Junior Athlete Development in Professional Australian Football: Physical Profiling, Match Analysis and Training to Improve Performance

by

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A thesis submitted for the degree of

Doctor of Philosophy

January 2019

Certificate of Original Authorship

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

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This research is supported by the Australian Government Research Training Program and Australian Postgraduate Award scholarship.

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2019

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PREFACE

This thesis is written as per the requirements of the degree Doctor of Philosophy and published according to the UTS "Thesis presentation and submission" guidelines. The manuscripts included in this thesis are logically progressive in nature and form a body of work that encompasses the investigation of the elite-junior athlete development within Australian Football.

The data collected during this candidature and associated research has resulted in two manuscripts being accepted for publication while a further three manuscripts are currently under review at peer-reviewed journals. The Introduction section provides a brief background of the literature, defines the research problem and outlines the aim and purpose of each study. The Literature Review provides a synopsis of the currently available literature describing athlete profiling in the context of anthropometric, physical and match-play activity characteristics. The subsequent five chapters encompass the manuscripts which are presented in a logical sequence that specifically address the research problems outlined in the introduction. For these chapters, the figures, tables and referencing format remains according to the specific journal guidelines. Each manuscript in Chapter Three to Chapter Seven outlines an introduction to the specific research problem, individual methodology, results and discussion. The final chapter, general discussion chapter provides a synopsis of the main findings from the various manuscripts. Additionally, the research contributions, practical applications, directions for future research and research conclusions are provided to exemplify the real-world relevance for coaches, recruiters, sport scientists and performance analysts. With the exception of the journal manuscripts, the APA 6th reference style has been used throughout the document and the reference list is located at the end of the thesis.

ACKNOWLEDGEMENTS

Firstly, I would like to thank my supervisor, A/Prof Mark Watsford. I can't thank you enough for your support and guidance, particularly down the final stages. Without doubt I could not have achieved everything to this point without your support, humour and advice. I truly can't thank you enough for everything. I would also like to thank my co-supervisor Dr. Damien Austin. Although I lost your daily advice when you left for Brisbane, you were always there to give feedback and to check over my work when needed. I owe a lot to you for your mentoring as I started out my career and I will always be thankful.

Thank you to the players and staff at the Sydney Swans Football Club and Sydney Swans Academy for your support and interest in this project. The club is certainly a special environment and that begins with Rob Spurrs. I am very grateful for your mentorship, support and friendship over the last number of years. Also a big thank you to Dr. Michael Rennie. Although you got to the finish line before myself, it has been an honour working through our projects side by side and thank you for your support and guidance on the journey.

To my friends and family, firstly my parents Seamus and Maureen, thank you for everything, this work is because of you. Also to my sisters Grainne and Olive and brother John, thank you for your interest in this project and support from afar. Thank you to all my friends for their constant support.

To my wife Shannon, son Finn and daughter Eden, this work is dedicated to you. This project could not have been done without you Shannon. Your support, understanding and feedback when I needed it was immeasurable. I love you all and now we can get on with life post PhD. Thank you, this work is for you.

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ABSTRACT

Australian Football is a field sport encompassing physical and technical skill elements. The physical and activity profiles of elite and sub-elite players have been described previously, however few studies have investigated elite-junior players. This thesis applies five study designs to profile the anthropometric, physical, activity and technical profiles across three competition tiers. *Study One* profiles and compares characteristics of elite-junior and professional players, finding progressive differences across the tiers. *Study Two* describes and compares the match-play activity profiles of elite-junior, sub-elite and elite players, finding an increase in match-play intensity across the tiers. *Study Three* describes and compares the characteristics of selected and non-selected elite-junior players, and suggests that sub-elite competitions provide a viable match-play pathway to develop elite-junior players. *Study Four* describes the characteristics of first-year players during the pre-season period, demonstrating increases to strength and power during an initial development period. *Study Five* examines the positive influence of a 12-week resistance training intervention on the strength and power characteristics of elite-junior players, compared to undertaking skills training alone. Together, these findings can influence and direct the training and match-play practices of elite-junior athletes, with the aim of optimally preparing and transitioning players to elite competition tiers.

KEYWORDS

Activity profiles

Athlete development pathway

Anthropometric profile

Australian football

Elite athlete

Elite-junior athlete

Energy cost

Global positioning systems

High speed running

Lower body strength and power

Muscular strength,

Neuromuscular power

Physical profiling

Pre-season

Selected junior players

Sub-elite athlete

Upper-body strength and power

LIST OF ABBREVIATIONS

AFL – Australian Football League

GPS – Global positioning systems

HR_{max} – Maximum heart rate

HSR – High-speed running

Hz – Hertz

Kilometer – km

kg – kilogram

$km \cdot h^{-1}$ – kilometers per hour

$kJ \cdot kg^{-1}$ – kilojoules per kilogram

kJ – kilojoule

Meter – m

$m \cdot min^{-1}$ – metre per minute

$m \cdot s^{-2}$ – metre per second squared (acceleration)

NEAFL – North East National Football League

$n \cdot min^{-1}$ – efforts per minute

RAE – Relative age effect

RPE – Rating of perceived exertion

VO_2max – Maximum oxygen consumption

TDE – Talent development

TID –Talent identification

TMA – Time motion analysis

VFL – Victorian football league

WAFL – Western Australian football league

$W \cdot kg^{-1} \cdot min^{-1}$ – watts per kilogram per minute

Yo-Yo IR test – Yo-Yo intermittent recover test

$\% \cdot min^{-1}$ – percentage of time spent per minute

CHAPTER ONE

INTRODUCTION

1.1 RESEARCH BACKGROUND

Australian football is a field sport comprising 18 players on the field and is characterised by a number of playing positions, including full-forward/back, centre-half forward/back, forward/back pocket and midfielders (wingers, ruckmen, ruck rover and rovers). The game involves four quarters with the total duration of match-play lasting approximately 118 - 126 minutes (Gray & Jenkins, 2010). The demands of Australian football are varied, involving high-intensity intermittent running and collision activities such as tackling, bumping and fending opponents. As a consequence, the physical profile of Australian football athletes has continually evolved to meet these demands. Applied research regarding the profiling of Australian Footballers has aimed to assess physical, technical and tactical characteristics. This has been performed using various parameters, including anthropometric and physical characteristics, team selection, career success and match-play performance. However, an in-depth analysis of physical or match-play activity profile differences between junior and professional Australian Footballers has not been conducted.

Currently, junior Australian footballers develop physical and technical skill acumen through school, clubs or Academy systems. Unlike European soccer Academies, elite-junior development pathways in Australian football are not directly connected to professional clubs, therefore the quality of coaching within these pathways is crucial for player development. As elite-junior Australian footballers progress towards their draft year, professional teams are afforded opportunities to profile the physical, technical and tactical characteristics of prospective recruits. Anthropometric and physical profiling is undertaken through the National draft combine, while match-play activity profiling is undertaken through the National under-18 competitions (Burgess, Naughton, & Hopkins, 2012). The National draft combine is an annual four-day event where recruiters and talent scouts objectively assess the physical, psychological, medical and skill characteristics of potential draftees (Burgess, Naughton, & Hopkins, 2012). The objective information garnered during this period is assessed with subjective measures of technical skill and tactical intellect during match-play. More recently, recruiters have been provided access to activity profile metrics measured through Global Positioning Systems (GPS) and accelerometers. This data, combined with subjective feedback from recruiters, provides professional teams with evidence to make informed decisions on future recruits.

By understanding the disparities between elite-junior and professional athletes, a defined pathway for optimal athlete development can be formed. While profiling can inform coaches on the characteristics of their athletes and determine strengths and weakness (Sporis, Jukic, Ostojic, & Milanovic, 2009), the ultimate goal is to develop athletes in an individual or team context (Impellizzeri & Marcora, 2009). Soccer Academies are one such model created to provide a structured pathway to develop and ultimately transition players to the professional competition tiers (Carling et al., 2009; le Gall et al., 2010). While this system provides a conduit to develop elite-junior players, a number of factors including injury (Emery, 2010; Pfirrmann et al., 2016), biological maturation (Lovell et al., 2016; Towlson et al., 2017), technical ability (Gouvea et al., 2016; Joo & Seo, 2016), anthropometric and physical characteristics (Canhadas et al., 2010; Carling, Le Gall, & Malina, 2012) and motor competency (Deprez et al., 2015; Rommers et al., 2018) can influence individual player outcomes. Indeed research across a broad range of sports demonstrated the influence of anthropometric and physical characteristics on player selection (Gabbett et al., 2009; Gabbett, 2009; Gravina et al., 2008; Till et al., 2011), playing position (Duncan et al., 2006; e Silva et al., 2010; Gabbett, 2005; Schwesig et al., 2017) and retention within development programs (Figueiredo et al., 2009a). While anthropometric and physical characteristics can profoundly influence outcome success (Figueiredo et al., 2010), these factors likely diminish with increasing biological maturation (Fransen et al., 2017; Malina et al., 2015). Therefore, the challenge for coaches is retaining players longitudinally within development programs. However, appropriate training programs to support this retention have not been researched in detail within Australian football.

