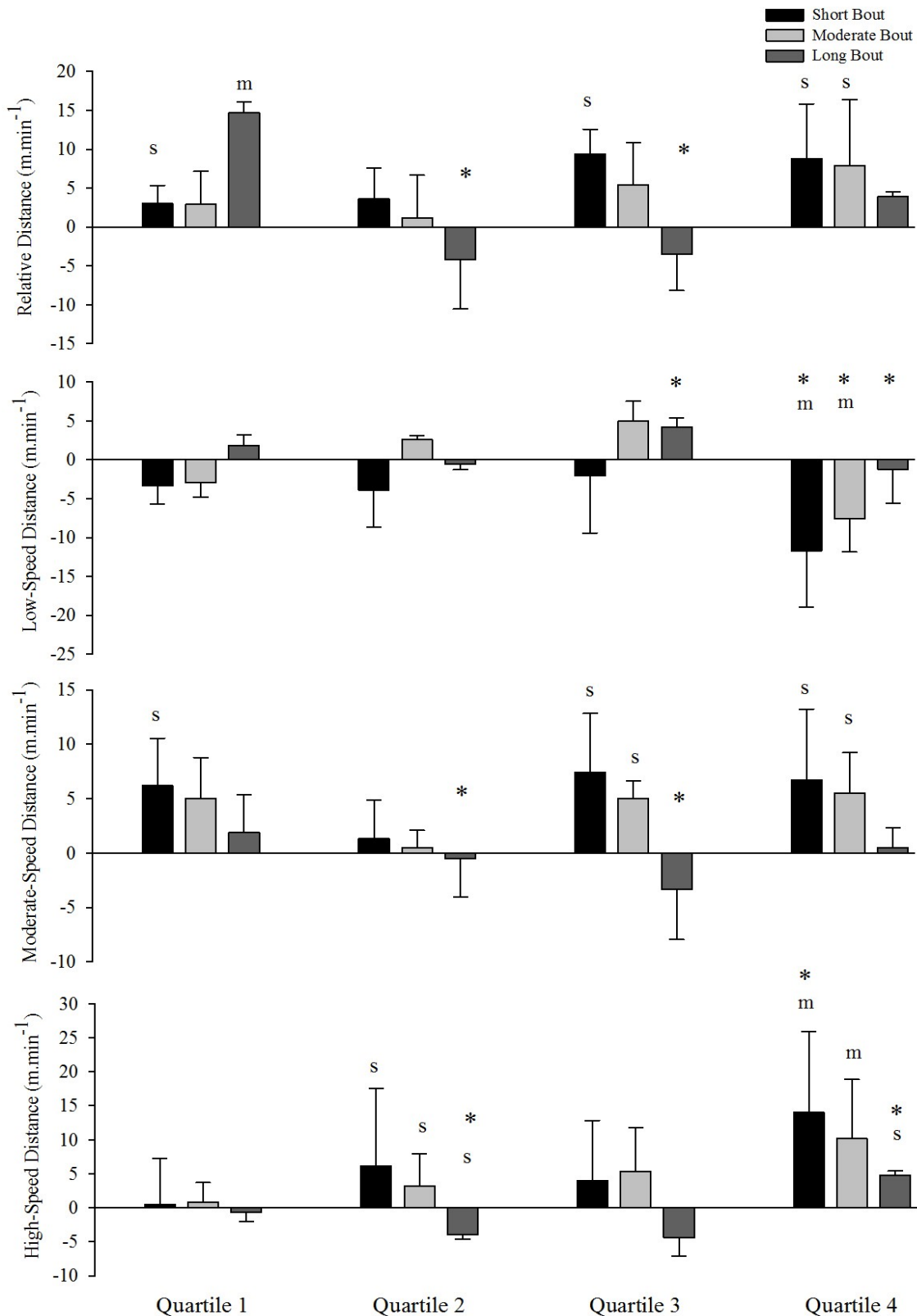
Figure 6.3. *Distances covered per minute relative to whole-quarter players (0-line) in short, moderate and long on-field bouts.*

"m" denotes a moderate difference (ES range = 0.61-1.2) from whole-quarter players; "s" denotes a small difference (ES range = 0.21-0.60) from whole-quarter players; "" denotes a meaningful difference (ES range = 0.51-1.29) from previous quarter.*

112

When analysing changes in running intensity within groups, following quartile one, long on-field bout duration players had large reductions in relative distances covered (ES = 1.29 ± 0.60; likelihood = almost certainly, 100%) in quartile two. These reductions in relative distances were matched by a decrease in relative moderate- (ES = 0.88 ± 0.72; likelihood = likely probable, 94%) and high-speed (ES = 0.75 ± 0.74; likelihood = likely probable, 89%) activity. Similarly, in quartile three, relative total- (ES = 0.51 ± 0.77; likelihood = likely probable, 75%) and moderate-speed (ES = 0.66 ± 0.71; likelihood = likely probable, 86%) distances were reduced in comparison with quartile two. During both short and long on-field bouts, relative high-speed distances were increased in the final quartile (ES ≥0.51 [90%CI: 0.12-1.78]; likelihood ≥91%).

6.4 Discussion

This study is the first to explore the activity profiles of female AF players during periods between rotations when compared with whole-quarter players. Our findings highlight that activity profiles progressively declined during quarters in the whole-quarter players. Following an initial reduction in relative moderate-speed distances covered during the first on-field rotation bout and an increase in relative low-speed distances covered during the second on-field bout, rotated players maintained a higher running intensity than the whole-quarter players over the course of the quarter. Furthermore, rotated players with a greater high-intensity running ability covered greater distances than those with lower high-intensity running ability during on-field bouts. However, when players were required to play a quarter without a rotation, running intensity was comparable across both fitness groups. These findings suggest that irrespective of fitness, to maintain or increase match intensity, players with a greater high-speed running ability still require rest periods within quarters. Additionally, we found players

who were on-field for short (4 to 6 minutes) and moderate (7 to 12 minutes) durations exhibited greater activity profiles than whole-quarter players. The results of this study highlight the effectiveness of rotations in female AF and for coaches provide insight into rotation periods that may enable players to maintain a higher running intensity across matches.

During the first on-field rotation bout, an all-out, or positive pacing strategy was adopted [82] ,whereby rotated players appeared to initially set a playing intensity that was unsustainable, highlighted by greater distances than whole-quarter players, before reducing their running intensity in the following quartile (Figure 6.1). Interestingly, while the overall running intensity and moderate-speed distances declined following the initial quartile, high-intensity distances increased over the duration of the first on-field bout. A plausible explanation for these findings may be that players attempted to conserve energy for high-speed activity to allow an increased work rate during the end of their on-field bout. Furthermore, it is likely players had prior knowledge of when they would be rotated off the field, which in turn may have resulted in an increase in high-speed activity as their on-field bout progressed. Although meaningful relationships were found between Yo-Yo IR1 performance and relative high-speed running distance, factors in addition to Yo-Yo IR1 performance (such as match contextual factors [39] and self-pacing strategies [82]) may also influence the activity profiles observed across quartiles. On the contrary, players during the second on-field bout seemed to adopt a negative pacing strategy [82], with an increase in both relative total and high-speed activity following the first quartile. In agreement with previous research [19], it is possible the players were aware that starting the second bout with a high running intensity may not be sustainable for the remainder of the quarter, therefore implemented a pacing strategy to delay the onset of fatigue [19]. Whole-quarter players used a similar strategy to the first on-field bout players, reducing running intensity as the quarter progressed. As previous research has linked rotations to an

increase in running intensity [78] it is not surprising that during the final two quartiles, the relative-, moderate-, and high-speed distances of rotated players surpassed whole-quarter players.

A notable finding from this study was the running performance of players during the second on-field bout. The bout on the bench resulted in greater relative- and high-speed distances during their second on-field bout compared with whole-quarter players. As pacing is regulated through a comparison of past experiences and current exercise demands [145], it is possible that during the second on-field rotation bout, players were aware of the time remaining in the quarter and therefore had an understanding of the bout endpoint. Although in disagreement with previous research in AF [37], this notion is further supported by the "end-spurt" (increase in intensity towards the end of a competition) [35] exhibited by the rotated players in quartile four, where greater high-speed distances were covered in comparison with the previous quartile. As poor levels of fitness have been associated with the preservation of energy in the early stages of competition in an attempt to complete matches [19], the disparity in evidence between our results and previous AF research may be partially explained by differences in fitness levels in the participants investigated.

While running intensity did not differ in the first quartile, players with a greater high-intensity running ability were able to cover greater relative total and high-speed distances during quartiles two through four than players with poorer Yo-Yo IR1 test scores during the first on-field bout. This finding highlights that superior Yo-Yo IR1 performance is associated with a greater running intensity and an even-paced pacing strategy[19] across the first on-field bout. Additionally, it appears that lower Yo-Yo IR1 performers adopted a similar running intensity

to the higher Yo-Yo IR1 group during the initial quartile. However, following the first quartile, low Yo-Yo IR1 performers either consciously or subconsciously identified they were unable to maintain that intensity and subsequently reduced running performance in an attempt to conserve energy and minimise the risk of physiological failure [19, 144, 145]. During the second on-field bout, although relative-distances were comparable across both fitness groups, the superior Yo-Yo IR1 performers covered greater high-speed distances across all quartiles than lower Yo-Yo IR1 players. Players with a greater high-intensity running ability were potentially able to increase their work rates when required within the context of the game (e.g. making leads for the football or creating space), whereas, the ability of low fitness players to increase work rate may have been limited by their lower Yo-Yo IR1 scores. Collectively, these results suggest high-intensity intermittent running ability is important for running performance in female AF players. However, when players were required to play full quarters with no rotations, no differences were reported between higher and lower fitness groups. While coaches may prefer players with greater high-intensity running ability to spend more time on-field, to gain the benefits of superior fitness levels and to maintain higher match intensities, these players still require rest periods within each quarter.

Our findings also demonstrate that the length of rotation influences running intensity across a quarter. Specifically, during short on-field bouts, greater relative- and moderate-speed distances were covered in quartiles one, three and four compared with whole-quarter players. Similarly, moderate on-field bout duration players covered greater moderate- and high-speed distances than whole-quarter players in a number of quartiles. Following the first quartile, long on-field duration players competed at a running intensity below that of whole-quarter players in the subsequent two quartiles. This finding disagrees with previous research that found running intensity only declined after between 5 and 9 minutes on-field [80]. Our findings

suggested players should be rotated off the field after between 4 and 12 minutes to maintain a running intensity greater than whole-quarter players. Interestingly, irrespective of rotation length, all rotated players covered greater relative- and high-speed distances in the final quartile compared with whole-quarter players. It seems whole-quarter players further reduced intensity in the final stages of a quarter to complete game tasks in a reasonable physiological state; in contrast, players who were rotated may increase their intensity as a result of knowledge of the exercise endpoint [146]. A plausible explanation for this finding is that players can be delivered messages on-field regarding when a rotation is required; this information could allow players to complete exercise bouts optimally [82] through an increase in running intensity.

Although this is the first study to investigate the influence of rotations on running performance in female AF, the small sample size and the restriction of player recruitment from only one Australian State competition are both limitations that require consideration when interpreting the results. Furthermore, due to the small sample size from only one positional group, this study did not investigate how rotations influenced running performance across different match quarters. Given that research has shown declines in running intensity as matches progress [29], it is possible that pacing strategies would differ across quarters. Additionally, the Yo-Yo IR1 was only assessed once at the end of preseason. As such it is possible that physical fitness may have improved or declined as the season progressed. Notwithstanding, these results provide coaching staff with evidence that running performance declines as the on-field bout duration increases and demonstrates the importance of high-intensity intermittent running ability in female AF match-play.

6.5 Practical Applications

Coaches should expect rotated players to perform at a higher intensity than whole-quarter players during their on-field bouts if they are rotated within 6 minutes of play. Players who are on-field for up to 12 minutes before being rotated will also maintain a higher match intensity than whole-quarter players.

The assessment of high-intensity running ability is important for female Australian football players, as superior Yo-Yo IR1 performance was linked with greater average match running intensity during the first on-field bout. Furthermore, during the second on-field bout for rotated players, higher Yo-Yo IR1 performers covered greater high-speed distances over all four quartiles than players with lower scores. Players with poorly developed physical fitness should be identified early in the preseason to address individual deficiencies and allow sufficient time for improvements.

Higher Yo-Yo IR1performers may only perform greater pacing strategies and match intensities if they are rotated within quarters. Coaches should aim to rotate players each quarter, irrespective of fitness levels, in order to maintain higher match intensities.

6.6 Conclusions

Players who were rotated within quarters covered greater relative and high-speed distances over a number of quartiles than whole-quarter players. Furthermore, while high-speed running progressively declined over quartiles in whole-quarter players, high-speed distances increased across quartiles in rotated players. When high and low Yo-Yo IR1performers were compared

during on-field rotation bout 1, higher Yo-Yo IR1performers were able to maintain a higher match running intensity across quartiles. During both on-field rotation periods, greater high-speed distances were covered by higher Yo-Yo IR1performance players compared to lower Yo-Yo IR1performance players. Conversely, activity profiles were comparable across fitness groups in whole-quarter players, suggesting that players with a greater high-intensity running ability required rotations within quarters to maximise the advantage of their superior physical fitness. Finally, our results suggested that players who were rotated after 4 to 12 minutes of play covered greater relative-, moderate- and high-speed distances than whole-quarter players. However, rotated players who remained on-field for longer than 12 minutes of play performed at a lower intensity than whole-quarter players during the second and third quartiles.

Chapter 7: The influence of contextual factors of running performance in female Australian football match-play

Collectively, Chapters 4 to 6 have presented the effect of physical fitness on match demands. While the presented findings are important for female football training, these chapters have not accounted for contextual factors that may influence activity profiles. Previous research has shown factors such as game outcome [39] and opposition quality [73, 127] influence running demands throughout team sport matches. Therefore, to address a consistent limitation of the studies presented in Chapters 4 to 6, Study 4 sought to determine the effect of contextual factors on the activity profiles of female Australian footballers.

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7.1 Introduction

The recent development of a national female Australian football (AF) tournament has resulted in a rapid growth of the sport and highlighted the lack of available research concerning the activity profiles of female AF match-play. Although it has been established that activity profiles in team sports can be influenced by numerous contextual factors [39, 147] the effect of these factors on female AF players is yet to be investigated. In elite male AF matches, total and high-speed distances covered decline from the first to the fourth match quarter [29]. In partial agreement with these results, reduced high-speed activity has been reported as matches progressed without changes in total distance covered across the four match quarters [39]. Although the importance of high-speed activity has been documented [15], there is a paucity of evidence providing associations between high-speed running and team success.

In elite soccer matches, total and high-speed running distances were greater when teams played higher quality opposition [128, 130]. Importantly, losing soccer teams covered greater distances than winning teams, with high-speed distances covered without the ball reported to be a distinctive indicator of soccer performance [128, 130]. Similar trends have emerged in women's rugby sevens match-play with greater total-, moderate- and high-speed distances covered in matches against the top four opponents compared with the bottom four opponents [147]. Furthermore, match activity profiles increased in elite male AF players [39] and women's rugby sevens [147] players in losing compared to winning matches. Interestingly, conflicting results have been reported in elite rugby league, where match demands were greater in winning than losing matches and when competing against lower ranked teams [43]. It was suggested that the competitive advantage of successful elite rugby league teams was closely linked to their ability to maintain a higher playing intensity than losing teams. Clearly, the

relationship between physical match activities and team success varies depending on the sport in question and team style of play. As such, further studies need to be conducted to investigate the link between high-speed running and performance in team sports.

Although the effect of match results on overall match-play running performance is important, pacing strategies of winning and losing teams have also been explored [35, 36]. Pacing strategies are well-established in self-paced endurance events [148], and also occur in high-intensity intermittent team sports [35, 36]. Rugby league matches have been previously separated into 8, ten-minute periods with players from winning teams setting a higher pacing strategy than players from losing teams, with a greater total distance and low-speed distance covered across all periods of the match [35]. It was proposed that winning teams set a pacing strategy intended to win the match, while the pacing strategies of losing teams were established based on "survival". However, interchanged players from losing teams demonstrated an "end-spurt" in the final stages of the match indicative of players increasing their work rates in an attempt to win the game [35].

Although variations in activity profiles between quarters have been investigated [38, 39], to our knowledge no research has examined the changes in running intensities within match quarters. Furthermore, as all AF research has been conducted on male performers, there is currently no evidence reporting pacing strategies employed by female AF players across different match stages. Collectively, this highlights the need for research that further develops the understanding of the factors that influence running demands during female AF match-play and examines how match outcomes are influenced by the pacing strategy that is implemented.

Therefore, the aim of this study was to identify differences in pacing strategies and activity profiles among female AF match-play, based on game outcome and opponent rank.

7.2 Methods

7.2.1 Experimental Approach to the Problem

This study used a longitudinal and observational study design to analyse the pacing strategies of female AF players from three teams in the six team Queensland AF competition. Each 20-minute quarter was divided into two 10-minute blocks so that each player had eight periods by the end of the match. Data collected during each match were sub-divided into (1) winning and losing matches and (2) matches played against the top 3 opponents and bottom 3 opponents based on final ladder position.

7.2.2 Subjects

Thirty-five players from the three teams competing in the Queensland Women's Australian Football (QWAFL) recreational league (mean ± SD height, 167.7 ± 4.4 cm; body mass, 67.3 ± 11.2 kg; age, 23.7 ± 5.3 years; Yo-Yo Intermittent Recovery 1 distance, 632 ± 255m; senior playing experience, 3.2 ± 2.0 years) volunteered to participate this study. The teams included in this study were the top three performing teams at the end of the season of interest. Before the study, all players received an information sheet outlining the experimental procedures and the risks and benefits associated with participation. This research was approved by the University's Human Research Ethics board and all subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

7.2.3 Procedures

Global positioning system (GPS) analysis was completed during 14 matches (totalling 178 appearances) over the 2016 QWAFL season. Players were separated into midfield, half-back (defensive) and half-forward (attacking) positional groups. For the purpose of this study, full back/forwards, back/forward pockets and ruckmen backs were excluded from the analysis as their activity profiles remained constant over four quarters. Data were removed if players were not on the field for at least 75% of the period. The midfield group was represented by 22 players (n=51 winning files; n=46 losing files; n=60 top 3 opponent; n= 35 bottom 3 opponent). Half-backs consisted of 9 players (n=24 winning files; n=21 losing files; n=30 top 3 opponent; n= 17 bottom 3 opponent). The half-forward group comprised 7 players (n=20 winning files; n=16 losing files; n=23 top 3 opponent; n=13 bottom 3 opponent). The average win/loss record for the teams included in this analysis was 12 wins (range: 9-14) and 4 losses (range: 2-7) across the season. Activity profiles were examined using GPS units (Catapult Sports, Docklands, VIC, Australia) sampling at 10 Hz. Acceptable validity and reliability of the GPS units (S5, Optimeye, Catapult Sports, Docklands, VIC, Australia) used in this study have previously been reported [63]. Prior to the warm-up, the GPS unit was switched on and placed in a pouch of a specifically-designed vest provided by the manufacturer so the unit was positioned on the upper-back, between the shoulder blades. Data were downloaded onto a laptop and analysed using software provided by the manufacturer (Sprint, 5.1.7, Catapult Sports, Docklands, VIC, Australia). Player activity profiles were determined using movement speeds corresponding to low-speed (0-2.78 m.sec-1), moderate-speed (2.79-4.15 m.sec-1), and high-speed (>4.15 m.sec-1) bands [16]. Only active field time was included in the analysis; data corresponding with players interchanging off the field were omitted.

The initial statistical approach involved linear mixed modelling to account for dependence arising from repeated measurements of performance variables from individual participants. A separate analysis was completed for game period, match result and opposition rank as the fixed effect in each model, respectively. The random effect of player identity was included in each analysis. Based on the practical application of the results, data were further analysed using Cohen's Effect Size (ES) statistic[137], likelihoods and 90% confidence intervals (CI). The likelihood of a difference between groups equal to or greater than the smallest worthwhile change was estimated as 0.2 x between-subjects *SD* (small ES). The magnitude of difference was considered practically meaningful when the likelihood was ≥75%. The magnitude of differences were then assessed with effect sizes of ≤0.2, 0.21–0.6, 0.61–1.2, 1.21–2.0, and >2.0 considered trivial, small, moderate, large, and very large, respectively [138]. A custom Excel spreadsheet (Version 16, Microsoft, USA) was used to report ES and confidence intervals [138]. All data were reported as means ± SD and the significance level was set at $p < 0.05$.

7.3 Results

7.3.1 Activity Profiles across Match

The average total game demands for each positional group are reported in table 7.1. Across all positional groups, match demands were greater in the first-half than the second-half of match-play (ES=0.39-0.50 [90%CI: 0.24-1.07], Likelihood 90-99%, $p < 0.01$) (Figure 7.1, A-C). For midfielders, greater relative- (ES ≥0.69 [90%CI: 0.43-1.07], Likelihood = almost certainly, 100%, $p < 0.001$) and moderate-speed (ES ≥0.53 [90%CI: 0.26-0.93], Likelihood 98-100%, $p < 0.001$) distances were covered during the first and third 10-minute periods compared with

periods two and four. High-speed distances were greater for midfielders in period one than period two (ES=0.51 [90%CI: 0.24-0.78], Likelihood = very likely, 97%, p=0.002). In the second half (i.e. periods five to eight) no differences were observed in distances covered by this group (ES ≤0.24 [90%CI: -0.10-0.52], Likelihood ≤65%, p≥0.850). In contrast, running performances for half-forwards and half-backs were constant throughout the match (periods 1 to 8) (ES ≤0.13 [90%CI: -0.19-0.46], Likelihood ≤59%, p≥0.639). Furthermore, low-speed distances were similar throughout the match for all positional groups (ES ≤0.16 [90%CI: -0.33-0.65], Likelihood ≤45%, p≥0.940).

Table 7.1. Average match demands of female Australian Football match-play.

	Midfielders	Half-backs	Half-forwards
Field time (min)	75 ± 7	78 ± 5	74 ± 8
Total distance (m)	8087 ± 895	7167 ± 1330	6706 ± 934
Relative distance (m.min^{-1})	109 ± 10	92 ± 15	91 ± 15
Low-Speed distance (m)	4336 ± 593	4278 ± 471	4056 ± 643
Relative Low-Speed distance (m.min^{-1})	58 ± 5	55 ± 5	55 ± 5
Moderate-Speed distance (m)	2682 ± 669	1915 ± 688	1780 ± 404
Relative Moderate-Speed distance (m.min^{-1})	36 ± 9	25 ± 8	24 ± 6
High-Speed distance (m)	1065 ± 341	972 ± 413	870 ± 228
Relative High-Speed distance (m.min^{-1})	15 ± 5	12 ± 5	12 ± 3

Data reported as mean ± SD

NB: 10-minute blocks were selected to allow an innovative analytical approach. This is the first AF research to investigate changes in running demands within individual quarters.
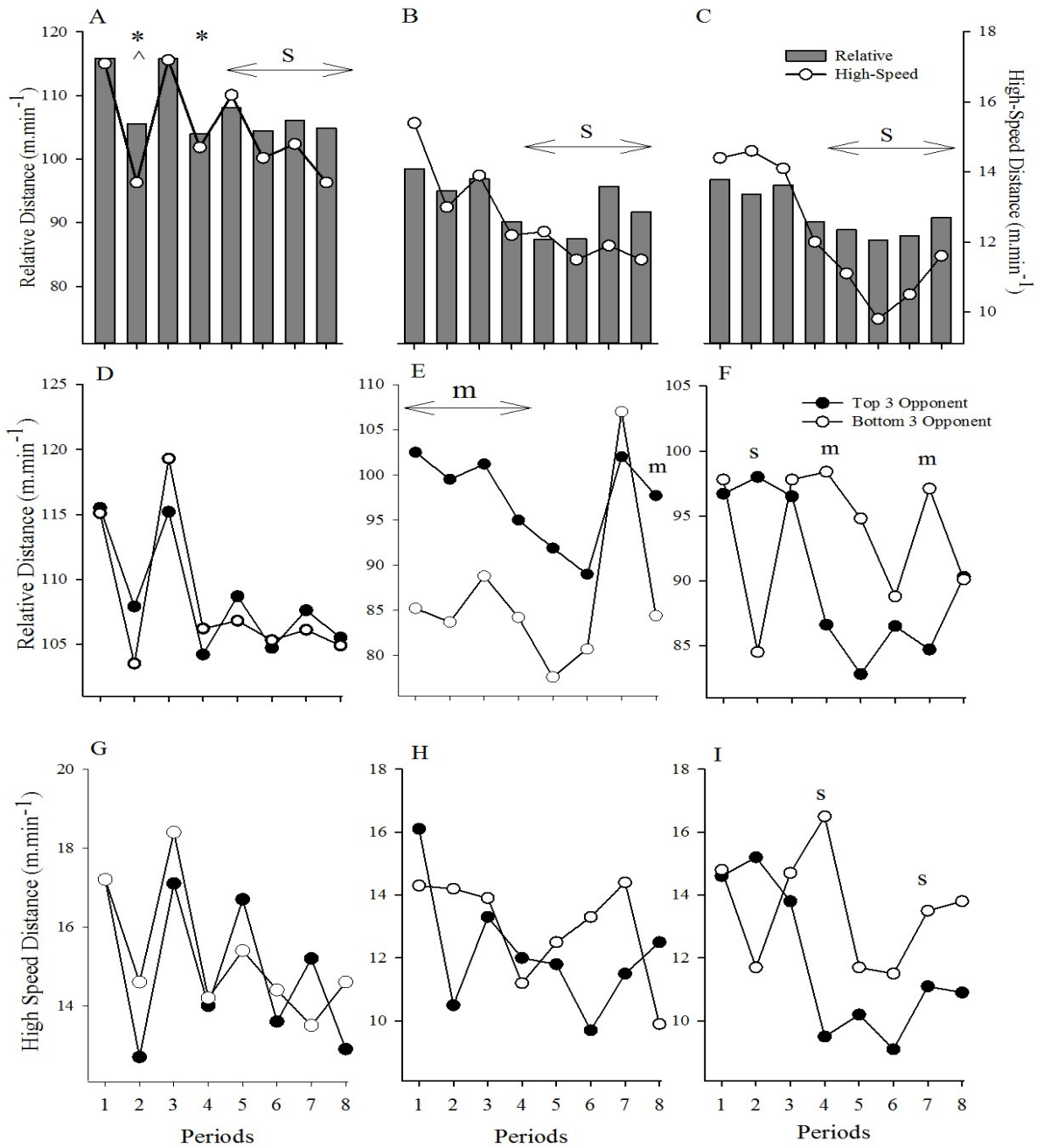
Figure 7.1. *Work rates of midfielders, half-backs and half-forwards across eight match periods.*

(A) Relative and high-speed distances covered by midfielders; (B) relative and high-speed distances covered by half-backs; (C) relative and high-speed distances covered by half-forwards; (D) relative distances covered by midfielders against top 3 and bottom 3 opponents; (E) relative distances covered by half-backs against top 3 and bottom 3 opponents; (F) relative distances covered by half-forwards against top 3 and bottom 3 opponents; (G) high-speed distances covered by midfielders against top 3 and bottom 3 opponents; (H) high-speed distances covered by half-backs against top 3 and bottom 3 opponents; (I) high-speed distances covered by half forwards against top 3 and bottom 3 opponents.