Profiling the anthropometric and physical characteristics of elite-junior and professional Australian football athletes has been considered and in doing so has established a number of important outcomes for player development. Specifically, professional Australian footballers have been profiled in relation to indicators of match performance (Gastin et al., 2013; Mooney et al., 2011), team selection (Pyne, Gardner, Sheehan, & Hopkins, 2006; Young et al., 2005) and career progression (Pyne, Gardner, Sheehan, & Hopkins, 2005). Additionally, some comparative investigations have been undertaken between player groups from elite-junior to professional cohorts (Bilsborough et al., 2015; Veale, Pearce, Buttifant, & Carlson, 2010; Woods, McKeown, Haff, & Robertson, 2016). Importantly, it appears from the literature that anthropometric and physical characteristics can distinguish elite Australian footballers from their sub-elite and elite-junior counterparts. Key characteristics including body mass, muscular strength, neuromuscular power and the ability to undertake high-intensity running seem to be exhibited by chronologically older and higher performing Australian footballers (Bilsborough et al., 2015; Caia, Doyle, & Benson, 2013; Hrysomallis & Buttifant, 2012; Veale et al., 2010). While relatively young athletes within Australian football teams will develop these characteristics over time, an understanding of the differences to elite performers and knowledge of the benchmarked targets will likely expedite this process.

Similar to professional Australian footballers, the anthropometric and physical characteristics of elite-junior Australian footballers have been investigated, with important findings for player development reported. In this context, anthropometric and physical characteristics have been assessed within and between chronological age groups (Bilsborough et al., 2015; Cripps, Hopper, & Joyce, 2016; Veale et al., 2010; Woods, Cripps, Hopper, & Joyce, 2017; Woods, McKeown, et al., 2016; Woods, Raynor, Bruce, & McDonald, 2016), selection and draft outcomes (Burgess, Naughton, & Hopkins, 2012; Keogh, 1999; Robertson, Back, & Bartlett, 2016; Woods et al., 2015; Woods, Veale, Collier, & Robertson, 2017), performance during match-play (Gastin & Bennett, 2014; Gastin, Bennett, & Cook, 2013) and the relationship to injury (Chalmers et al., 2013; Lathlean, Finch, Gastin, & Newstead, 2017). Similar to other field sports, a positive relationship has been reported between stature, body mass, muscular strength, neuromuscular power and team selection within elite-junior Australian football (Keogh, 1999; Pyne et al., 2006; Robertson, Woods, & Gastin, 2015; Woods, et al., 2015). Conversely, investigations of match-play performance and career success reported a strong relationship to intermittent high-speed running and sprint performance (Gastin, Bennett, et al., 2013; Woods et al., 2017). Interestingly, from a draft perspective match-play activity profiles provided a stronger indication of future games played compared to physical testing performance at the National Draft Combine. Rather than considering anthropometric and physical characteristics in isolation, it seems beneficial to examine all facets of player development including technical and tactical skills. This may include the assessment of cognitive based skills such as decision making, anticipation and reading opponent cues (Williams et al., 2000). Since the decisions made by players during match-play directly influence match running and other physical attributes such as acceleration or change of direction movements, these are important components to consider when assessing player performance. Interestingly, players rated as higher skilled by coaches undertook less physical activity during match-play (Johnston et al., 2012; Sullivan et al., 2014), highlighting that numerous performance factors must be considered. It is likely that no single element predicts success, as such contemporary evidence is required to understand how each of these elements can be developed to achieve optimal transition to a professional teams.

Profiling athletes during match-play has evolved from traditional time motion analysis (TMA) methods to GPS and accelerometer microtechnology, providing greater quantities of data to analyse. TMA developed from manual hand-notation systems, whereby the researcher was extensively involved in the collection and transfer of activity profiles to be analysed on computerised video-based systems. With the introduction of video camera technology, the collection of match-play activity profiles and technical events was enhanced. This increased the ease of data collection for skill activities such as kicks and handballs or the analysis of more in-depth phases of match-play (Appleby & Dawson, 2002; Mooney et al., 2011; Rennie et al., 2018; Sullivan et al., 2014). However, a limitation of TMA systems has always been the laborious and time-consuming nature of collecting, processing and analysing the activity profile data and the reliance on an individual operator's experience and accuracy when recording and analysing data (Barris & Button, 2008; Petersen, Pyne, Portus, & Dawson, 2009).

The introduction of modern GPS microtechnology has allowed further ease of collection, analysis, and interpretation of the data (Dobson & Keogh, 2007). The advent of this microtechnology reduced the need for time restrictive collection and analysis methods (Di Salvo et al., 2009; Rampinini et al., 2007). GPS technology allows the determination of the distance traveled by calculating the change in position of the device (Larsson, 2003) and the velocity at which the device is traveling (Schutz & Herren, 2000). The accuracy of this microtechnology has consistently improved, with manufacturers initially developing 1 Hz and 5 Hz sampling devices, however, sampling rates of 10 Hz or 15 Hz are now common. As with TMA systems, research provided an estimate of the validity and reliability of these devices (Barbero-Álvarez et al., 2010; Coutts & Duffield, 2010; Jennings et al., 2010; Johnston et al., 2014; Johnston et al., 2012; Johnston et al., 2013), with notable reductions in accuracy when recording higher velocity or change of direction movements (Coutts & Duffield, 2010; Johnston, Watsford, Kelly, et al., 2014; Johnston et al., 2012). However, the introduction of microtechnology has enabled multiple athletes to be monitored at the same time and the subsequent analysis of activity profile data to be expedited.

GPS and accelerometer microtechnology is now commonly used to track the match-play activity profiles of field sports including soccer (Ehrmann et al., 2016; Fiorenza, Iaia, Alberti, & Fanchini, 2015; Mallo, Mena, Nevado, & Paredes, 2015; Rago et al., 2018; Rossi et al., 2017), Gaelic football (Malone, Solan, Collins, & Doran, 2017; Malone, Solan, Collins, & Doran, 2016; McGahan et al., 2018; J. H. McGahan et al., 2018; McIntyre & Hall, 2005; Reilly, Akubat, Lyons, & Collins, 2015; Shovlin, Roe, Malone, & Collins, 2018), rugby union (Cunniffe, Proctor, Baker, & Davies, 2009; Cunningham et al., 2018; McLaren et al., 2016; D. Read et al., 2017; Read et al., 2017; Read et al., 2018; Tee, Lambert, & Coopoo, 2017), rugby league (Austin & Kelly, 2014; Gabbett, 2015; Gabbett & Gahan, 2016; Gabbett, Jenkins, & Abernethy, 2012; Hausler, Halaki, & Orr, 2016; Kempton, Sirotic, Rampinini, & Coutts, 2015; McLellan, Lovell, & Gass, 2011; Waldron et al., 2011), field hockey (Casamichana, Morencos, Romero-Moraleda, & Gabbett, 2018; Chesher et al., 2018; Gabbett, 2010; Jennings, Cormack, Coutts, & Aughey, 2012; MacLeod, Morris, Nevill, & Sunderland, 2009; Macutkiewicz &

Sunderland, 2011) and American football (Wellman, Coad, Goulet, & McLellan, 2016, 2017). More recently, with the development of accelerometry technology within GPS devices the analysis of indoor sports such as basketball has been enabled (Montgomery & Maloney, 2018; Puente et al., 2017). Regarding Australian football, three levels of match-play including elite (Aughey, 2010, 2011b; Black, Gabbett, Naughton, & McLean, 2016; Coutts et al., 2010; Delaney et al., 2017; Gastin, Fahrner, et al., 2013; Gastin, Mclean, Breed, & Spittle, 2014; Gronow et al., 2014; Hiscock, Dawson, Heasman, & Peeling, 2012; Johnston et al., 2015c; Johnston, et al., 2016; Johnston et al., 2012; Kempton et al., 2015; Mooney et al., 2011; Rennie et al., 2018; Ryan, Coutts, Hocking, & Kempton, 2017; Sullivan et al., 2014), sub-elite (Aughey, 2013; Brewer et al., 2010; Johnston et al., 2015c; Stein, Gabbett, Townshend, & Dawson, 2015) and junior (Gastin, Bennett, et al., 2013; Henderson, Cook, Kidgell, & Gastin, 2015; Woods, Joyce, & Robertson, 2016; Woods et al., 2017) have been investigated using this microtechnology. To date, the majority of comparative match-play analysis has focused on elite versus sub-elite competition tiers (Aughey, 2013; Brewer et al., 2010; Johnston et al., 2015c).

Notably, this research has clearly identified differences in match-play intensities between these competition tiers. This information has enabled coaches to condition and advance players from sub-elite to elite level teams, which can be regularly required due to injury or player form. With an understanding of the differences between these competition tiers, coaches have been made aware of information to design and apply training prescription to ensure players are prepared for the demands of the elite competitions. However, with limited data comparing elite-junior Australian footballers to senior competition tiers, contemporary research is required to inform coaches on the differences between the three tiers of Australian football match-play with a view to enhancing and optimising development pathways.