"S" denotes small effect size difference in relative distance covered compared to first half; *denotes significant difference in relative distance compared to previous quarter; ^ denotes significant difference in high-speed distance compared to previous quarter; "s" denotes small effect size difference (0.21-0.60) between top and bottom 3 opponents; "m" denotes moderate effect size difference (0.61-1.19) between top and bottom 3 opponents.

7.3.2 Opposition Ranking

Midfielders spent a greater time on field (9.9 ± 0.02 *vs.* 9.3 ± 1.5 minutes; ES ≥0.59 [90%CI: 0.14-1.30], Likelihood 92-97%, p≤0.04) and covered greater total distances (1101.3 ± 56.2 *vs.* 1009.4 ± 95.5 metres; ES ≥0.44 [90%CI: 0.03-1.10], Likelihood 87-100%, p≤0.02) during periods 1 to 3 when playing top ranked teams compared with bottom ranked opposition. Midfielders' relative distance remained constant independent of opposition ranking (ES ≤0.10 [90%CI: -0.34-0.40], Likelihood ≤50%, p≥0.196). Half-backs covered similar high-speed distances across eight periods, independent of opposition ranking (ES≤0.15 [90%CI: -0.73-0.82], Likelihood ≤44%, p≥0.131). From period 1 to period 4, half-backs covered greater relative distances than other positions when playing higher quality opposition (ES ≥1.0 [90%CI: 0.29-1.80], Likelihood 97-99%, p<0.01) (Figure 7.1). The greater first half demands of the half-backs against top-ranked opponents were matched by a greater amount of distance covered at low- (ES ≥1.1 [90%CI: 0.37-2.0], Likelihood 98-100%, p<0.007) and moderate-speed (ES ≥0.67 [90%CI: 0.03-1.51], Likelihood 87-98%, p<0.05). During the final match period, half-backs covered greater relative (ES=0.94 [90%CI: 0.22 -1.67], Likelihood = very likely, 95%, p=0.02) and low-speed (ES=0.77 [90%CI: 0.08-1.15], Likelihood = likely probable, 92%, p=0.05) distances when competing against higher-ranked opponents.

Although not statistically significant (p = 0.07), half-forwards covered meaningfully greater relative distances during period two against top-ranked opponents (ES=0.56 [90%CI: 0.08-

1.43], Likelihood = likely probable, 80%). During periods four (ES=0.73 [90%CI: -0.05-1.43], Likelihood = likely probable, 90%, p=0.05) and seven (ES=0.68 [90%CI: 0.08-1.68], Likelihood = likely probable, 91%, p= 0.05) half-forwards covered greater relative distances against lower standard teams than higher ranked opposition teams (Figure 7.1). These differences were matched by greater distances covered at high-speed against higher-ranked opponents (ES ≥0.54 [90%CI: 0.03-1.48], Likelihood 82-91%, p<0.05).

7.3.3 Game Result

Figure 7.2 shows the influence of match outcome (winning *vs.* losing) on relative and high-speed distances covered by midfielders, half-backs and half-forwards. High-speed activity remained unchanged across a match in midfielders ($p \geq 0.351$). Winning midfielders covered greater relative- (ES = 0.49 [90%CI: 0.11-0.87], Likelihood = likely probable, 89%, p=0.05) and moderate-speed (ES = 0.54 [90%CI: 0.13-0.89], Likelihood = likely probable, 91%, p=0.03) distances than losing midfielders in the final match period. Losing half-backs had a higher running intensity than winning half-backs across a number of match periods. During periods one (ES=0.95 [90%CI: 0.35-1.54], Likelihood = very likely, 98%, p=0.03), two (ES=0.87 [90%CI: 0.31-1.43], Likelihood = very likely, 97%, p=0.210) and eight (ES=0.74 [90%CI: 0.11-1.37], Likelihood = likely probable, 92%, p=0.141) of matches, losing half-backs covered meaningfully greater relative distances than in winning matches. They also covered greater high-speed distances in losing matches during period one (ES=0.90 [90%CI: 0.25-1.54], Likelihood = very likely, 96%, p=0.03), three (ES=1.06 [90%CI: 0.39-1.50], Likelihood = very likely, 98%, p=0.05), four (ES=0.94 [90%CI: 0.07-1.43], Likelihood = very likely, 98%, p=0.05) and eight (ES=0.75 [90%CI: 0.07-1.43], Likelihood = likely probable, 91%, p=0.06) than in winning matches. For half-forwards, physical match demands were similar across the eight periods regardless of match result ($p \geq 0.454$), with the exception of period 8 where these players covered greater high-speed distances in matches won than matches lost (ES = 0.89 [90%CI: 0.25-1.53], Likelihood = very likely, 96%, p=0.02).
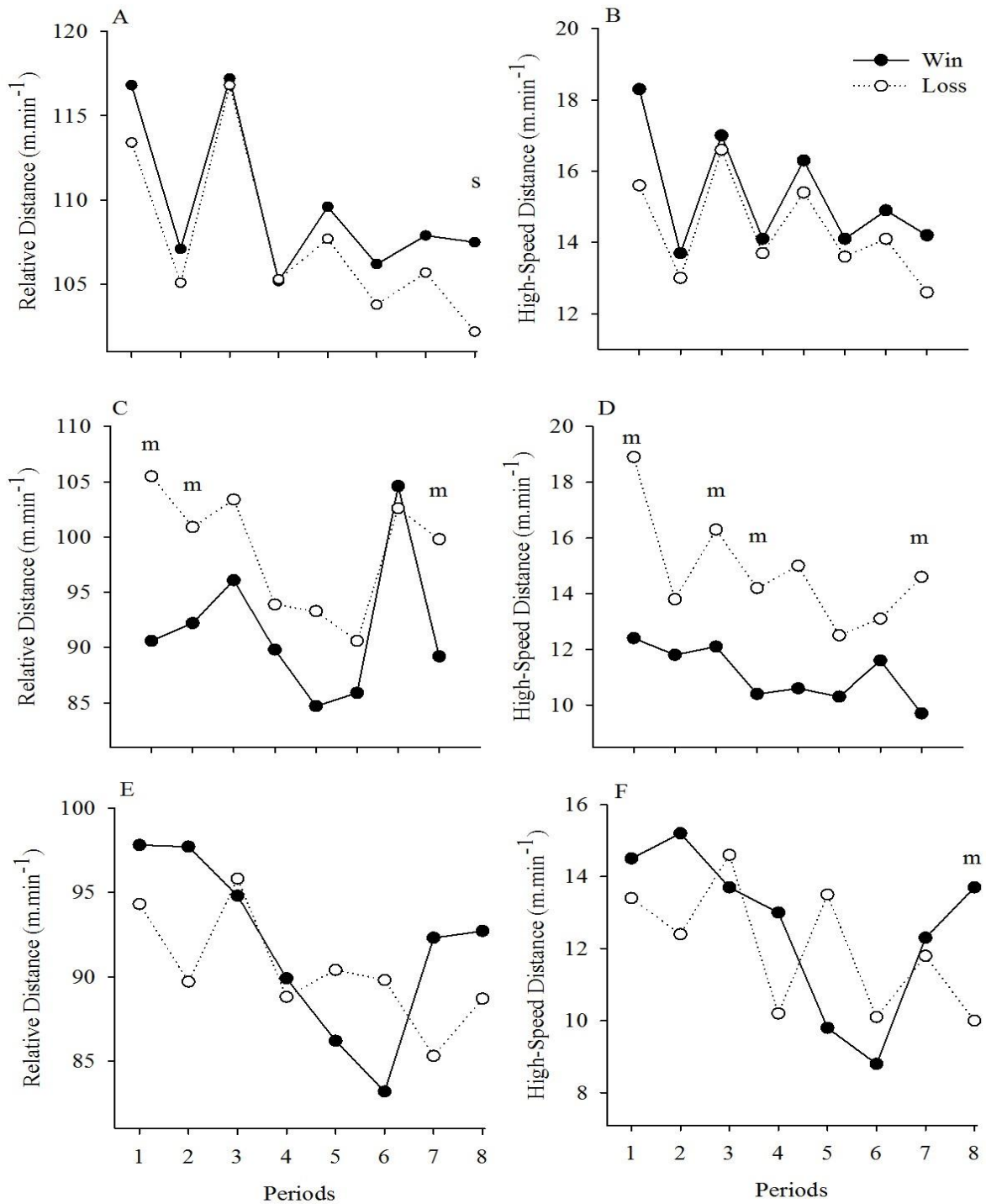
Figure 7.2. *Comparison of work rates of midfielders, half-backs and half-forwards during matches won and matches lost.*

(A) Midfielders relative distance covered; (B) midfielders high-speed distance covered; (C) half-back relative distance covered; (D) half-back high-speed distance covered; (E) half-forward relative distance covered; (F) half-forward high-speed distance covered.

"s" denotes small effect size difference (0.21-0.60) between matches won and lost

"m" denotes moderate effect size difference (0.61-1.19) between matches won and lost.

131

7.4 Discussion

This is the first study to investigate the influence of contextual factors (game period, opponent rank and game outcome) on the activity profiles and pacing strategies of female AF players. Despite all positional activity profiles being reduced following the first half of match-play (periods 1-4) the influence of other contextual factors varied across positional groups. Matches against higher standard opposition led to greater game intensity in half-back/forward players irrespective of match outcome. Half-backs were the only positional group for whom game outcome altered running performance over several match periods. However, during the final period of the total match, midfielders and half-forwards produced a higher work-rate in winning rather than losing matches. These findings suggest that activity profiles, and more specifically pacing strategies, differ across positional groups and are dependent on game outcome and the quality of opposition players.

Match running performance was greater during the first half of match-play for all positional groups, which is consistent with other team sport research [75, 130] that has demonstrated decreased match intensity across halves. Collectively, these results are suggestive of match-related fatigue [128] and imply that team sport athletes often adopt a high-intensity during the first half of play that is not sustainable for the entire match. Notwithstanding, players may have elicited this positive pacing strategy [145] in an effort to dominate their opposition and perhaps gain an early match lead on the scoreboard. This finding is in agreement with previous performance profiles of an initial high work-rate followed by a reduction in activity within the middle section of an event during prolonged duration activities [145]. During the second half, it is hypothesised that pacing strategies are adjusted in attempt to reduce the effect of match-related fatigue.

This is the first study to separate AF matches into eight match periods. Our findings highlighted an "all-out" or "positive" pacing strategy [149] being implemented by female AF midfielders during the first two quarters. It is possible that, at the onset of quarters 1 and 2, midfielders used a higher work-rate with the knowledge they may be interchanged at some point during the quarter [149]. As the quarter progressed, match intensity decreased, which may suggest these players implemented a pacing strategy that they were unable to sustain. Alternatively, in considering the positive association between rotations and match running performance [78], the observed decline in work-rate during the latter stages of the game may suggest that midfielders were not rotated regularly enough, leading to increased player fatigue. Further research investigating the influence of rotation number on running performance in female AF players is warranted.

In contrast to the midfield group, both half-backs and half-forwards maintained running intensity within each match quarter. A possible explanation for this finding is that the midfield group covered approximately 20% greater relative distances during a match than other positional groups. Therefore, the less demanding nature of match-play in the half-back and half-forward positional groups may elicit less fatigue, which allows these players to maintain a consistent running performance within quarters.

One interesting finding from this study was that reductions in match intensity were not due to reductions in low-speed activity. Across the eight periods, low-speed distances remained unchanged for all positional groups. While this result is consistent with findings from one elite AF study [37], the majority of research to date has suggested low-speed activity is reduced in

attempt to maintain high-speed activity [19, 31, 85]. This may be due to poorly developed physical qualities in which players exhibit a larger fatigue response and further results in greater reductions in activity profiles [19].