Currently, there is a paucity of research regarding athlete profiling in an Australian football context, specifically investigations comparing elite-junior and professional (elite or sub-elite) players. Although the selection of elite-junior talent within sports is not a purely objective or precise procedure, knowledge of the capabilities of successful athletes is a useful tool to guide development and coaching practices (Reilly, Williams, Nevill, & Franks, 2000; Tomas, Karim, Carlo, & Ulrik, 2005; Williams & Reilly, 2000). Therefore, comprehensive athlete profiling research is required, assessing physical capacity and match-running demands across a broad spectrum of ages and competition tiers within Australian football. Such research will assist with the identification of performance indicators and key physical capacity measures that relate to match-play, with the aim of improving athlete development strategies. By identifying gaps in anthropometric, physical or activity profiles between athletes of varying ages, benchmark data can be determined for elite-junior athletes. Accordingly, this sequence of research studies provides a comprehensive overview of anthropometric, physical and match-play activity profiles from a cohort of elite-junior and professional Australian footballers.

1.2 STATEMENT OF THE PROBLEM

While a number of Australian football investigations have described the anthropometric, physical and activity profiles of elite-junior players, minimal contemporary research has compared between competition tiers (Bilsborough et al., 2015; Burgess, Naughton, & Norton, 2012; Veale et al., 2010; Woods, McKeown, et al., 2016). The available research has provided a broad understanding of the relationships between anthropometric and physical characteristics with draft outcomes (Burgess, Naughton, & Hopkins, 2012; Robertson et al., 2015; Woods, Joyce, et al., 2016; Woods et al., 2017), team selection (Pyne et al., 2006; Woods et al., 2015; Young & Pryor, 2007), physical performance during tests or match-play (Gastin & Bennett, 2014; Gastin, Bennett, et al., 2013; Mooney et al., 2011; Woods et al., 2017) and career success (Pyne et al., 2005). However, there is an absence of contemporary research assessing the differences in anthropometric and physical characteristics between elite-junior and professional Australian footballers. Notably, there is limited evidence regarding the development of physical characteristics that likely aid with the transition of elite-junior players to professional teams. Limited research has considered the match-play activity profiles of elite-junior Australian footballers (Burgess, Naughton, & Norton, 2012; Gastin, Bennett, et al., 2013; Henderson et al., 2015; Veale & Pearce, 2009) and importantly, no investigations have directly reported differences in the match running demands between elite-junior, sub-elite and elite competition tiers. Contemporary research on this topic can provide a detailed insight into the physical characteristics that are indicative of professional Australian footballers and assist with the generation of training programs and monitoring systems to optimise the development pathway for elite-junior athletes.

1.3 RESEARCH OBJECTIVES

Five studies were designed to investigate the anthropometric, physical and match-play activity profiles of elite-junior and professional Australian footballers and substantially contribute to research regarding junior player development. Figure 1.1 provides the theoretical framework adopted for comprehensively profiling elite-junior Australian footballers. The first objective (S*tudy One*) determined whether anthropometric and physical differences existed across a broad chronological age group of Australian footballers, from elite-junior to professional. The second objective (S*tudy Two*) compared and described match-play activity profile differences between elite-junior, sub-elite and elite Australian footballers. The third objective (*Study Three*) was twofold; firstly to describe the anthropometric and physical characteristics of selected and non-selected elite-junior Academy Australian footballers. Secondly, the study compared and described the match-play activity profiles between the selected Academy players and professional Australian footballers competing in the same matches of a National sub-elite competition. The fourth objective (*Study Four*) aimed to determine the anthropometric and physical characteristic changes of first-year Australian footballers during their initial pre-season period at a professional club. Finally, the last objective (*Study Five*), aimed to determine whether a 12-week resistance training intervention could improve a component of training in elite-junior Australian footballers that were identified in *Study One* as being lower than the older, professional players. Specifically, the training focused on improving the muscular strength and neuromuscular power characteristics of elite-junior Australian footballers. An overview of each study is provided below.

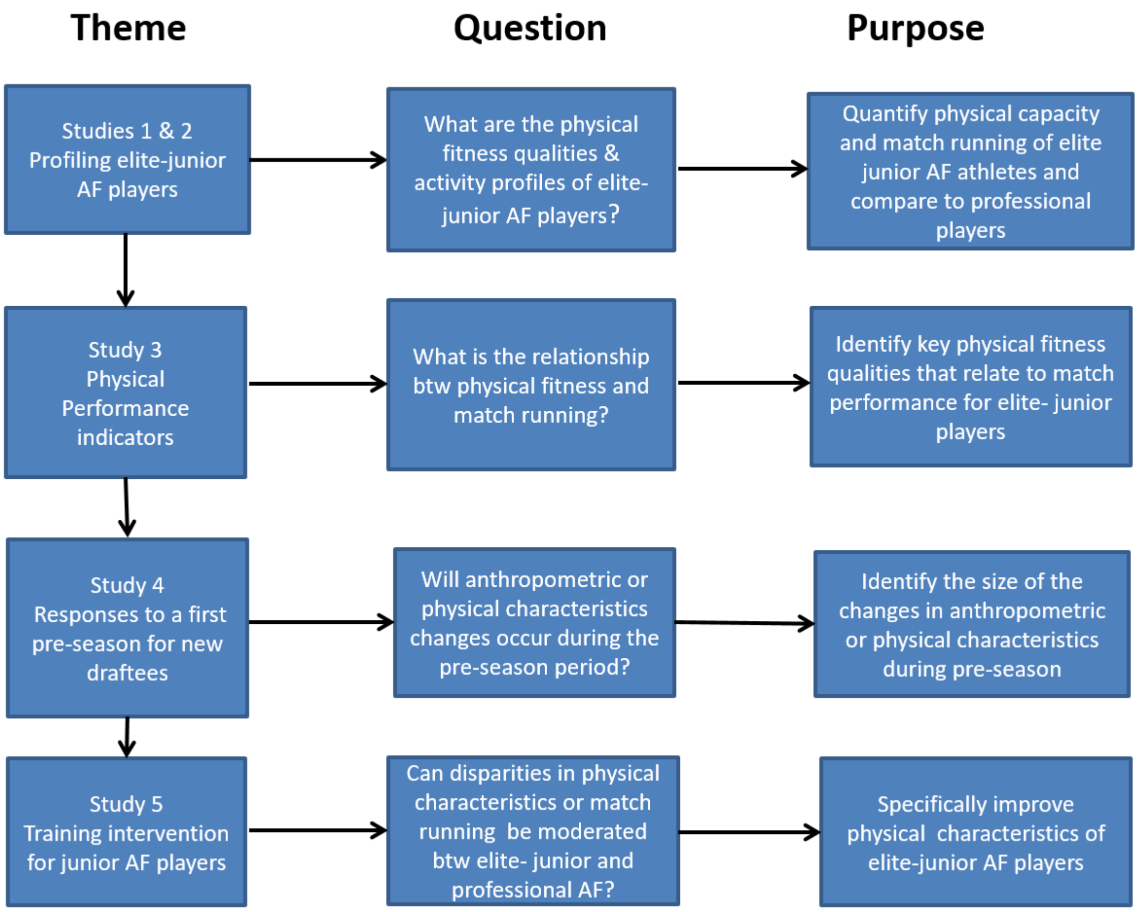

Figure 1.1: Objectives of this research provided by a theoretical framework of athlete profiling. AF, Australian Football.

STUDY 1. DIFFERENCES IN PHYSICAL CAPACITY BETWEEN JUNIOR AND SENIOR AUSTRALIAN FOOTBALLERS

Aim

To assess the anthropometric and physical profile between 5 groups of Australian footballers of varying chronological ages and playing experience, in order to identify differences in anthropometric or physical characteristics.

Significance

While many studies have identified the anthropometric and physical characteristics of elite-junior Australian footballers, few investigations have been undertaken to compare this cohort with professional players. This investigation enabled a greater understanding of anthropometric and physical characteristics differences across a broad group of Australian footballers of varying chronological ages and playing experience and established key areas of development for elite junior Australian footballers.

STUDY 2. MATCH-PLAY ACTIVITY PROFILES AND ENERGY COST OF ELITE-JUNIOR, SUB-ELITE AND ELITE SENIOR AUSTRALIAN FOOTBALLERS

Aim

To identify differences in the activity profiles of elite-junior, sub-elite and elite Australian football players during match-play. This was undertaken using GPS and accelerometer microtechnology, recording a number of activity profile and metabolic power metrics.

Significance

While the match-play activity profiles of elite-junior, sub-elite and elite match-play have been described, no investigation has directly compared between the three competition tiers. This investigation provides an understanding of the differences in physical competencies and energy demands in match-play across three competition tiers. Specifically, these findings assist to provide coaches with an understanding of optimal match-play pathways to develop elite junior Australian footballers.

STUDY 3. ACTIVITY PROFILE DIFFERENCES BETWEEN ELITE-JUNIOR AND PROFESSIONAL AUSTRALIAN FOOTBALLERS DURING SUB-ELITE MATCH-PLAY

Aim

To examine the anthropometric and physical characteristics of elite-junior Australian footballers who were either selected or not selected to play with professional players during match-play. Secondly, to compare the activity profiles of the selected elite-junior cohort and that of professional players during the same matches of a National sub-elite competition.

Significance

While a number of investigations have described the anthropometric and physical characteristics that are indicative of selection outcomes for elite-junior Australian footballers, no study has directly compared the activity profiles of a selected cohort with that of professional players playing in the same series of matches. This study adds to the body of research regarding the physical characteristics of selected elite-junior Australian footballers while examining the prospect of elite-junior Australian footballers competing in senior match-play tiers prior to being drafted.