The influence of opposition ranking varied considerably across positional groups. Greater field time and total distances were recorded for midfielders when playing against higher quality opposition. However, relative match distances were similar irrespective of opposition ranking across all match periods. Given that match intensity was comparable in games regardless of opposition quality, coaches could aim to rotate midfielders more frequently throughout quarters when playing against Top 3 competitors in attempt to increase player work-rate during these matches. During 5 of 8 periods half-backs worked at a greater intensity during games against top 3 opponents. These results are similar to those found in women's Rugby Sevens [147] whose activity profiles increased when competing against higher quality opposition. Interestingly, with the exception of quartiles 4 and 7, no differences were reported in running performance between different quality opposition in half-forwards. This finding is difficult to reconcile, although it is possible that differences lie in the number of skill involvements in this positional group between high and low standard opposition [130]. However, it may also be that this positional group's ability to find space and "lead" for the football is not influenced by opposition quality.

The half-back positional group exhibited a higher work rate in losing than winning matches. A plausible explanation is that when losing, this positional group is under a greater amount of defensive pressure and subsequently match intensity is increased. As has been previously suggested [39], it may be important to consider strategies of rotating this positional group into

a back-pocket position or off the field for short periods of time when losing matches to ensure they can withstand defensive pressures throughout the match. While the activity profiles of half-backs were greater when losing than winning, contrasting results were demonstrated in the midfield and half-forward positional groups. For seven of the eight match periods analysed over each match, no differences were reported between winning and losing midfielders and half-forwards. Consistent with some [42], but not all research [43], our results highlight that an ability to cover greater distances is not necessarily indicative of match success. This finding is not surprising given that previous research [39] has suggested that match success is more dependent on skill involvement and efficiency than greater activity profiles in elite male AF players. However, during the period, when matches were won, these positional groups exhibited an "end-spurt" and covered greater distances compared to losing players. While this finding is in disagreement with previous research [35], it is suggested that rather than lowering physical work-rate in the final match stage, perhaps these players finally gained a competitive match edge that allowed them to find space from their opposing players and increase their running intensity.

Although this study is the first to investigate the influence of contextual factors on running performance in AF match-play, a limitation of this research was the relatively small sample size. It should be taken into consideration that all participants were recruited from one recreational competition and therefore may not be representative of all female football competitions. Furthermore, only the three top teams in the competition took part in this study so the influence of opposition may differ from bottom placed teams.

The findings of this study demonstrate running performance was influenced by match period, quality of opposition and game results in female AF match-play. All positional groups decreased running intensity during the second half of the match. However, midfielders were more affected by match-related fatigue than other positional groups. Half-backs were the only positional group in whom running intensities were affected by game result and opposition ranking. Greater match intensities were exhibited by half-backs when losing and during matches against higher quality opposition, most likely as a result of greater defensive pressures during these games. This research highlights the importance of understanding contextual factors, and the magnitude of these factors on activity profiles in female AF players in all levels of competition

7.5 Practical Applications

Across all positional groups, match-related fatigue resulted in a reduction of player work-rate during the second half of matches. Coaches could use player rotations early in the match in an attempt to delay the effect of fatigue, especially in the midfield positional group. Moreover, coaches could aim to rotate players more frequently in the second half to allow players to work at a higher match intensity for shorter periods of time.

High-speed running was relatively unaltered by match conditions in this population. However, to aid in the advancement of these players and the women's game, training could focus on developing high-speed running performance and exposing players to high-speed activities in attempt to delay the onset of fatigue.

Greater activity profiles during losses and when competing against high-quality opposition should be taken into consideration when programming recovery and subsequent training, particularly in the half-back players.

Chapter 8: A skill profile of the national women's Australian football league (AFLW)

Collectively, the findings of Studies 1 to 4 have identified the running demands of female AF match-play, which should aid in the development of match-specific conditioning sessions and inform player rotations within matches. However, skill performance is of equal importance in AF matches. Specifically, skill involvements are greater when winning matches compared with losing matches and are also greater in quarters that are won compared with quarters that are lost [93]. Given that the skill involvements important for match success in female Australian football are currently unknown, Study 5 of this dissertation analysed data from the inaugural season of the Women's Australian Football League competition to address this need.

This study is under peer review with the *Science and Medicine in Football:*

Black GM, Gabbett TJ, Johnston RJ, Cole M, Naughton G, Dawson B. A skill profile of the national women's Australian football league (AFLW). *Science and Medicine in Football.* (Resubmitted after reviewer comments)

8.1 Introduction

Women's Australian football has grown exponentially during the last 5 years, culminating with the inaugural season of the Australian Football League Women's competition (AFLW) being played in 2017. Australian football (AF) is a high-intensity intermittent, invasion contact game with the objective of advancing the ball down the field using either foot (kicking) or hand (handball) skills with the final aim of kicking the ball between upright posts at the opposing end of the field [95]. An AF match consists of two teams competing over four 20-minute ball-in-play quarters; typically, teams consist of 22 players, with 18 players on the field at any one time and 4 interchange players. However, the AFLW competition modified the traditional rules to facilitate a free-flowing style of football. During the AFLW season, teams comprised 22 players, with 16 (2 wingers removed) on-field players (6 interchange). Games consisted of 15-minute quarters with time on for goals and injuries that interrupted play. Additional time excluded periods when the ball went out of bounds. As such, the rule modifications have highlighted differences in running intensities between sub-elite (78-107 $m.min^{-1}$) and elite (102-128 $m.min^{-1}$) female AF match-play [150, 151]. With the recent development of women's football at both the state and national level, and within the context of differences in game rules at the top level of the game, skill profiling in female football warrants greater investigation.

Influences on match results on running demands in AF have been investigated [39, 152]. Recently, greater relative total distances (metres per minute) were associated with matches won in elite male AF players [152]. In contrast, high-speed running was greater during matches lost than won [39, 152]. It has been reported that high-speed running may be greater during losses, as teams spend a lower percentage of time in possession [153] and hence perform more high-speed efforts in chasing and attempts to regain possession of the ball [152]. On the contrary,

early evidence from sub-elite female players has suggested activity profiles have little effect on match outcome [141]. Running-based match performance is often reported as the distances covered over the course of a game. However, performance is arguably more dependent on the skill efficiency of a team. Skill involvement has influenced game outcome in elite AF players, with winning teams completing a greater number of disposals, kicks and marks than losing teams [39]. More recently, researchers identified that the number of kicks and goal accuracy were the most influential technical predictors of match success [95]. While recent research has highlighted the average skill profile of elite female AF [151], this data is only representative of one competitive team and did not account for the influence of match outcome on overall skill demands. As technical skill profiles of a number of team sports have demonstrated significant contributions to performance [39, 95, 130], it is likely that skill involvements influence match outcome in women's AF. With this in mind, the aim of this research was two-fold; (1) to examine the skill profiles of female AF and compare with male AF match-play and (2) investigate the relationship between team performance indicators, match outcomes and team success in the AFLW.

8.2 Methods

8.2.1 Procedures

This study used a retrospective, observational design in which average team technical data were obtained from the 2017 AFLW (teams n = 8; total matches n = 28) season. Two games were removed from the analysis as they resulted in a drawn match. The skill involvements reported in this study are described in Table 1, and are commonly reported performance indicators in AF [95]. All match statistics were freely accessible on the official AFL website (AFL.com, Victoria, Australia). Data from this provider have shown acceptable reliability for reporting

skill profiles in AF [154]. To allow comparisons between male AF match-play, ball-in-play time was manually recorded from women's match broadcast video footage. To assess intra-rater reliability of the ball-in-play time, two AFLW matches were analysed on two separate occasions, two weeks apart. The Cronbach's alpha test for internal consistency was used to assess reliability of the ball-in-play time. The Cronbach's alpha (α) result for internal consistency reliability was 0.95 for intra-rater reliability.

Table 8.1 Description of technical skills of AF assessed in this study.

Technical skill	Description
Kick	Disposing of the ball with any part of the leg below the knee including kicks off the ground
Handball	Disposing of the ball by striking it with a fist while it rests on the opposing hand
Disposals	Summation of kicks and handballs
Disposal Efficiency (%)	The percentage of disposals that hit attended target or are placed to the advantage of team mates
Contested possession	Possessions obtained while in congested, and physically pressured situations
Uncontested possession	Possessions obtained while a player is under no physical pressure from the opposition
Mark	When a player catches a kicked ball that has travelled more than 15 m without it having touched the ground or another player impeding the ball
Contested mark	A mark achieved while engaging in a contest.
Clanger	A disposal which goes directly to an opposition player; a conceded free kick; dropped mark or fumble under no pressure.
Tackle	Using physical contact to prevent an opposition in possession of the ball from getting an effective disposal
Inside 50	An action of moving the ball from the midfield into the forward 50 m zone
Goal accuracy (%)	The percentage of shots on goal compared to goals scored, expressed as a percentage
Inside 50:goals scored	The number of inside 50's compared to the number of goals scored expressed as a ratio

This study also compared multiple skills to create two derived performance indicators [95]; goal accuracy and the ratio of the number of times the ball entered the zone within 50 metres of the goals (inside forward 50s) to goals scored. Goals and behinds (points) were removed from the analyses, as they were not deemed technical skills, rather match-specific outcomes. All matches were divided into two subsets (win/loss) based on the match outcome. The score margin was also recorded at the end of each match. For the final component of the study, data were sorted into ladder position (8 levels). A ladder position closer to one was indicative of a higher ranked team, while a position closer to eight was indicative of a lower ladder position.

8.2.2 Statistical Analyses

Descriptive statistics (mean ± SD) for all technical involvements were obtained for the 2017 AFLW season. A one-way ANOVA was also used to determine difference between winning and losing teams for each of the performance indicators for match outcome. A chi-squared automatic interaction detection (CHAID) classification tree was used to model the relationship between skill involvements and match outcomes. The CHAID classification tree estimated a regressive relationship between variables and a binary outcome (win/loss). A minimum of five cases were required to create a "child" node. Furthermore, the partitioning ceased when the null hypothesis could not be rejected ($p>0.05$) [155]. Classification trees model non-linear phenomena, and also provide visual data easily interpreted by non-analysts [95, 100, 156]. Ordinal binary logistic regressions were used to examine the relationship between skill involvements and (1) winning score margins, (2) losing score margins and (3) final ladder position. Prior to the regressions analysis, multicollinearity was assessed using the variance inflation factor (VIF> 10) [157]. Handballs, contested possessions and uncontested possessions were subsequently removed from the regression analysis due to displaying VIF greater than 10.

8.3 Results

Significantly greater kicks (p=0.008), marks (p=0.025), uncontested possessions, (p=0.022), disposal efficiency (p=0.002), and a superior inside 50: goals scored ratio (p=0.002) were found for winning teams compared to losing AFLW teams. The inside 50: goals scored ratio and uncontested possessions were the only variables included in the CHAID model, explaining 88.5% of match outcomes. The model successfully classified 20 of the 26 recorded wins (76.9%) and 26 of the 26 losses (100%).
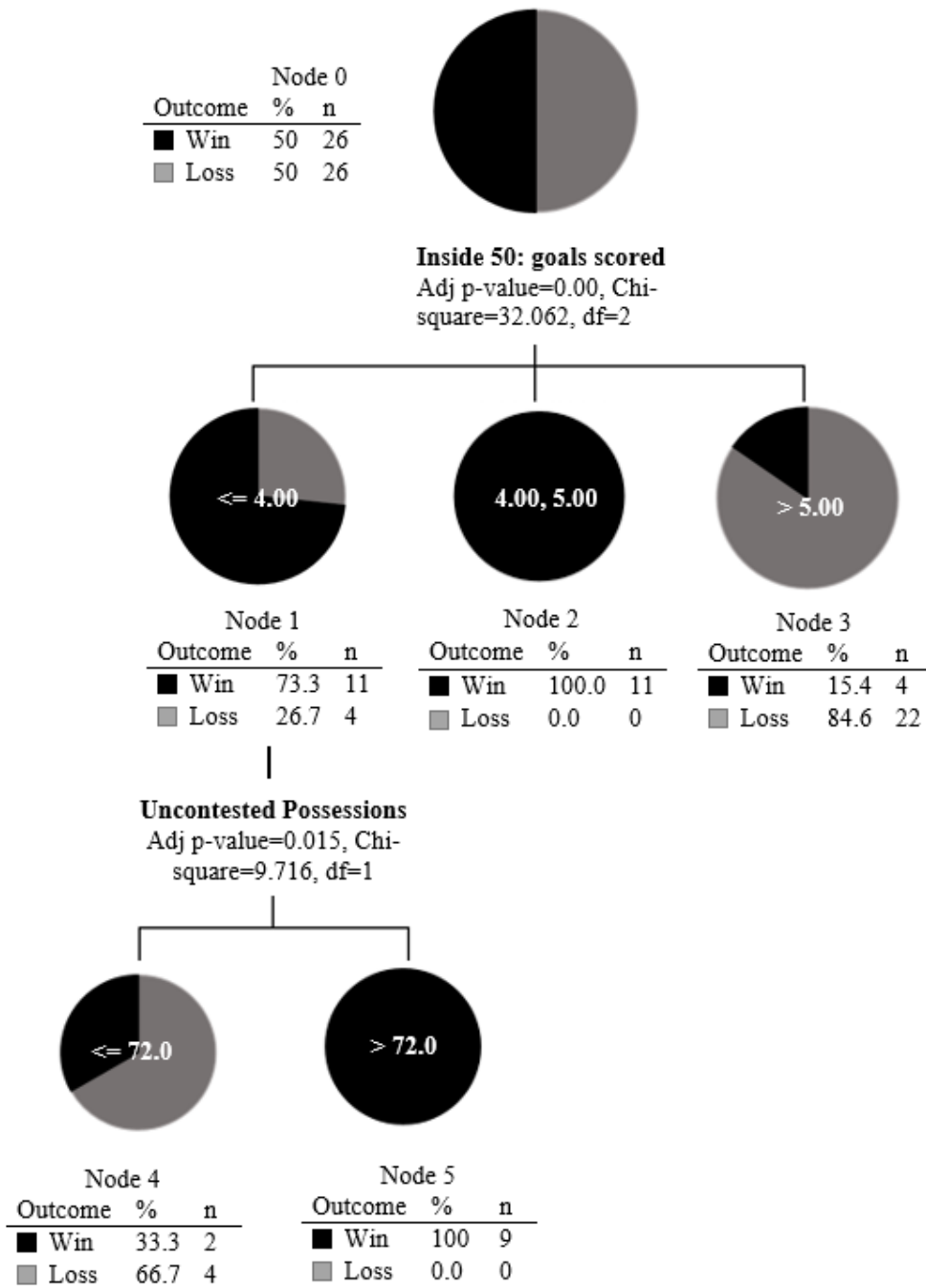
Figure 8.1 *CHAID classification tree model results explaining match outcome in the AFLW*