STUDY 4. CHANGES IN THE PHYSICAL PROFILE OF FIRST YEAR AUSTRALIAN FOOTBALL PLAYERS DURING PRESEASON TRAINING

Aim

To examine the transition of elite-junior Australian football athletes to a professional Australian football team, by identifying changes within their anthropometric and physical characteristics during a pre-season training period.

Significance

No study has specifically examined the anthropometric and physical development of first-year players during the pre-season period. This cohort is at particular risk of injury and performance decrements due to the increased training volumes from junior to professional competitions. The findings provide coaches with an understanding of the responses of first-year players to pre-season training in a professional Australian football team.

STUDY 5. EFFECTS OF A 12-WEEK RESISTANCE TRAINING PROGRAM ON THE STRENGTH AND POWER CHARACTERISTICS OF ELITE JUNIOR AUSTRALIAN FOOTBALL PLAYERS

Aim

To implement a specific training intervention established from findings within Studies One to Three. This study aimed to develop specific anthropometric or physical characteristics identified within these investigations, notably, lower muscle strength and neuromuscular power.

Significance

While a number of field sport training programs have been implemented in soccer and Australian football, no investigations have assessed the effectiveness of resistance training programs with a cohort of elite-junior Australian footballers. As substantial strength and power differences have been identified between elite-junior and professional players within Australian football and other field sports, this investigation assists coaches with resistance training programming and prescription with elite-junior athletes in an attempt to optimise outcomes and elite-junior athlete resilience along with readiness to perform in professional competitions.

1.4 RESEARCH HYPOTHESES

The following hypotheses were proposed for this research:

1. A number of anthropometric and physical characteristics, including body mass, stature, strength, power, aerobic and anaerobic capacity will significantly distinguish elite-junior from professional Australian footballers. Specifically, elite-junior athletes will present lower absolute and relative strength and power scores for each of the tested variables.
2. A number of key activity profile, metabolic power and technical metrics will distinguish elite junior from sub-elite and elite Australian footballers during match-play, with elite junior athletes presenting lower activity profiles metrics to

sub-elite and elite players.

3. Elite-junior Australian footballers selected to compete in a sub-elite senior competition will exhibit superior anthropometric and physical characteristics compared to the non-selected cohort. Thereafter, professional Australian footballers competing in a sub-elite competition will exhibit greater absolute and relative activity profile metrics than the selected elite-junior player cohort.
4. Draftees undertaking their first pre-season training period within their first year at a professional Australian football club will significantly change their anthropometric and physical profile, with increased body mass, running capacity, strength and power.
5. The addition of a strength and power training program for elite-junior Australian footballers, established from the findings from Studies One to Three, will provide superior outcomes compared to a control group who undertake skills only training.

1.5 Limitations of the Research

The following limitations were present for this research:

1. Assessment times were generally dictated by the team's training schedule during the course of the pre-season training.
2. The sample size was affected by player injury rates and specific instructions from team management regarding player selection for each match.
3. Although testing was undertaken at the same indoor and outdoor facilities for the elite-junior and professional players, testing times varied between participant groups. The differences in testing times yielded minor changes in environmental conditions, principally during outdoor field testing.

4. Some physical testing results were recorded during the pre-season period, therefore results may have been biased by the activity levels of individual athletes during the off-season period.
5. While recommendations were provided to participants regarding nutritional intake prior to the assessments, it was not possible to control the actual macronutrient intake of each participant prior to either the testing or training sessions or matches.
6. Due to fluctuations in player selection due to coach's decisions, player form and injury status, some pseudo-replication with the *Study Three* data were encountered.
7. Although variation in weekly training load was apparent for *Study Four*, data were collected from three consecutive pre-season periods to capture a sufficient sample size of first year players.
8. Due to the industry-based, applied nature of *Study Four* and the use of a professional Australian football player cohort, it was not possible to utilise a control group.
9. Although the groups were age-matched within *Study Five*, ultimate control over group selection was made by coaching staff and therefore the research team were unable to randomise group selection due to player availability to complete the training program and injury status.

1.6 Delimitations of the Research

The following delimitations were present for this research:

1. The sample size was delimited to a single Australian football club, encompassing Academy-level players and the entire roster of a professional Australian football team.

2. *Study One* divided the elite-junior participants into two groups based on age and training experience. Accordingly, the professional playing group was divided into three groups based on the number of years since drafted to a professional Australian football team.
3. Activity profile, metabolic power and technical skill metrics within *Studies Two* and *Three* were selected due to their known reliability and validity.
4. The use of controlled strength testing in *Studies One, Three* and *Five*, using 3-5 repetition maximum loads with elite-junior players for lower body tests, in order to reduce the injury risk.
5. The use of field-based running time trials for assessment of aerobic capacity for *Studies One, Three* and *Four*.
6. Although not commonly undertaken with younger athletes, the Yo-Yo intermittent recovery test (level 2) was performed during *Studies One, Three*, and *Four* due to the established relationship to Australian football match-play running.
7. Physical capacity measures assessed during *Study Four* were selected due to their prescription within the testing period of the professional Australian football team
8. Exercise selection and the training program design for *Study Five* were based on the assessment of these exercise during the testing period and prior application within resistance training investigations.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The physical profile of athletes has been reported in a number of field based sports including soccer (Boone et al., 2012; Canhadas et al., 2010; Deprez et al., 2015; Sporis et al., 2009), Gaelic football (Cullen et al., 2013; Cullen et al., 2017; McIntyre & Hall, 2005; Shovlin et al., 2018), rugby league (Darrall-Jones, Jones, & Till, 2015; Gabbett, 2006a; Till et al., 2014), rugby union (Argus, Gill, & Keogh, 2012; Argus et al., 2009), American football (Pryor et al., 2014; Sierer et al., 2008) and Australian football (Bilsborough et al., 2015; Caia et al., 2013; Gastin, Fahrner, et al., 2013; Hrysomallis & Buttifant, 2012; McGuigan, Cormack, & Newton, 2009; Mooney et al., 2011; Veale et al., 2010; Young et al., 2005). Within Australian football the physical profile of junior athletes has been investigated in the context of draft outcome (Woods, Joyce, et al., 2016; Woods et al., 2017), team selection (Woods et al., 2015; Young & Pryor, 2007), career success (Burgess, Naughton, & Hopkins, 2012; Pyne et al., 2005) and injury risk (Chalmers et al., 2013). While research has investigated differences in the physical characteristics of junior and elite level athletes (Bilsborough et al., 2015; Woods, McKeown, et al., 2016), very few studies have included the typical transition stage, that of sub-elite level athletes. The inclusion of this conduit stage of development is required to provide a comprehensive examination of the Australian football pathway from elite-youth through to the elite players.

With the advent of GPS and microtechnology sensors, the activity profiles of elite match-play of Gaelic football (Malone et al., 2017; Malone et al., 2016), rugby league (Austin & Kelly, 2014; McLellan et al., 2011) and rugby union (Coughlan et al., 2011; Cunniffe et al., 2009) have been investigated. Within an Australian football context, match-play activity profiles have been extensively investigated for elite match-play. Although some investigations have quantified sub-elite match-play, minimal research has described the activity profile metrics of elite-junior match-play. While investigations within Australian football suggests a substantial gap between elite and elite-junior match-play (Burgess, Naughton, & Norton, 2012), contemporary data is required to assess current match-play trends between competition tiers following recent rule changes and the general evolution of professional match-play. Furthermore, differences between the sub-elite competition tier and elite-junior match-play have yet to be specifically quantified. Therefore, a greater understanding of the various competition tiers in Australian football is required to aid training practices within the junior development pathway and ultimately assist the transition of Australian footballers to professional teams.

This literature review will inform on the current practices regarding physical profiling and match-play activity profiling of youth and adult sporting populations, with a particular focus on Australian football. The review will demonstrate that the current research has profiled physical and match performance characteristics in relation to individual adult athlete cohorts. Therefore, it appears that a wider breadth of research is required to assess youth athletes with reference to a criterion measure of a professional Australian football athlete. The initial component of this review considers research investigating the growth and maturation of elite-junior athletes and talent identification in junior sports. Following this, an overview of the research investigating the physical profiling of team sport athletes will be presented. The various components of anthropometric, physical and match performance profiling are discussed, while the final section of the review will outline research investigating training programs in team sport athletes and the outcomes on changes in physical characteristics from these programs.

Articles included in this literature reviewed were acquired through a number of online search databases including PubMed, SPORTDiscus and Google Scholar. The reference lists of relevant publications were also examined. The following keywords were used in different combinations:, ‘Australian football’, ‘physical profiling’, ‘youth athletes’, ‘elite athletes’, ‘sub-elite athletes’, ‘movement demands’ ‘global positioning systems’, ‘performance measures in field sports’ and ‘training programs for team sport’. Other studies that included physical profiling of athletes in alternate team sports were considered, due to the limited investigations comparing youth and adult athletes from the same cohort. The focus on sports-related to Australian football aided with limiting the number of articles retrieved, although there was no limit to the search period.