Table 2 demonstrates the ordinal logistic regression for the relationship between score margin and skill involvements during wins and losses. A negative relationship was reported between larger winning margins and marks 'inside 50' (p=0.040) and inside 50: goals scored ratio (p=0.007). As losing margins increased 'inside 50's'decreased (p=0.019). Although not

statistically significant a positive relationship was observed between tackles and losing margin (p=0.059) while a negative relationship was recorded between disposal efficiency and losing margin (p=0.089), as increased margins resulted in lower disposal efficiency.

Table 8.2. Ordinal logistic regression results demonstrating the relationship between score margin and skill involvements

Technical involvement	Estimate	SE	LCI	UCI	p-value
Win					
Marks	-0.140	0.078	-0.257	0.050	0.185
Tackles	0.020	0.046	-0.070	0.110	0.657
Contested marks	0.163	0.155	-0.140	0.467	0.292
Marks Inside 50	-0.139	0.068	-0.272	-0.006	0.040 *
Inside 50	0.162	0.089	-0.013	0.337	0.070
Ratio	-0.388	0.144	-0.671	-0.150	0.007 *
Efficiency	-0.008	0.097	-0.198	0.182	0.935
Kicks	0.036	0.047	-0.056	0.129	0.441
Loss					
Marks	0.109	0.073	-0.034	0.252	0.134
Tackles	0.080	0.042	-0.003	0.163	0.059
Contested marks	-0.030	0.223	-0.466	0.406	0.893
Marks Inside 50	-0.088	0.059	-0.203	0.028	0.137
Inside 50	-0.211	0.090	-0.388	-0.034	0.019 *
Ratio	0.073	0.053	-0.031	0.177	0.171
Efficiency	-0.140	0.082	-0.302	0.021	0.089
Kicks	-0.060	0.040	-0.138	0.017	0.127

Estimate denotes the beta coefficient estimate; SE denotes the standard error of the coefficient; LCI denotes the lower 95% confidence interval of the estimate; UCI denotes the upper 95% confidence interval of the estimate.

Table 8.3 demonstrates the results of the ordinal logistic regression between ladder position and skill involvements. A significant relationship was reported between ladder position and kicks (p=0.034) and contested marks (p=0.04), with the number decreasing as the ladder position moved away from one. No other skill involvements significantly explained final ladder position.

Table 8.3. Ordinal logistic regression results demonstrating the relationship between ladder position and skill involvements

Technical involvement	Estimate	SE	LCI	UCI	p-value
Marks	0.79	0.051	-0.021	0.178	0.120
Tackles	0.008	0.028	-0.047	0.063	0.766
Contested marks	-0.259	0.126	-0.506	-0.012	0.040 *
Marks Inside 50	0.059	0.039	-0.018	0.136	0.131
Inside 50	-0.096	0.055	-0.203	0.012	0.082
Ratio	0.011	0.043	-0.073	0.095	0.795
Efficiency	-0.004	0.058	-0.118	0.109	0.939
Kicks	-0.064	0.030	-0.123	-0.005	0.034 *

Estimate denotes the beta coefficient estimate; SE denotes the standard error of the coefficient; LCI denotes the lower 95% confidence interval of the estimate; UCI denotes the upper 95% confidence interval of the estimate

*denotes significance (p < 0.05).

8.4 Discussion

This study is the first to explore the skill profile of female AF match-play, and to investigate which, if any, skill involvements influenced match outcome. Here, winning teams performed with greater disposal efficiency and had more kicks, marks, and uncontested possessions than the losing teams. Furthermore, winning teams also converted more 'inside 50s' into goals than losing teams. However, the CHAID model demonstrated the ratio between 'inside 50' entries and goals scored and uncontested possessions were the only significant predictors of match outcome, predicting 88.5% of match outcomes in the first AFLW season. No other differences were reported between wins and losses, suggesting that other factors, such as physical fitness [30] and physical activity profiles [42] may also influence match success in female footballers. Given the number of similarities in skill profiles in winning and losing teams, developing the skills and game-play of female footballers should serve to further delineate winning teams from losing teams in the AFLW competition.

The inaugural season of the AFLW demonstrated that women's football follows a more congested match style, with an average stoppage occurring every 60 seconds of match-play, compared with 1 every 78 seconds (Champion Data ©) in men's AFL. Data obtained from freely available sources (www.afl.com.au) demonstrated female teams were involved in a greater number of contested possessions (2.1 ± 0.4 for females vs. 1.8 ± 0.2 for males), tackles (1.3 ± 0.3 for females vs 0.9 ± 0.2 for males) and clangers (0.8 ± 0.4 for females vs 0.6 ± 0.1 for males) per minute of match-play than male teams. Male AF teams complete a greater number of handballs, uncontested possessions, contested marks and reported a higher disposal efficiency than female teams. It important to note that over the past 30 years, male AFL players have become full-time athletes, which has subsequently resulted in better physical conditioning, aerobic fitness, skill ability and well-practiced coordinated attacking and defensive strategies [158]. Irrespective of differences across competitions, this early research should highlight the importance of gender specificity when developing training and game strategies for female AF.

In agreement with previous elite male AF research [39], winning AFLW teams performed more kicks at a greater disposal efficiency than their losing counterparts. Winning teams also completed more marks than the losing teams, suggesting that winning teams are able to maintain possession for longer periods of time, which has been associated with winning quarters in AF [159]. Interestingly, handballs, contested possessions, clangers, and the number of 'inside 50s' were consistent across games irrespective of match outcome in female teams. Generally, an 'inside 50' entry is likely to result in a scoring opportunity in male AF matches [96]. Therefore, it is important to investigate the distances from goal from such entries that

have the greatest association with goals scored in female AF. Furthermore, ball delivery into the attacking 50 m zones ('inside 50') should be analysed to promote other ball entry options, as opposed to (the traditional) kicking long to a congested centroid. These results highlight that factors other than skill ability may be more predictive of match outcome in this league. Notwithstanding, the only predictors of match outcome in female AF were uncontested possessions and the ratio between 'inside 50s' and goals scored. Given there were no differences in marks taken 'inside 50' between winning and losing teams, it may be that goals are more likely to be scored from ball contests close to goal or from uncontested run-on plays following a kick to space. Future research should aim to investigate the passages of play that lead to goals scored in female AF matches.

When analysed according to the magnitude of match outcome margins, large winning margins were associated with less marks 'inside 50' and lower inside 50: goals scored ratio. The lower number of marks 'inside 50' suggest that as winning margins increase, teams may be able to find more space and run the ball 'inside 50' as opposed to kicking long to marking contests. Larger losing margins were associated with less 'inside 50's' and demonstrated trends of reduced disposal efficiency and increased tackles. As research has shown tackles negatively influence disposal efficiency during offside touch [160], it is possible the increase in tackles result in a reduced disposal efficiency during female AF matches. As early evidence concerning the running demands of female AF shows little difference between the winning and losing teams [141], our findings suggest that total skill involvements may influence game outcome to a greater extent than running-based activity profiles. However, further research is required to understand the complex relationship between activity profiles and skill involvements in female AF.

Interestingly, kicks and contested marks were the only technical involvements that displayed a relationship with ladder position. In AF a mark constitutes a "free-kick", therefore a greater number of contested marks suggests higher ranked teams may spend a greater amount of time in possession with the football [159]. Furthermore, contested possessions have previously been associated with subsequent draft success in junior male AF [96]. Similarly, AFLW coaches may need to recruit players who have the ability to "win" marking contests. Irrespective of these findings, the absence of any other significant relationships between technical involvements and final ladder position may be explained by the short competitive season, with each team playing a total of seven matches. It is likely coaching strategy, player fitness and opposition strategy were developed and manipulated throughout the season. As success in AF is multifactorial, future research is warranted to explore the differences in skill ability, physical fitness and running performances between high and low-quality teams in order to advance the AFLW competition.

While the findings reported in this study are novel, the small sample size (one season) should be considered when interpreting the results as teams only competed against each other on one occasion. Future research should expand data collection to include multiple seasons to confidently establish key metrics that contribute to success in the AFLW. Finally, given the complex relationship between technical and running demands in team sports, future research should aim to incorporate both skill and running-based activity profile data into predictive models to understand which, if any, running variables contribute synergistically or independently to match success.

8.5 Practical Applications

The novelty of the reported findings provides early evidence to suggest the ratio between inside 50s and the number of goals scored and uncontested possessions are the greatest predictors of match success in female AF. As 'inside 50's'are not associated with match success in the female competition, coaches should assess their game plans, perhaps aiming for a number of passes 'inside 50' to allow closer shots on goal. Furthermore, as uncontested possessions were associated with match success, evasive and reactive agility drills that promote "finding space" and quick ball movement should be programmed into training. Additionally, coaches may need to draft players who are able to "win" contested marks to improve ladder position in future competitive seasons.

Chapter 9: Summary and Conclusions

9.1 Overview

The program of research in this thesis was the first to investigate the influence of physical qualities on match activity profiles in female AF. The research was undertaken in response to the exponential growth of female AF and the introduction of a national competition within Australia. Overall, the research highlighted the importance of high-intensity intermittent fitness on running demands in female Australian football and further identified the influences of contextual factors on activity profiles. Innovation continued with exploratory analysis of rotation/interchange profiles that identified the optimal rotation duration and the effect of intermittent fitness on running performances during on-field bouts. To gain an understanding of the total demands of female Australian football, a match skill profile of the national competition involving publicly available data from all eight teams in the inaugural AFLW was also investigated.

Table 9.1. Summary of study title, aims, hypotheses and findings.

Thesis Chapter	Study title	Aims	Hypotheses	Findings
Chapter 4	Physical qualities and activity profiles	1. Highlight the physical qualities that influence team selection 2. Investigate the activity profiles of female AF players. 3. Explore the relationships between physical qualities and running performance in matches	• Selected players will possess superior lower body power, speed and intermittent fitness. • Superior physical qualities will be associated with greater distances covered during matches.	*i*) Selected players were faster over 30 m and possessed superior high-intensity intermittent fitness. Lower body power was comparable across groups (*ii*) Acceleration, speed and high-intensity intermittent running ability were associated with greater high-speed distances covered during match-play.

Publication details: **Black GM, Gabbett TJ, Johnston RD, Cole MH, Naughton G, Dawson B. The influence of physical qualities on activity profiles in female Australian football match-play.** *International Journal of Sports Physiology and Performance*. **2017, doi: 10.1123/ijspp.2016-0723**

Thesis Chapter	Study title	Aims	Hypotheses	Findings
Chapter 5	Physical qualities and peak exercise periods	1. Identify positional differences in peak running periods during matches 2. Investigate the influence of fitness on peak periods and responses to intense exercise periods	• Midfielders will exhibit greater peak periods than half-line players • Greater high-intensity intermittent fitness will allow players to cover greater distances during match peak, and subsequent mean periods	(*iii*) Midfielders covered greater relative total distances during peak periods, but high-speed distances were comparable with half-line players (*iv*) Superior Yo-Yo performers covered greater high-distances during the match peak periods than low Yo-Yo performers (*v*) Higher fitness midfielders covered greater high-speed distance during peak periods than lower fitness players; higher fitness half-line players covered greater low-speed distances than lower fitness players

Publication details: **Black GM, Gabbett TJ, Johnston RD, Cole MH, Naughton G, Dawson B. Physical fitness and peak running periods during female Australian football match-play.** *Science and Medicine in Football* **doi:10.1080/24733938.2018.1426103**

Table 9.1. Continued.

Thesis Chapter	Study title	Aims	Hypotheses	Findings
Chapter 6	Rotations and match running performance	1. Compare and identify changes in activity profiles between rotated and whole-quarter players across on-field bouts 2. Investigate the influence of fitness of running performance during a rotation bout 3. Identify the effect of on-field bout duration on running intensities	• Rotated players will have a higher match intensity across all stages of their on-field bout compared to whole-quarter players. • Greater high-intensity intermittent fitness will allow players to perform at higher match intensity than lower fitness players across on-field bouts. • Shorter on-field bouts will be associated with greater running intensities.	(*vi*) Superior Yo-Yo performance only allowed players to cover greater high-speed distances if rotated. However, running intensities were comparable across quartiles in whole-quarter players, irrespective of fitness (*vii*) Rotations should be implemented after 4 to 12 minutes in the midfield positional group

Publication details: **Black GM, Gabbett TJ, Johnston RD, Cole MH, Naughton G, Dawson B. The influence of rotations on running performance in female Australian football midfielders.** *International Journal of Sports Physiology and Performance.* **2017,   doi: 10.1123/ijspp.2017-0175**

Thesis Chapter	Study title	Aims	Hypotheses	Findings
Chapter 7	Contextual factors and running performance	1.Identify pacing strategies of positional groups across a match 2. Investigate the influence of match outcome and opposition ranking on pacing strategies	• Players will reduce low-intensity activity in order to maintain high-speed running during matches • Players will set a higher pacing strategy when winning compared with losing matches. • Higher quality opposition will result in higher match running intensities than lower quality opponents.	(*viii*) Low-speed activity is maintained across matches in all positional groups. (*xi*) Half-backs were the only positional group influenced by the opposition and match outcome across quartiles

Publication details: **Black GM, Gabbett TJ, Johnston RD, Cole MH, Naughton G, Dawson B. The influence of contextual factors of running performance in female Australian football match-play.** *Journal of Strength and Conditioning Research.* **2017, doi: 10.1519/JSC.0000000000002142**

Table 9.1. Continued.

Thesis Chapter	Study title	Aims	Hypotheses	Findings
Chapter 8	Skill profile of female AF	1. Identify the skill involvements that are the biggest predictors of match success 2. Document the differences in skill profiles between large and small margins 3. Identify the relationship between skill involvements and ladder position	• Winning teams will perform a greater number of skill involvements, at a greater efficiency than losing teams. However, disposal efficiency and 'inside 50's' will be the best predictor of match outcome • Superior ladder position will be associated with a greater number of total skill involvements. More specifically, higher ranked teams will complete more kicks at a greater efficiency and will convert more 'inside 50's' into goals.	(*x*) The ratio between inside 50s: goals scored is the strongest predictor of match success in female AF (*xi*) Larger winning margins were associated with a greater number of skill involvements, whereas the number of marks and disposal efficiency were the only differences reported between small winning and losing margins (*xii*) Kicks and contested marks were the only involvements associated with final ladder position

Publication details: **Black GM, Gabbett TJ, Johnston RD. Cole MH, Naughton G, Dawson B. A skill profile of the national women's Australian football league (AFLW). S***cience and Medicine in Football (submitted)*

9.3 Additions to existing knowledge

Table 9.1 highlights the research outline from the five independent but inter-related studies completed as part of this dissertation in women's AF. It summarises the aims, hypotheses, and major findings of each results chapter. Additions to the existing knowledge from the findings in this thesis are discussed below:

- Superior high-intensity intermittent fitness and 30 m speed were associated with team selection and match running performance in female football players.

The findings partially supported the original hypotheses and agrees with some [100, 104], but not all [109] previous research. Partial agreement with the hypothesis is attributed to not all physical qualities being associated with team selection. Based on this result, players could be exposed to the important physical qualities of speed and high-intensity intermittent training to increase their prospects of team selection. Additionally, the fact that the physical quality of lower-body power did not influence team selection in female Australian footballers provides support for the idea that systematic strength, power, and sport-specific training programs could be implemented into these players' weekly schedules. In Study 2 (Chapter 5), the findings supported the second hypothesis as higher Yo-Yo performance was associated with players covering greater distances during match peak and subsequent periods. Following intense passages of play, high fitness midfielders were able to exhibit greater high-speed activity, whereas higher fitness half-line players covered greater distance at low-speed than low fitness players. Collectively these findings validate the use of the Yo-Yo IR1 test in female AF players and emphasise the importance of physical qualities, such as high-intensity, intermittent running

performances in team selection. However, some position-specific differences in outcomes of training might be expected from supporting high-speed running during match-play.

- Higher fitness midfielders reduced running intensity to that of the lower fitness players when not rotated within individual quarters.

The findings presented in Study 3 (Chapter 6) partially supported the original hypotheses because superior high-intensity intermittent fitness was only advantageous in exhibiting a greater running intensity if midfielders were rotated off the field [78]. While these findings were expected following chapter 5, running intensities were comparable across quartiles in whole-quarter players, irrespective of fitness. Additionally, as initially hypothesised, relatively short durations of on-field bouts allowed players to cover greater relative total- and high-speed distances than whole quarter players. However, players who were required to remain on-field between 12 to 18 minutes showed a reduced running performance than whole-quarter players. In summary, these findings highlighted the importance of (1) rotating midfielders off the field every quarter to maintain their playing intensity, (2) rotating players within 12 minutes of commencing an on-field bout and (3) using the Yo-Yo IR1 to measure fitness and incorporating high-intensity training into sessions regularly.

- Differential positional responses to contextual match factors

Higher quality opposition and losing matches were associated with greater activity profiles in the half-back positional group. This result highlighted the importance of rotating this positional

group either (1) into a back-pocket position or (2) off the field when their opponent was rotated during a match that was being lost or played against higher quality opposition. Although match outcome and opposition had little influence on the activity profiles of the other positional groups, it is postulated the skill ability influenced performance to a greater extent in midfielders and half-forwards than the half-backs. Therefore, this finding only partially supported the third hypothesis in chapter 7 as the physical response depended on playing position. Furthermore, the findings presented in Study 4 (Chapter 7) differed from the majority of previous research [19, 31, 32]; showing low-speed distances remained unchanged across quarters. However, previous reports have not involved the sport of female AF and have more often focussed on professional rather than emerging athlete pools. Although a reduction in running intensity could be predicted as matches progress [78], improvement in high-speed running ability may reduce the effect of match-related fatigue and enable players to maintain high-speed running during matches.

- Skill performance associated with match outcome, ladder position and score margin.

Despite differences in disposal efficiency between winning and losing teams, the only technical skills that significantly explained match outcome were the ratio between the number of times the ball entered a team's attacking 50-metre arc (termed 'inside 50s') and the number of goals scored and, uncontested possessions. No differences were reported between match results for the number of inside 50s alone, suggesting that coaches could develop training drills to promote lateral thinking, creating space and optimal skill accuracy when passing the ball inside the attacking 50 m zone. Furthermore, the relationship between contested marks and ladder position suggested coaches may need to consider drafting players based on their marking

ability. Coaches could target the use of small-sided games to promote "winning" aerial contests and "finding space" in match simulated environments.

9.4. Points of Difference

The work presented in this thesis is the first to investigate the physical and skill-based demands of female AF. The findings should aid in the physical development of female Australian footballers and also highlight the skill qualities important for success.

The points of difference presented in this research are:

(i) Physical qualities, specifically speed and high-intensity intermittent fitness comprise a fundamental prerequisite in female AF. Specifically, (1) both 30 m sprint time and Yo-Yo IR1 scores influenced team selection and (2) speed and intermittent fitness were associated with relative distances covered during female AF matches. Although these findings are similar to those in male research [103, 110], the results strengthened the evidence around the use of these two tests because of their strong relationship to match performances in female AF players. Coaching and conditioning staff could use these tests to monitor and develop physical qualities in their athletes, which may lead to improved on-field performances, increased player longevity, and reduced injury risk.

(ii) The novel findings in this thesis provided information on the positional activity profiles of female football. This research was a *'snapshot'* of not only the average match demands of recreational female AF, but also described the demands of peak periods of match-play. Understanding the average and peak intensities placed on female footballers is important for the development of game-specific training drills. Coaching and conditioning staff now have

access to benchmark training intensities that are vital for the development of female Australian football. Additionally, identifying and exposing players to peak exercise intensities during training may increase preparedness for potential match situations.

(iii) This research reported optimal on-field bout durations for female midfielders. Rotation bouts were divided into quartiles within quarters and changes in running performance were determined across short, moderate and long duration and, whole-quarter bouts. As a game strategy, this evidence on rotations may emerge as particularly relevant to coaches to increase match running intensities. Until now, there has been no research to inform coaches on the implementation of rotations in the female component of the sport.

(iv) Applied sport science research often focusses on the physical demands, as opposed to the skill demands of team sports. The final study presented in this thesis is the first to explore the skill profile of the inaugural AFLW competition. The information presented in the research informs female football coaches of the importance of skills training to promote "winning" contests and demonstrates players should be encouraged to search for alternative options when passing the ball inside the attacking 50-metre zone.

In addition to the above points of difference, a number of similarities and differences were highlighted in this thesis between male and female AF players (Table 9.2). Superior Yo-Yo IR1 [104] and IR2 [12] and speed [115] have been linked to team selection and activity profiles in both sub-elite [11] and professional [29] formats of the game. However, female AF players reported lower values on all physical parameters than previously reported for male footballers. As the professional standards of the relatively new national competitive league evolves, a more comprehensive analysis (e.g. strength, power) of physical qualities is required to increase the understanding of the physical qualities important for female AF success.

Table 9.2 A comparison of physical variables between female and male AF players.

Physical parameter	Female AF	Male AF
30 m time (s)	4.28-5.60	3.97- 4.24*
Yo-Yo IR1 (m)	240- 1080	1438- 1910 [#]
Relative distance (m.min^{-1})	75 -107	107- 135 *
% distance > 15 km.hr^{-1}	6- 23	26-37 [a] *

[a] *range approximated from average reported data. Data extracted from multiple studies [6, 75, 104, 115]. # represents elite junior data (U18); * represents elite senior male data*

In agreement with research in males, the current results suggest shorter rotation bouts (of approximately 5 minutes) are important to maintain higher running intensities [80]. However, the results in this thesis demonstrated on-field durations of up to 12 minutes still allowed players to maintain a higher running intensity than whole-quarter players.

Although previous research has linked winning matches to reduced running intensities [39], the current results found match outcome influenced running intensities differently across positions. Furthermore, male AF research has not investigated the influence of opposition ranking on activity profiles. Based on the findings presented in this thesis, match outcome and opposition ranking may also influence positional activity profiles in male AF players.

While a comparison between sexes provides insight into the differences between male and female Australian football, until now, it has not been evident how female AF players compare with the athletes competing in other female running-based team-sports (Table 9.3). The studies that formulate this thesis add to the currently under-researched field of female team sports. Inter-sport comparisons highlight some deficiencies in the physicality of the female AF players tested in the current thesis. Consistent with previous research, speed [123] and Yo-Yo IR1 [10] performance were greater in the selected players than non-selected players. However, the Yo-

Yo IR1 scores and maximum speeds reported in previous female research were higher than

found in the present cohort of female AF players (Table 9.3). However, diversity in the level

of competition may require caution in the interpretation of this comparative table. Therefore,

the development of speed and fitness in the female AF population should be targeted. Strength

and conditioning coaches should program maximal strength and high-intensity training to assist

in the development of female footballers.

Table 9.3 Comparison of physical variables between female AF, soccer and sevens athletes

Physical parameter	Female AF	Elite female soccer	Elite women's sevens
30 m speed (km.hr^{-1})	19.0-25.2	22.5-24.3 [a*]	22.3-24.9
Yo-Yo IR1 (m)	280-1080	1051-1455	1373-2031
Relative distance (m.min^{-1})	47-107	92-114 [a]	81.9-89.7
% distance > 15 km.hr^{-1}	6-23	9-12 [a]	12-18^

[a] *range approximated from average reported data. *35 m speed. ^ high speed >18 km.hr^{-1}*
Data extracted from multiple studies [22, 46, 118, 123, 161]

The results presented in this thesis are the first to identify the relationship between acceleration

and speed on activity profiles in female field sport athletes. Additionally, the findings provide

further support [22, 46] for the use of the Yo-Yo IR1 in female team sport athletes. The average

running intensity of female AF match-play was comparable with elite female soccer matches

[24], with the exception of full-line players. Furthermore, peak 5-minute high-intensity running

distances were similar to previously reported in elite female soccer players [161]. Therefore,

based on these similarities, the results reported in Study 3 (Chapter 6) may be applied to other

female team sports to ensure that players are exposed to "intense" running periods during

training.

9.4 Future Directions

This thesis has investigated the influence of physical qualities on match demands in female Australian football, which will allow practitioners to better develop a sport-specific training stimulus for this population. Nevertheless, there are still a number of important areas that were beyond the scope of this dissertation and, hence, should be investigated in future studies. Some of these areas include:

(i) Further research on the running-based activity profiles in match performances of different state leagues and the AFLW competitions. A comparison of the demands of matches during regular seasons and the AFLW will better inform coaches of training strategies and benchmark training intensities.