2.2 Overview of Australian Football Match-Play

Australian football is an intermittent running and collision sport that resembles a combination of soccer, rugby league, rugby union and basketball (Gray & Jenkins, 2010). In addition to the intermittent running requirements, players frequently execute various technical skills such as kicking and passing the ball, along with tackling, fending opposition players or competing for possession of the football (Coutts et al., 2010; Dawson et al., 2004b; Gray & Jenkins, 2010). The physical demands of the sport require players to cover distances from 11000 to 13500 meters at intensities ranging from 110 to 130$m \cdot min^{-1}$ (Coutts et al., 2010; Johnston et al., 2015c). Additionally players can cover 1300 to 4300 meters of high-speed running at intensities ranging from 27 to 29 $m \cdot min^{-1}$ (Brewer et al., 2010; Johnston et al., 2015c). Regarding technical skills metrics, elite junior and senior players reportedly average 0.33 to 0.42 skill involvements per minute (Burgess et al., 2012. Further, players can average 3.4 marking (Hiscox et al., 2012) and 3.9 tackle contests (Gastin et al., 2013) during match-play. The physical demands of the sport require players to possess a highly developed aerobic energy system (Gray & Jenkins, 2010; Norton, Craig, & Olds, 1999), with estimated maximum oxygen consumption (VO_2max) scores of 61 ± 3.3 to 63 ± 4.8 $ml \cdot kg^{-1} \cdot min^{-1}$ reported within the literature (Aughey, 2013; Young et al., 2005). Team selection is based on a team of 22 players, with 18 players permitted on the field at any one time, while the remaining players are positioned on an interchange bench (Ebert, 2000).

A representation of the dimensions of a match-play oval and the various playing positions within Australian football can be viewed within Figure 2.1. Australian football comprises three main positional groups: fixed forwards, fixed defenders and nomadic players (Wisbey, Montgomery, Pyne, & Rattray, 2010). The aim of fixed forwards is to kick goals from free play or from a catch/mark possession, while fixed defenders aim is to prevent the opposition scoring. Midfield or nomadic players are generally involved in greater portions of match-play by winning possession during free-play or stoppages and moving the football forward to the attacking end (Coutts et al., 2015). Interchange players are rotated with the on-field players throughout match-play, therefore participants are required to undertake variable work to rest bouts (Gray & Jenkins, 2010). Match duration is comprised of four 20 minute quarters and time added on, therefore quarters typically last 25 to 30 minutes, for total game time of approximately 120 minutes (Coutts et al., 2010). Within this time-frame, Australian footballers are required to exhibit highly developed physical and technical skill characteristics, alongside tactical intelligence. The competition tiers within Australian football are comprised of three main levels, including elite-junior, sub-elite and elite. The elite-junior competition contains teams or players from each state and territory and involves a two-tier standard. The sub-elite competitions are generally state-based, however, teams within the North East National Football League (NEAFL) are required to play interstate and territory matches. Finally, the elite competition is the Australian Football League (AFL) and is regarded as the premier match-play tier.

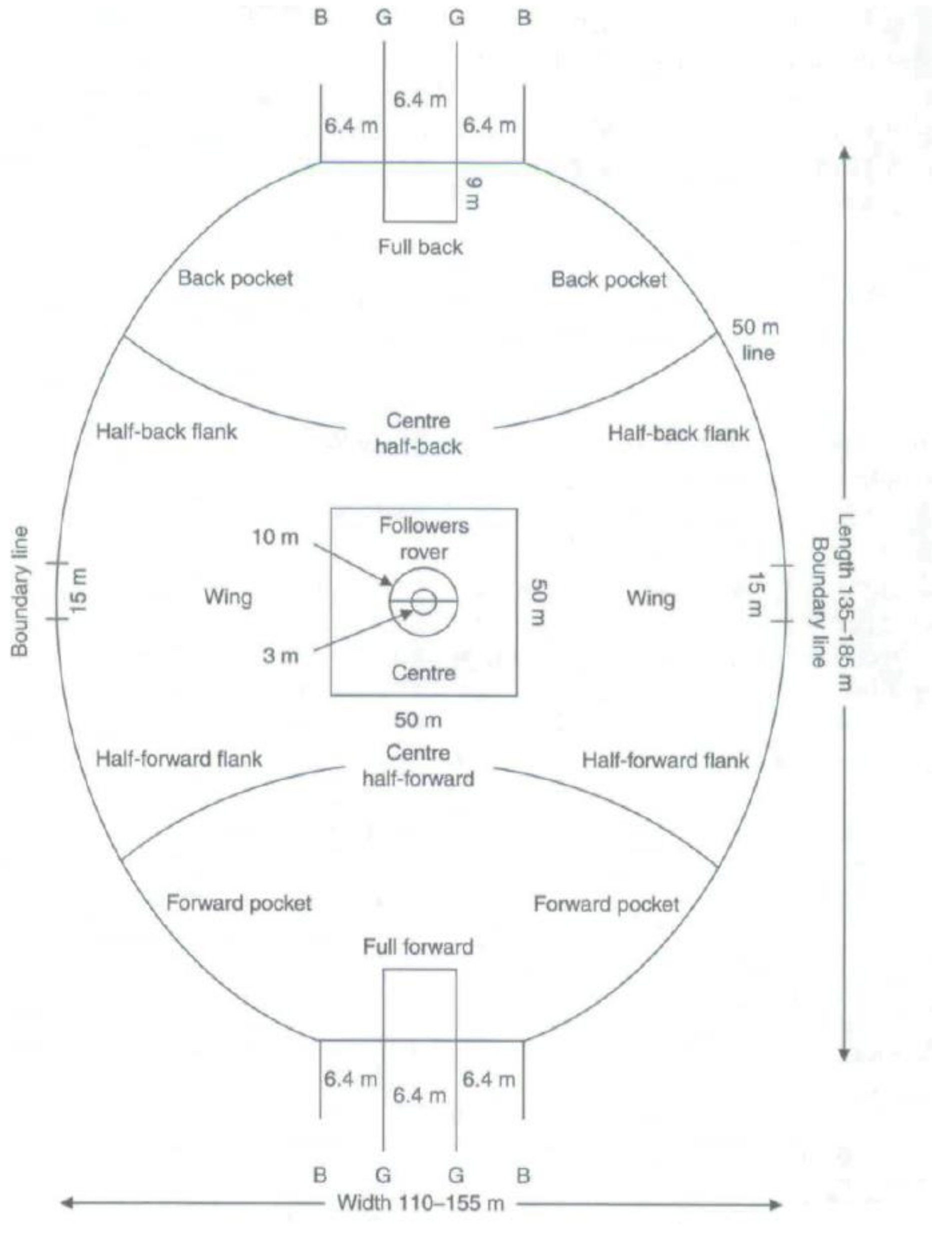

Figure 2.1: Playing positions and field dimensions within Australian football (Gray & Jenkins 2010). B: Behind post (1 point awarded); G: Goal post (6 points awarded).

Recording methods to measure activity profiles within Australian football were initially centred around TMA, using manual hand notation techniques of tracking individual player movements using video recording (Appleby & Dawson, 2002; Dawson et al., 2004b). To record player movements, a calibrated console representing the playing field or an event recorder, coded activities based on a set of operational definitions (Dogramaci, Watsford, & Murphy, 2011; King, Jenkins, & Gabbett, 2009). While video-based movement tracking has traditionally been popular within soccer (Ade, Harley, & Bradley, 2014; Burgess, Naughton, & Norton, 2006; Carling, Bloomfield, Nelsen, & Reilly, 2008; Carling, Bradley, McCall, & Dupont, 2016; Folgado, Duarte, Fernandes, & Sampaio, 2014), largely due to the inability to use GPS devices during match-play, the current research techniques within Australian football have utilised GPS satellite technology (Aughey, 2010, 2011a, 2011b, 2013; Brewer et al., 2010; Coutts et al., 2015; Coutts et al., 2010; Gronow et al., 2014; Johnston et al., 2015c; Johnston et al., 2016; Johnston et al., 2012; Kempton et al., 2015; Rennie et al., 2018; Sullivan et al., 2014). Importantly, this method can quantify activity profiles of athletes during training or match-play, with increasing usage across competition tiers of Australian football. With the integration of GPS and tri-axial accelerometers, distance, velocity, Playerload^{TM}, acceleration, deceleration and metabolic power metrics can be captured for training and match-play (Johnston et al., 2015c; Kempton et al., 2015). Preliminary investigations using these metrics indicated mixed reliability and validity outcomes. PlayerLoad^{TM}, while derived from accelerometer and GPS measures, appears to be a valid generic workload measure (Johnston et al., 2012). Conversely, the recording of acceleration and deceleration metrics appears less accurate and may result from the current technology's ability to record shorter time-frame movements (Johnston et al., 2015a). As a consequence metabolic power, an energy cost measure derived from acceleration and deceleration metrics may underestimate normal locomotor activity during field sports (Buchheit et al., 2015). Initial data collection within sports was provided by 1 Hz and 5 Hz recording devices, however these devices were superseded by 10 Hz and 15 Hz devices, which now provide the standard for GPS data collection (Coutts & Duffield, 2010; Jennings et al., 2010;

Johnston, Watsford, Kelly, et al., 2014; Johnston et al., 2012; Johnston et al., 2013). This has enabled coaches to ascertain detailed performance profiles and better understand player movements, enabling the design and implementation of specific training programs in an attempt to optimise performance outputs.