(ii) Although this research highlighted field-based tests that correlated with performance, identifying the strength and power profiles of female AF players is important. Determining the role of strength on team selection and on-field performance should encourage further gym-based training to develop these qualities. Furthermore, well-developed off-field physical qualities have previously demonstrated an ability to reduce the effect of post-match fatigue [162]. Future research could extend to investigating the physiological responses (e.g. creatine kinase or heart rate) to female Australian football matches and identify the influence of strength, power and aerobic fitness on these responses.

(iii) Understanding the match demands of competition is important for training prescription. However, the development of load monitoring could be explored to gain insight into (1) the total training loads to which players are exposed (2) the level of preparedness for competition, and (3) the relationship between training load and injury in female footballers.

(iv) Future research could aim to synchronise GPS and skill data to understand how these components interrelate during match-play. It is important to understand and monitor the evolution of both running-based activity profiles and skill ability in premier matches as female AF continues to develop.

(v) Finally, sport-specific decision-making ability could be assessed in this population. As the findings demonstrated, inside 50: goals scored was one of the greatest predictors of match outcome, which may be influenced by a number of factors including decision-making ability.

The performance model illustrated below highlights the factors that are currently known and unknown to contribute to female football performance (Figure 9.1). The findings presented in this thesis are the first to identify that physical fitness influences match running performance and team selection in female Australian football players. Current findings suggested the development of speed and intermittent fitness were important for female Australian football performance. While innovative, these results arguably outline the basic physical and skill-based foundations that underpin success in female Australian football. Therefore, further investigation is required to understand (1) if a broader number of off-field physical qualities and overall match performance are inherently linked, (2) how training load determines preparedness for competition and identifies subsequent injury risk, and (3) the influence of a number of off-field physical qualities on multiple physiological responses to match-play.
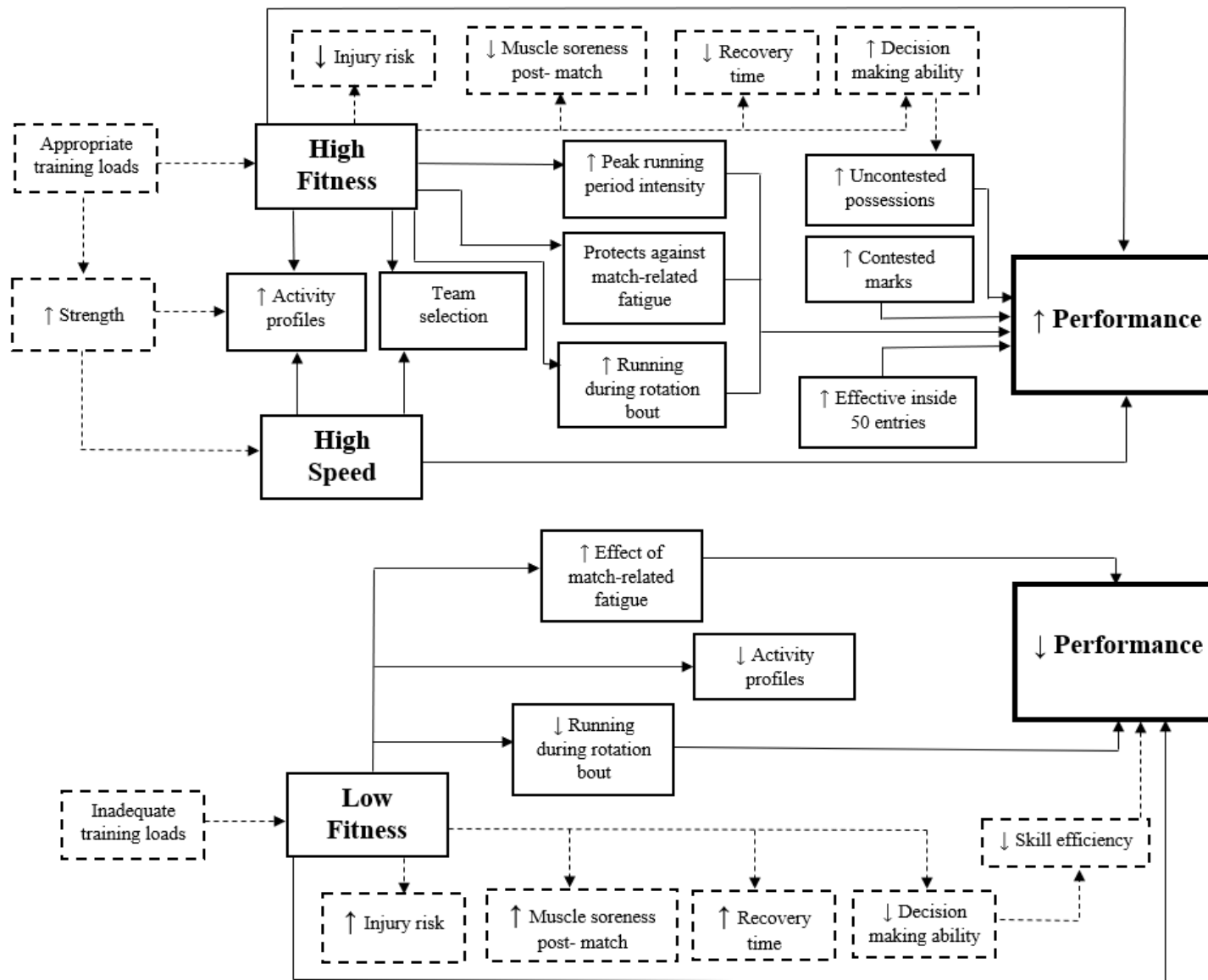
Figure 9.1 P*erformance model of female Australian football.* ⟶ *= known contributors to performance;* ⇢ *= unknown contributors to performance (fitness in this schema denotes Yo-Yo IR1 performance).*

9.6 Research Strengths

An overarching strength of the thesis was provided by access to extensive, reliable and relevant data over a prolonged period of time. The strengths of this research are summarised simply as:

(i) The first investigation into the match demands and identification of relevant physical qualities for athletes participating in the emerging professional sport of female AF.

(ii) Provided coaches with benchmark training intensities to meet in order to increase preparedness for competition.

(iii) Provided an overview of skills important to develop to increase the likelihood of success in female AF.

(iv) Provided evidence around the most effective means to use rotations during match-play.

9.7 Research Limitations

Although the body of research presented is innovative there are a number of limitations that should be highlighted:

(i)   The dataset was drawn from one state-based recreational competitive season (chapters 4 to 7). Nonetheless, statistical power on key performance metrics was supported when analyses involved two groups such as selected and non-selected players.

(ii)   There were smaller sample sizes in the positional comparisons. Although the results from these exploratory analyses of positional differences may be slightly underpowered, they still provide hypothesis generating evidence for future research.

(iii)   Match demands and the physical capabilities of players may vary between different state-based leagues and/or within the national AFLW competition. However, it should be noted that 60% of the players who formed the "selected" group in study one competed in the inaugural AFLW competition; with their team placing second overall.

(iv)   Physical qualities of the female AF athletes were only assessed once; at the end of preseason. Nevertheless, with the exception of the Yo-Yo IR1 test, athletes performed three trials of the off-field tests and the best performance was used for the analyses.

(v)   Lower body power, speed and high-intensity intermittent fitness may have improved or declined over the competitive season

(vi)   Physical testing battery lacked a test of upper body power; an attribute that is arguably important for AF performance.

(vii)   Running and skill match demands were independently assessed in different chapters. To gain a complete understanding of female AF demands, research is required to explore the relationship between skill and activity profiles during competitive matches.

9.8 Practical Applications

The program of research in this thesis is the first to provide information on the running demands of female AF. The average and peak running demands presented in this thesis provide coaches with baseline training intensities to which players could be exposed. The GPS units that are readily-available within sporting organisations can be worn routinely during training and game situations to identify and manage the load placed on these players on a weekly basis. While

running is not the only possible measure of load, the advantages of GPS include access to long-term objective data and the provision of information related to the distances covered and times spent in different speed zones.

High-intensity running ability could be assessed using the Yo-Yo IR1 in female Australian footballers as it was shown to influence (1) team selection; (2) running demands during peak and subsequent periods of activity; and (3) running intensity during multiple rotation bouts across quarters. Future off-field physical testing batteries should aim to include this validated test over numerous stages of a macrocycle.

Coaching staff could consider the increased match running demands that are placed on half-back players when programming recovery and subsequent training. Players from this positional group were required to cover greater distances at high-speed when competing against top 3 opponents and when losing matches. As research has shown that large changes in weekly high-speed running is associated with increased injury risk [163], management strategies need to ensure that (1) players are well conditioned to meet these high-speed demands and (2) post-match recovery is monitored closely in this positional group.

Finally, players' ability to win marking contests and "find space" should be continually developed in female footballers to further progress the sport. Furthermore, coaches could implement match scenarios into training to ensure effective inside 50 entries that allow players to have a closer shot on goal, as opposed to kicking long to a congested centroid.

9.9 Conclusions

This thesis represents a *'snapshot'* of the emerging sport of women's Australian football. The overall aims of this research were to determine the match demands and physical qualities important for performance in female AF. The findings presented highlight relevant, reliable physical tests that could be utilised in monitoring player fitness and contribute to explanations of running performance during match-play. Additionally, well-developed high-intensity intermittent fitness and 30 m speed was associated with team selection. Greater Yo-Yo IR1 performances lead to greater running performances during peak periods of match-play and during rotation bouts. Moreover, when higher fitness midfielders were not rotated during individual quarters, running intensity was reduced to that of the lower fitness players. Although reductions in activity profiles are inevitable across matches, well-developed high-intensity running ability, coupled with rotations, may minimise the declines in running performance. Finally, evidence from this thesis can be used to encourage coaches to expose players to the average and peak match intensities during training. Improved players physical preparedness for competition may increase the likelihood of success.

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160.   Johnston RD, Gabbett TJ, Jenkins DG, Speranza MJ. The effect of different repeated-high-intensity-effort bouts on subsequent running, skill performance, and neuromuscular function. Inter J Sports Physiol Perform. 2016;11(3):311-8.

161.   Trewin J, Meylan C, Varley MC, Cronin J. The match-to-match variation of match-running in elite female soccer. J Sci Med Sport. 2017; 21(2):196-201.

162.   Johnston R, Gabbett T, Jenkins D, Hulin B. Influence of physical qualities on post-match fatigue in rugby league players. Journal of science and medicine in sport. 2015;18(2):209-13.

163.   Malone S, Owen A, Mendes B, Hughes B, Collins K, Gabbett TJ. High-speed running and sprinting as an injury risk factor in soccer: Can well-developed physical qualities reduce the risk? J Sci Med Sport. 2017; doi: 10.1016/j.jsams.2017.05.016.

Appendices

Appendix A: Evidence of Publication

Study 1

Black G, Gabbett T, Johnston R, Cole M, Naughton G, Dawson B. The influence of physical qualities on activity profiles in female Australian football match-play. *International Journal of Sports Physiology and Performance.* 2017,doi: 10.1123/ijspp.2016-0723

International Journal of Sports Physiology and Performance - Decision on Manuscript ID IJSPP.2016-0723.R2

International Journal of Sports Physiology and Performance <onbehalfof+ralph.beneke+staff.uni-marburg.de@manuscriptcentral.com>
Tue 19/09, 3:05 AM
Georgia Black ⌄

Inbox

Flag for follow up. Start by Tuesday, 19 September 2017. Due by Tuesday, 19 September 2017.

You forwarded this message on 19/09/2017 8:39 AM

18-Sep-2017

Dear Ms Black,

It is a pleasure to accept your manuscript entitled "The influence of physical qualities on activity profiles in female Australian football match-play" in its current form for publication in the International Journal of Sports Physiology and Performance.

The In Press and MedLine listings should be available approximately 4 weeks from now.

Thank you for your fine contribution. On behalf of the Editors of the International Journal of Sports Physiology and Performance, we look forward to your continued contributions to the Journal.

Yours sincerely,

Prof. Ralph Beneke MD PhD FACSM
Editor, International Journal of Sports Physiology and Performance

Study 2

Black GM, Gabbett TJ, Johnston RJ, Cole MH, Naughton, G, Dawson B. Physical fitness and peak running periods during female Australian football match-play. *Science and Medicine in Football.* doi: 10.1080/24733938.2018.1426103

↩ Reply all | ⌄ 🗑 Delete Junk | ⌄ •••

Science and Medicine in Football - Decision on Manuscript ID RSMF-2017-0082.R2

S Science and Medicine in Football <onbehalfof@manuscriptcentral.com>
Thu 4/01, 6:18 PM
Georgia Black ⌄

Inbox

> You forwarded this message on 5/01/2018 8:24 AM

04-Jan-2018

Dear Ms Black:

Ref: Physical fitness and peak running periods during female Australian football match-play

Our reviewers have now considered your paper and have recommended publication in Science and Medicine in Football. We are pleased to accept your paper in its current form which will now be forwarded to the publisher for copy editing and typesetting. The reviewer comments are included at the bottom of this letter, along with those of the editor who coordinated the review of your paper.