Despite the benefits of GPS devices over alternate time-motion analysis systems, there are a number of limitations with this method of data collection. Initial research using 1 Hz and 5 Hz GPS devices presented validity and reliability issues capturing movements at high-speed, over short distances and involving changes of direction (Coutts & Duffield, 2010; Johnston et al., 2012; Johnston et al., 2013; Portas, Harley, Barnes, & Rush, 2010). This was particularly prevalent with 1 Hz GPS, with this microtechnology unable to accurately detect changes in running distances at speeds above 20 $km \cdot h^{-1}$ (Coutts & Duffield, 2010; Johnston et al., 2012; Portas et al., 2010). This yielded problems with field sports data collection, where frequent and short linear change of direction movements are common (Barris & Button, 2008; Dawson et al., 2004b). However, this microtechnology has evolved, with the introduction of 10 Hz and 15 Hz sampling devices reportedly offering improved validity and reliability (Johnston et al., 2014).

Within Australian football, elite-junior and sub-elite competition tiers likely require diverse physical, technical and tactical demands. It has been recognised that as the level of professionalism has evolved, the intensity and speed of elite match-play has increased, creating a gap between these competitions tiers (Aughey, 2013; Burgess, Naughton, & Norton, 2012). Indeed, differences in intensity have been reported between elite match-play and both elite-junior (Burgess, Naughton, & Norton, 2012) and sub-elite match-play (Aughey, 2013; Johnston et al., 2015c). Although elite and sub-elite players may be exposed to homogenous training practices, the physical and technical skill demands of elite Australian football match-play appear greater, with sub-elite competitions including the Victorian football league (VFL) (Aughey, 2013), Western Australian football league (WAFL) (Brewer et al., 2010) and NEAFL competitions (Johnston et al., 2015c), all reportedly involving lower intensity match-play demands.

While insight into the differences between elite and sub-elite competition tiers has been established within the literature, very little research has examined differences between the match-play characteristics of elite-junior and elite Australian football. Additionally, an examination of differences between elite-junior and sub-elite match-play has not been undertaken to date. Specifically, activity profile metrics including accelerations, decelerations and metabolic power output have not been investigated. This is particularly important as the pathway to the elite competition tier involves players competing in the National under-18 and National sub-elite competitions. The following sections of the literature review will describe the activity profiles of elite, sub-elite and junior match-play in detail, as measured by GPS and accelerometers. Further, the technical skill requirements of these competition tiers will be presented.

2.2.1 GAME TIME AND DISTANCE COVERED IN ELITE, SUB-ELITE AND ELITE-JUNIOR MATCH-PLAY

Differences in mean total match time of elite Australian football match-play have been reported, with times ranging from 100.5 to 118.7 minutes (Gray & Jenkins, 2010). Recently, elite players reportedly played an average of 105.4 minutes during match-play (Johnston et al., 2015c). Interchange modifications and other rule changes have likely caused changes to match time for elite players over time. In terms of playing positions within Australian football, nomadic players record less game time (99 ± 14.9 minutes) than forwards (103 ± 14.4 minutes) or defenders (104.5 ± 13.1 minutes) (Wisbey et al., 2010). The increased bench time for nomadic players is likely due to a greater number of rotations for this positional group. Individual participation in sub-elite level match-play has been shown to be greater than elite match-play, lasting 109.3 minutes (Johnston et al., 2015c). Fewer rotations for sub-elite players may influence these findings, while the running demands of this competition tier are lower compared to elite match-play (Aughey, 2013). Finally, the average time of elite-junior match-play is reportedly 67.5 to 81.13 minutes (Burgess, Naughton, & Norton, 2012; Veale & Pearce, 2009), therefore appearing to be substantially lower than elite or sub-elite competition tiers. There are a number of implications regarding conditioning athletes for this large discrepancy in time between the competition tiers.

Elite Australian football match-play has revealed mean total distances ranging from 10,600 to 14,300 meters and mean relative distances from 110.0 $m \cdot min^{-1}$ and 143.3 $m \cdot min^{-1}$ (Aughey, 2010; Brewer et al., 2010; Coutts et al., 2010; Johnston et al., 2012). More recent research utilising 10Hz GPS devices reported average total distances ranging from 12,948 to 13,556 meters and relative distances of 123 to 129.6 $m \cdot min^{-1}$ (Johnston et al., 2015c; Kempton et al., 2015). Total distance varies according to playing position, with nomadic players (midfielders and centre-half forwards/backs) covering the most distance (12,300 to 20,100 meters) compared with forwards (10,800 to 18,800 meters) or defenders (10,800 to 18,800 meters) (Brewer et al., 2010; Wisbey et al., 2010). When considering mean relative distances, nomadic players reportedly cover 136 $m \cdot min^{-1}$, with forwards and backs averaging 119 $m \cdot min^{-1}$ (Hiscock et al., 2012).

Compared with elite Australian footballers, a mean total distance of 12,502 meters and a relative distance of 117 $m \cdot min^{-1}$ has been reported for sub-elite players in the WAFL competition (Brewer et al., 2010). Research has demonstrated a substantial increase regarding distances covered by elite players over a two year period, while the distances covered from the VFL sub-elite competition decreased during this timeframe (Aughey, 2013). Recently, a mean total distance of 13,547 meters and a relative distance of 124.5 $m \cdot min^{-1}$ was reported for sub-elite players in the NEAFL competition (Johnston et al., 2015c). Although tending to be lower than elite players, differences between competition tiers were not significantly different. Currently, little is known about the distances covered by junior Australian footballers during match-play. Mean total distances of 13,625 meters have been recorded using TMA (Veale & Pearce, 2009), while relative distances of 113.07 to 118.94 $m \cdot min^{-1}$ have been reported over a five year period using similar methods (Burgess, Naughton, & Norton, 2012). Contemporary research using GPS and accelerometers reported total distance covered of 10,786 ± 2052 meters and a relative distance of 105 ± 16 $m \cdot min^{-1}$ during junior match-play (Henderson et al., 2015). Alternatively, Gastin, Bennett & Cook (2013) reported relative distances ranging from 67.3 ± 17.8 $m \cdot min^{-1}$ to 97.8 ± 15.2 $m \cdot min^{-1}$ with junior player groups from 11 years to 19 years. Interestingly, both of these investigations reported substantial differences regarding match-play and training demands. Unlike elite or sub-elite match-play, there appears to be a general absence of information from a range of state or age group competitions. This is not unexpected for junior sport given the resource implications of microtechnology for tracking and monitoring these outputs.

2.2.2 VELOCITY METRICS DURING ELITE, SUB-ELITE AND ELITE-JUNIOR MATCH-PLAY

While high-intensity movements account for a low percentage of the total distance covered in field sports (Coutts et al., 2015; Johnston et al., 2012; Wisbey, Rattray, & Pyne, 2008), they are considered a better representation of match-play demands due to their high anaerobic requirement (Gabbett, King, & Jenkins, 2008). Additionally, these movements often occur during crucial moments, with high-speed running over short distances often fundamental to success in field sports (Austin, Gabbett, & Jenkins, 2011; Delaney et al., 2017; Sayers, 2000). While early research reported the majority of time spent and distance covered by Australian football players involved walking, jogging and striding, players completed 3,880 high-speed running meters and 271 high-speed efforts ($\geq$15 km·h^{-1}) on average during match-play (Coutts et al., 2010). When analysing distance covered per minute of game time at high-velocity, average high-speed running distances of 30.3 ± 6.9 m·min^{-1}, with 2.1 ± 0.4 efforts per minute (Johnstonet al., 2012). More recent investigations reported lower average high-speed running distances (28.6 ± 6.3 m·min^{-1}) and efforts (1.6 ± 0.3 n·min^{-1}) per minute of game time for elite players (Johnston et al., 2015c). These outcomes may have resulted from recent rule changes or the calibre of the reference team. Analysis of high-speed running for playing positions reported nomadic players (midfielders, centre-half forwards and centre half backs) achieved the highest running intensities (Brewer et al., 2010; Wisbey et al., 2010). Interestingly, while forwards and backs perform more standing and walking compared to other playing positions, these positions also undertake more sprint efforts (Dawson et al., 2004b). Such results are likely due to the specific demands of these playing positions, requiring forwards to undertake repeated high-speed efforts to gain possession of the ball, with backs aiming to prevent forwards from gaining possession and being required to react to the opponent's maneuvers. However, more recent investigations have disputed these findings, with nomadic players performing more high-intensity strides and sprint efforts (Brewer et al., 2010; Hiscock et al., 2012).

Sub-elite players within the NEAFL competition reportedly undertake an average of 27.6 ± 5.6 m·min^{-1} of high-speed running and 1.5 ± 0.2 high-speed efforts per minute (Johnston et al., 2015c). Alternatively, players within the WAFL competition recorded more high-speed efforts during match-play (2.45 ± 0.6 $n \cdot min^{-1}$) (Brewer et al., 2010). Interestingly a reduction in high-speed running was found over two competition seasons for players competing in the VFL competition (Aughey, 2013). A number of investigations have compared differences in high-speed running between elite and sub-elite competition tiers. Elite players reportedly performed 20% more high-speed running distance (15-36 $km \cdot h^{-1}$) during match-play (Aughey, 2013). It was also reported that elite players performed 6% more high-speed running distance and 7% more high-speed running efforts per minute of game time (Johnston et al., 2015c). It is clear that sub-elite match-play is performed at a lower intensity compared to elite match-play and therefore presents a number of challenges for coaches to prepare athletes transitioning to elite match-play.

Junior players reportedly undertake an average of 144 high-speed efforts during match-play (Veale & Pearce, 2009). A longitudinal investigation revealed an increase in sprint efforts over a five year period from 0.33 ± 0.16 $n \cdot min^{-1}$ to 0.42 ± 0.2 $n \cdot min^{-1}$ (Burgess, Naughton, & Norton, 2012). Conversely, high-speed running distance across five age groups in Australian football increased from 6.3 ± 4.5 $m \cdot min^{-1}$ to 20.2 ± 6.3 $m \cdot min^{-1}$, indicating a noticeable rise in match-play intensity with chronological age (Gastin, Bennett, et al., 2013). Contemporary research reported that junior players cover 2911 ± 903 m of high-speed running during match-play and significantly less during training sessions (1288 ± 484 m). Little is currently known about the high-speed running differences between elite and elite-junior Australian footballers. Early TMA research reported lower absolute distances in all speed zone classifications for junior players compared to the elite players (Veale & Pearce, 2009). Alternatively, while high-speed running demands for junior and elite match-play appear to be increasing, differences of 50% between the competition tiers has been reported (Burgess, Naughton, & Norton, 2012). It is clear that contemporary research using updated GPS and accelerometer devices is essential to compare high-speed running demands between junior, sub-elite and elite match-play. Due to the continued increases in high-speed running within elite match-play and the limited high-speed running data pertaining to junior match-play, further research involving junior players is required. Collectively, by further understanding the gap in match-play demands between each competition tier, coaches can progress training practices and prescribe more unique and individualised programs to optimally develop junior athletes.

2.2.3 ACCELERATION, DECELERATION AND METABOLIC POWER METRICS DURING ELITE, SUB-ELITE AND ELITE-JUNIOR MATCH-PLAY

While the research outcomes regarding low- to high-speed running have been extensively investigated with Australian footballers, relatively little data is available for acceleration, deceleration and metabolic power metrics. Given Australian football is an intermittent running sport, the omission of these variables risks underestimating the true activity cost of match-play (Dwyer & Gabbett, 2012). An investigation within soccer revealed that the majority of maximal accelerations occur at speeds defined as lower than high-speed running (Varley & Aughey, 2013), with Australian football likely similar due to the intermittent running nature of these field sports. A further application within the realm of microtechnology, in particular GPS, is the calculation of metabolic power to estimate power output and the energy cost of intermittent running (di Prampero et al., 2005; Osgnach et al., 2010). Whilst conjecture persists regarding the accuracy of the current microtechnology (Gaudino et al., 2013; Highton et al., 2017; Rampininiet al., 2015), 10Hz devices can correctly determine that an acceleration and deceleration effort has occurred

(Varley & Aughey, 2013) and accurately estimate energy expenditure during continuous running and jogging (Brown, Dwyer, Robertson, & Gastin, 2016). While this presents challenges for field-based sports, there continues to be a body of research (Coutts et al., 2015; Delaney et al., 2017; Johnston et al., 2015c; Kempton et al., 2015; Malone, Solan, et al., 2017; Rampininiet al., 2015) that utilises this metric to provide a holistic estimation of training or match-play demands.

Within elite Australian football match-play, players reportedly average 2.99 ± 0.57 low to high decelerations per minute and 3.16 ± 0.46 low to high accelerations per minute of match-play (Johnston et al., 2015a). In contrast, an previous investigation assessed the relationship between accelerations and decelerations and rating of perceived exertion (RPE) from match-play (Johnston et al., 2015b). Players were classified as a high or low load group, based on their subjective opinion of match-play intensity. The high-load group reportedly covered a greater distance in the moderate acceleration and moderate and high deceleration zones, while also undertaking more efforts in the high deceleration zone (Johnston et al., 2015b). The relationship between these movements and mechanical muscular fatigue highlights the importance of assessing these variables with field sport athletes (Greig & Siegler, 2009).

In terms of position specificity, it has been reported that backs perform the highest number of accelerations (103), while forwards recorded the highest number of decelerations (125) (Coutts et al., 2015). Additionally, the influence of quarter outcome and score margin on activity profiles has been described, with a similar number of accelerations undertaken during small, moderate and large score differentials or win/loss outcomes (Sullivan et al., 2014). In contrast to elite Australian footballers, very little research has reported on the acceleration and deceleration profiles of sub-elite or elite-junior Australian footballers with an investigation reporting an average of 2.86 ± 0.54 low to high decelerations per minute and 3.10 ± 0.43 low to high accelerations per minute of match time for sub-elite Australian footballers (Johnston et al., 2015c). When compared with elite players, this study revealed that sub-elite players recorded significantly less distance, time and efforts in the acceleration and deceleration zones, with the exception of the low and moderate acceleration classifications. Similarly, sub-elite players undertook 28% and 23% fewer accelerations than the elite players over two competitive seasons (Aughey, 2013). It is clear that a paucity of acceleration and deceleration data exists for elite-junior Australian footballers, therefore a holistic understanding of match-play activity profiles is yet to be determined.

When considering metabolic power data, initial research reported that the average energy expenditure of Australian Footballers match-play ranged from 57-66.6 $kJ \cdot kg^{-1}$ (Coutts et al., 2015). It seems that metabolic power output varies according to playing position within Australian football, with midfielders recording the highest average energy expenditure (Coutts et al., 2015). Conversely, a recent investigation reported a higher average energy expenditure for both elite (75.58 $kJ \cdot kg^{-1}$) and sub-elite (73.65 $kJ \cdot kg^{-1}$) Australian footballers (Johnston et al., 2015c) than initial investigations. Despite the relevant metabolic data available on elite match-play and with comparisons to sub-elite match-play, a comprehensive examination of these variables with junior Australian footballers has not been established. There is a clear requirement for contemporary research to examine differences between the competition tiers within Australian football in order to provide more detailed information on the optimal match-play and training development strategies for junior players.

2.2.4 TECHNICAL SKILL METRICS OF ELITE, SUB-ELITE AND ELITE-JUNIOR MATCH-PLAY

Technical skill output within Australian football has been investigated and includes kicks, handballs, total disposals (kicks and handballs), tackles, marks, ruck-contests and possession (Burgess, Naughton, & Norton, 2012; Dawson et al., 2004a; Dawson et al., 2004b; Gronow et al., 2014; Hiscock et al., 2012; Johnstonet al., 2012; Kempton et al., 2015; Rennie et al., 2018; Sullivan et al., 2014; Woods et al., 2017). Within Australian football, technical skills are coded by an independent statistics provider (Champion Data™) for the AFL. Skills coded by Champion Data™ include uncontested skills (no physical pressure) such as kicks and handballs and contested skills (under physical pressure) such as marking or catching the football and tackling. Recently, the reliability and validity pertaining to the coding accuracy of technical skills has found a high level of agreement (ICC = 0.947 to 1.000) and low absolute error (root mean square error range = 0.0 to 4.5) between the statistics provider (criterion measure) and independent coding (Robertson et al., 2016).

A number of investigations have reported on technical skill output within junior and senior Australian football match-play. Across junior player cohorts, a number of technical skill metrics were meaningfully associated with under 16 and under 18 match-play (Woods et al., 2016). Players within the under 18 competition accrued more total marks and clearances per minute, while under 16 players recorded more contested marks and contested possessions per minute (Wood et al., 2016). These contested nature of under 16 match-play suggests a less free flowing game and likely reduction in uncontested skills such as kicking and handballing. Regarding elite senior match-play, lower calibre players (as rated by coaches), accrue fewer skill involvements, while undertaking higher running outputs (Johnston et al., 2012). Compared with physical performance metrics recorded by GPS and accelerometers, greater match-to-match variation was reported for technical skill measures within Australian football (Kempton et al., 2015). While technical skill measures such as Champion Data™ rank or kicks are recognised as sensitive performance metrics (Sullivan et al., 2014), high match-to-match variation regarding these metrics suggests some caution when interpreting match data. Within quarter analysis suggests that the win/loss outcome of each quarter can impact directly on technical skill performance within subsequent quarters (Sullivan et al., 2014). Across junior and elite senior competitions, a divergence in game speed was apparent over a number of competition seasons (Burgess et al., 2012). Game speed appears to be a useful measure to differentiate competition tiers, due to its relationship to decision making, ability to execute skills under pressure and physical movement (Burgess et al., 2012). Investigations within Australian football appear to indicate that contextual factors such as game speed (Bugess et al., 2012), match score (Sullivan et al., 2014 or player decision making (Lorains et al., 2013) and not solely physical performance can influence technical skill proficiency during field sports and therefore requires consideration in applied research.