You will receive proofs for checking, and instructions for transfer of copyright in due course.

The publisher also requests that proofs are checked through the publisher's tracking system and returned within 48 hours of receipt.

Thank you for your contribution to Science and Medicine in Football and we look forward to receiving further submissions from you.

Sincerely,
Tim Meyer and Franco Impellizzeri
Editor in Chief, Science and Medicine in Football
tim.meyer@mx.uni-saarland.de, franco.impellizzeri@gmail.com

Study 3

Black G, Gabbett T, Johnston R, Cole M, Naughton G, Dawson B. The influence of rotations on match running performance in female Australian football midfielders. *International Journal Sports Physiology and Performance,* doi: 10.1123/ijspp.2017-0175

International Journal of Sports Physiology and Performance - Decision on Manuscript ID IJSPP.2017-0175.R2

International Journal of Sports Physiology and Performance <onbehalfof+ralph.beneke+staff.uni-marburg.de@manuscriptcentral.com>
Thu 3/08, 4:40 PM
Georgia Black ⌄

Inbox

You forwarded this message on 3/08/2017 4:48 PM

03-Aug-2017

Dear Ms Black,

It is a pleasure to accept your manuscript entitled "The influence of rotations on match running performance in female Australian football midfielders" in its current form for publication in the International Journal of Sports Physiology and Performance.

The In Press and MedLine listings should be available approximately 4 weeks from now.

Thank you for your fine contribution. On behalf of the Editors of the International Journal of Sports Physiology and Performance, we look forward to your continued contributions to the Journal.

Yours sincerely,

Prof. Ralph Beneke MD PhD FACSM
Editor, International Journal of Sports Physiology and Performance

Black G, Gabbett T, Johnston R, Cole M, Naughton G, Dawson B. The influence of contextual factors of running performance in female Australian football match-play. *Journal of Strength and Conditioning Research,* doi: 10.1519/JSC.0000000000002142.

JSCR Decision ACCEPT

em.jscr.0.546c50.424248f7@editorialmanager.com on behalf of Journal of Strength and Conditioning Research <em@editorialmanager.com>
Mon 10/07, 4:02 AM
Georgia Black ⦙

Inbox

Flag for follow up. Start by Monday, 10 July 2017. Due by Monday, 10 July 2017.

You replied on 16/07/2017 6:56 PM.

Action Items

Jul 09, 2017

RE: JSCR-08-8674R1, entitled "The influence of contextual factors on running performance in female Australian football match-play"

Dear Dr. Black,

I am pleased to inform you of the official acceptance of your manuscript, JSCR-08-8674R1, entitled "The influence of contextual factors on running performance in female Australian football match-play" for publication in the Journal of Strength and Conditioning Research. Congratulations to you and your co-authors in meeting the very high standard of quality that is required for publication in this Journal.

The production staff at Lippincott, Williams and Wilkins (LWW) will be sending galley proofs and work with you to put your manuscript into proper format for publication.

I want to take this opportunity to remind you to check the page proofs promptly and carefully for accuracy when you eventually receive them. You will receive them via email so please be attentive to such communications.

PARTICIPANT INFORMATION LETTER

PROJECT TITLE: Activity profiles of female Australian Football: the influence of physical qualities

PRINCIPAL INVESTIGATOR: Dr Tim Gabbett
STUDENT RESEARCHER: Georgia Black
STUDENT'S DEGREE: Doctor of Philosophy (PhD)

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?
The research project investigates the activity profiles of Women's Australian Football match play. The aims of this project are to

a) describe the activity profiles of Women's Australian Football match-play; b) investigate the influence of physical qualities on activity profiles; and c) to investigate differences in game demands between winning and losing teams.

Who is undertaking the project?
This project is being conducted by Georgia Black and will form the basis for the degree of Doctor of Philosophy at Australian Catholic University under the supervision of Dr Tim Gabbett. Georgia Black graduated with a bachelor of exercise and sport science (Honours) and this research will form part of her postgraduate study. Georgia has conducted several studies using GPS analysis that have been published in peer reviewed journals. Tim holds two PhD's and is a world leader in applied sport science. Tim has published over 200 peer-reviewed articles and has presented at over 200 national and international conferences.

Are there any risks associated with participating in this project?
The possible risks, inconvenience and/or discomfort to you/your child are negligible and will not be beyond those you experience during your normal training or matches. The GPS monitoring is the only novel task being undertaken by yourself/your child and should have negligible impact on match performance.

What will I be asked to do?
You/your child will be asked to complete a number of fitness tests as part of preseason training including; (a) height; (b) mass; (c) 20m sprint; (d) countermovement jump: you will be asked to jump as high as possible on a force platform; (e) plyometric push up: you/your child will be asked to start in a press-up position with your hands on the force platform in a self-selected position, and arms extended. You/your child will be asked to lower your body by

flexing the elbows to a self-selected depth before extending the elbows as fast as possible so that your hands leave the platform; (f) Yo-Yo Intermittent Recovery test that aims to measure high-intensity running ability during a 20m shuttle test; and (g) 2km time trial. You/your child will also be asked to participate in a GPS analysis of six regular season matches to be undertaken during the 2016 season. This GPS analysis will be only provided to the coaching staff (and no-one else) and only with your permission. You can choose to participate in the study and have your results remain confidential.

How much time will the project take?
The preseason testing will be completed during normal training session times over two sessions. The GPS monitoring will occur throughout the 2016 season. You/your child may be asked to participate in one more match analysis if the first GPS analysis did not capture at least 75% of the total match time. This may be due to injury, suspension, or technical difficulty with the GPS device.

What are the benefits of the research project?
This project provides participants a GPS match analysis that is generally restricted to elite team-sport athletes, such as professional AFL players. Due to the extremely high cost of each GPS unit, GPS match analysis is beyond the limited resources of local and community-level football clubs. You/your child will be provided with an individual match performance report outlining the total distance covered during the match, the total distance covered low-speed, moderate speed, high-speed and very-high speed running and with a comparison to the average results of the entire group. These results will be provided prior to de-identification of your data.

Can I withdraw from the study?
Participation in this study is completely voluntary. You are not under any obligation to participate. If you/and your child agree to participate, you/your child can withdraw from the study at any time before GPS match analysis has been de-identified without adverse consequences. You/your child cannot withdraw after de-identification of GPS data because individual results may not be able to be identified. Participation or non-participation will not affect ongoing selection in the side or affect your relationship with the researcher.

Will anyone else know the results of the project?
With your permission, your/your child GPS match analysis will be shared with coaching staff. You/your child can choose to participate in the study and have your results remain confidential. It is the intention of the researchers to use this data for a number of studies and to publish these studies in peer reviewed scientific journals. If these studies are accepted for publication, no individual or identifiable results will be published, only aggregated data will be published. The data will be stored on a password-protected computer in a locked office on the ACU Brisbane campus as non-identifiable data.

Will I be able to find out the results of the project?
Prior to de-identification of all participants' data you will be provided with a report of your results as outlined previously.

Who do I contact if I have questions about the project?
Should you have any questions regarding this project, please contact the Principal Supervisor and/or the Student Researcher:

Dr Tim Gabbett
(07) 3623 7589
tim.gabbett@acu.edu.au
School of Exercise Science
ACU National, Brisbane Campus, 1100 Nudgee Rd, Banyo, Queensland 4014.

Georgia Black
0435 237 178
georgia.black@acu.edu.au
School of Exercise Science
ACU National, Brisbane Campus, 1100 Nudgee Rd, Banyo, Queensland 4014

What if I have a complaint or any concerns?
The study has been approved by the Human Research Ethics Committee at Australian Catholic University (approval number 2016 XXXX). If you have any complaints or concerns about the conduct of the project, you may write to the Chair of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Research Ethics Manager (ResEthics.Manager@acu.edu.au)
Office of the Deputy Vice-Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
North Sydney NSW 2059.

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?
You will need to complete both copies of the Informed Consent form and either hand them back to the researcher or scan them to the following email address:

Email: georgia.black@acu.edu.au

Yours sincerely,

Dr Tim Gabbett   Georgia Black
Principal Investigator   Student Researcher

CONSENT FORM
Copy for Researcher

TITLE OF PROJECT: *Activity profiles of female Australian Football: the influence of physical qualities*

SUPERVISOR: Dr Tim Gabbett

STUDENT RESEARCHER: Georgia Black

I .... *(the participant)* have read and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this study that involves physical quality testing including; (a) height; (b) mass; (c) 30m sprint; (d) countermovement jump; (e) plyometric push up; and (f) Yo-Yo Intermittent Recovery test; and global positioning system (GPS) analysis during match-play, realising that I can withdraw my consent at any time (without adverse consequences). I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

☐   I give permission for my GPS results to be provided to the club coach.

NAME OF PARTICIPANT: ....

SIGNATURE ....   DATE

....

SIGNATURE OF SUPERVISOR:...

DATE:………………..

SIGNATURE OF STUDENT RESEARCHER: ....

DATE:……………………….

CONSENT FORM
Copy for Participant to Keep

TITLE OF PROJECT: *Activity profiles of female Australian Football: the influence of physical qualities*

SUPERVISOR: Dr Tim Gabbett

STUDENT RESEARCHER: Georgia Black

I .... *(the participant)* have read and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this study that involves physical quality testing including; (a) height; (b) mass; (c) 20m sprint; (d) countermovement jump; (e) plyometric push up; (f) Yo-Yo Intermittent Recovery test; and (g) 2km time trial; and global positioning system (GPS) analysis during match-play, realising that I can withdraw my consent at any time (without adverse consequences). I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

☐   I give permission for my GPS results to be provided to the club coach.

NAME OF PARTICIPANT: ....

SIGNATURE ....   DATE

....

SIGNATURE OF SUPERVISOR: ....

DATE: ………………………..

SIGNATURE OF STUDENT RESEARCHER: ....

DATE: ....

Appendix C: Ethics Approval

016-27H Ethics application approved!

Pratigya Pozniak <Pratigya.Pozniak@acu.edu.au>

 on behalf of

Res Ethics <Res.Ethics@acu.edu.au>

 Thu 3/24/2016 10:38 AM

To:

Tim Gabbett <Tim.Gabbett@acu.edu.au>

Cc:

Res Ethics <Res.Ethics@acu.edu.au>;

Georgia Black

PhD

Dear Applicant,

Principal Investigator: Dr Timothy Gabbett
Student Researcher: Georgia Black [HDR Student]
Ethics Register Number: 2016-27H
Project Title: Activity profiles of female Australian Football: the influence of physical qualities
Risk Level: Low Risk
Date Approved: 24/03/2016
Ethics Clearance End Date: 30/06/2018

This email is to advise that your application has been reviewed by the Australian Catholic University's Human Research Ethics Committee and confirmed as meeting the requirements of the National Statement on Ethical Conduct in Human Research.

The data collection of your project has received ethical clearance but the decision and authority to commence may be dependent on factors beyond the remit of the ethics review process and approval is subject to ratification at the next available Committee meeting. The Chief Investigator is responsible for ensuring that outstanding permission letters are obtained, interview/survey questions, if relevant, and a copy forwarded to ACU HREC before any data collection can occur. Failure to provide outstanding documents to the ACU HREC before data collection commences is in breach of the National Statement on Ethical Conduct in Human Research and the Australian Code for the Responsible Conduct of Research. Further, this approval is only valid as long as approved procedures are followed.

If your project is a Clinical Trial, you are required to register it in a publicly accessible trials registry prior to enrolment of the first participant (e.g. Australian New Zealand Clinical Trials

Registry http://www.anzctr.org.au/) as a condition of ethics approval.

If you require a formal approval certificate, please respond via reply email and one will be issued.

Researchers who fail to submit a progress report may have their ethical clearance revoked and/or the ethical clearances of other projects suspended. When your project has been completed a progress/final report form must be submitted. The information researchers provide on the security of records, compliance with approval consent procedures and documentation and responses to special conditions is reported to the NHMRC on an annual basis. In accordance with NHMRC the ACU HREC may undertake annual audits of any projects considered to be of more than low risk.

It is the Principal Investigators / Supervisors responsibility to ensure that:
1.   All serious and unexpected adverse events should be reported to the HREC with 72 hours.
2.   Any changes to the protocol must be reviewed by the HREC by submitting a Modification/Change to Protocol Form prior to the research commencing or continuing. http://research.acu.edu.au/researcher-support/integrity-and-ethics/
3.   Progress reports are to be submitted on an annual basis. http://research.acu.edu.au/researcher-support/integrity-and-ethics/
4.   All research participants are to be provided with a Participant Information Letter and consent form, unless otherwise agreed by the Committee.
5.   Protocols can be extended for a maximum of five (5) years after which a new application must be submitted. (The five year limit on renewal of approvals allows the Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).

Researchers must immediately report to HREC any matter that might affect the ethical acceptability of the protocol eg: changes to protocols or unforeseen circumstances or adverse effects on participants.

Please do not hesitate to contact the office if you have any queries.

Kind regards,

Kylie Pashley
on behalf of ACU HREC Chair, Dr Nadia Crittenden

Ethics Officer | Research Services
Office of the Deputy Vice Chancellor (Research) Australian Catholic University