While the analysis of the technical skill of elite players has focused on relationships to physical capacity or win/loss outcomes, investigations involving junior players have typically included the relationship to draft selection or development outcomes. It seems that early maturing players are perceived by coaches to have superior technical skill ability (Cripps et al., 2016) and accordingly Woods et al. (2016) suggested that junior coaches should implement training drills that promote improvements in contested match-play, such as the use of small-sided games. Regarding the importance of technical skills, contested possessions and marks were closely associated with earlier draft selection in Australian football (Woods et al., 2017). Contested possessions and the number of inside-

50s were the most influential match variables associated with draft selection for under-18 state representative players (Woods, Joyce, et al., 2016). When assessing technical skills with the under-16 and under-18 competitions, a number of conflicting findings have been evident. Under-16 match-play involved a greater number of contested marks and possessions, therefore suggesting a less free-flowing game (Woods, Bruce, Veale, & Robertson, 2016). Interestingly, under-16 match-play may involve fewer uncontested skills including kicks and handballs and therefore limit the opportunity to improve these skills.

Currently, insights into the technical skill output of elite and elite-junior match-play are evident in the literature, sub-elite players have yet to be incorporated into the research. Many elite-junior players will transition through a sub-elite match-play pathway prior to selection at the elite level. Therefore, a greater understanding of the technical skill requirements of sub-elite match-play is required to assess its effectiveness in elite-junior player development. The integration of skill involvements to traditional physical performance metrics within the research has provided context into match-play performance. It seems limited investigations comparing technical skills across competition tiers within Australian football have been undertaken. A thorough understanding of the skill requirements across these competition tiers will enable the design of training drills to optimise improvements in sub-elite and junior players. While a broad understanding of the technical skill variables related to draft selection is known, further research comparing elite-junior to sub-elite and elite players is certainly required.

While measuring and improving elements of physical and technical skill are recognised as important elements of player development, little is known about the execution of decision making skills within Australian football match-play. Cognitive- based skills such as anticipation and decision making are evident between skilled and less skilled players within sport (Williams & Davis, 1995). Greater skilled players appear to recall and react faster to patterns of play, while anticipating opponent's movements based on visual cues (Williams & Reilly 2000). Current training modalities and objective measures of cognitive skills have largely used video based techniques (Lorains, et al., 2013; Lorains et al., 2014, Woods et al., 2016), with application to on-field performance questionable (Pinder, et al., 2011). Alternatively, subjective measures of player performance within the current research is largely reported using a coach's rating. A number of investigations within Australian football have demonstrated higher skilled players as rated by coaches, undertaking less physical activity (Johnston et al., 2012, Sullivan et al., 2014). Therefore, assessing physical output during match-play must be viewed in the context of overall technical, tactical and cognitive skills. From a junior player development perspective within Australian football, talent identified U18 players displayed greater accuracy with game-based decisions than their non-talent identified peers (Wood et al., 2016). Additionally, senior Australian footballers classified as better decision makers by coaches and during laboratory testing, undertook more structured sporting activities and deliberate practice prior to draft selection (Berry, et al., 2008). The authors suggested the time practicing and not the type of activity practised had the greatest influence on future decision making outcomes. These findings suggest sport specific methods and not solely video based training can develop cognitive skills within junior player cohorts. While a combination of these methods may also benefit senior players (Lorains et al., 2013), exposing senior players to competitive match scenarios may further develop this player cohort (Farrow et al., 2008). The paucity of investigations regarding cognitive skill development within Australian football warrants further investigation to enhance the current training methods and transferability to on-field performance.

2.2.5 SUMMARY

The examination of match-play activity profiles across competition tiers in Australian football has provided an insight into the physical demands of each match-play tier. The majority of research findings have focussed upon the elite competition, however, differences are evident to sub-elite and elite-junior competitions. Importantly, it appears the intensity of elite match-play is increasing over time (Burgess, Naughton, & Norton, 2012; Johnston et al., 2015c) and therefore may widen the disparity between competition tiers. When comparing across competition tiers, it appears that elite players undertake more high intensity running distance and efforts than their sub-elite and junior counterparts. This is occurring despite lower match duration and the players undertaking less total distance than sub-elite players. Accelerations, decelerations and metabolic power metrics exhibit a similar pattern, with elite players typically recording the highest estimated energy expenditure (Johnston et al., 2015c).

Notwithstanding the research directly comparing sub-elite and elite competition tiers, there is a distinct paucity of investigations concerning elite-junior Australian footballers. Furthermore, while recent advances in microtechnology have improved the accuracy of data collection limited research regarding movement variables, such as PlayerLoad™, accelerations, decelerations and metabolic power has been reported across the competition tiers. However contemporary research using these metrics can benefit coaches and conditioning staff across the development pathways, with the ultimate aim of optimally transitioning junior players to professional teams. Collectively, by understanding the match-play demands and physical requirements of their athletes, coaches can develop and apply physical preparation programs across all levels of Australian football. However, any junior development program must be mindful of the varying stages of biological maturation and training experience within their player group. Only then can individual and targeted training prescription be successful.

2.3 Junior Athlete Maturation

2.3.1 ASSESSMENT OF PHYSICAL STATUS IN JUNIOR ATHLETES

Due to the varying biological age within chronological age groups, it is unlikely that physical parity exists within junior sports. Although early maturation is not always associated with skillful performance attributes (le Gall et al., 2010), several authors have reported relationships with greater anthropometric characteristics (Figueiredo et al., 2009b), muscular power (Vaeyens et al., 2006) and endurance running (Gastin, Bennett, et al., 2013). Assessing the biological maturity or growth of junior athletes can be challenging due to the ethical considerations involved with this player cohort. Within the research, the terms maturity and growth are often used interchangeably however, each term has a distinct definition. "Growth" refers to observable and measurable changes in anthropometric characteristics, while "maturation" refers to more qualitative changes including skeletal development, and secondary sex characteristics (Malina et al., 2015; Malina., 2004). Current methods to assess biological maturity involves invasive and non-invasive techniques, with common clinical assessments involving X-rays to measure skeletal age or clinical observations of secondary sex characteristics (Fransen et al., 2017; Malina et al., 2015). Both techniques provide evidence of maturation in relation to same-age peers and may aid with training prescription during each stage of adolescent athlete development (Meylan, Cronin, Oliver, & Hughes, 2010).

Invasive or clinical techniques to measure maturity include the assessment of skeletal age through X-rays of the left hand, wrist or knee. Chronological age is then subtracted from skeletal age to determine early, medium or late maturers using a positive or negative score (Fransen et al., 2017; Malina et al., 2000; Malina et al., 2015). The skeletal system provides a useful indication of biological development due to its continued growth until reaching full maturation (Meylan et al., 2010). This method is utilised by European soccer football academies and replaced chronological age to classify player groups (Carling et al., 2009; le Gall et al., 2010). Exposing children and adolescents to radiation for the purposes of screening is a complex ethical issue, as is the financial cost of such screening, resulting in its unavailability to a number of organisations and athletes. A further invasive technique involves the assessment of dental age or sexual maturity traits. One such method of assessing secondary traits is the Tanner stages of puberty scale (Malina., 2004). Although this method provides an opportunity to measure more athletes from a financial perspective, it is deemed less reliable and indeed more invasive than the X-ray method (Meylan et al., 2010). Interestingly, research with junior soccer players has observed a positive relationship between skeletal maturity and the Tanner method (Figueiredo et al., 2009b). Finally, measuring circulating androgen or growth hormone levels has been used to estimate stages of maturity. Increased strength and power in pubescent soccer players reportedly coincided with increased androgens and insulin-like growth factor I (Hansen, Bangsbo, Twisk, & Klausen, 1999). Despite the benefits arising from this screening method, consideration of the different ethical considerations of each method is essential and a non-invasive approach may be preferable with junior athletes.

A number of non-invasive techniques have been developed to assess maturity with minimal physical or psychological intrusion. The age at peak height velocity (PHV) is one such method to determine longitudinal changes and is calculated using height, trunk length, leg length, body mass and chronological age to predict an estimated age of maturity. This generally occurs around 14 years of age and is significant for the large maturational differences at this stage of physical development (Armstrong, 2007; Gastin, Fahrner, et al., 2013; Till et al., 2014). While reported to be practical and reliable ($R^2 = 0.96$), a number of limitations have been reported for the calculation of the age at PHV, including equations based on non-athletic populations or the prediction of later ages for earlier matures and earlier ages for later maturing boys and girls (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002; Mooney et al., 2011). Additionally, a noted practical limitation of this technique involves the requirement to take multiple measures around the PHV occurrence, with the results generally viewed retrospectively (Meylan et al., 2010). An alternative method is the expression of height in relation to the percentage of predicted adult height using age, height, weight and mid-parent height (Roche, Tyleshevski, & Rogers, 1983). Due to the chance of over-estimation of height by the parent, this value is then adjusted with gender-specific equations (Epstein, Valoski, Kalarchian, & McCurley, 1995). This method has been validated against biological markers of skeletal maturity (Malina et al., 2007) and has been used in a practical setting to provide an indication of maturity with junior soccer players (Malina et al., 2006). Finally, tracking height and weight changes using percentiles from growth charts can be a useful marker of biological development using normative population data (Malina et al., 2004; Sherar, Baxter-Jones, Faulkner, & Russell, 2007). However, a number of limitations are apparent with this approach, including the potential for an individual to never reach a height in relation to normative data (Meylan et al., 2010) or variations based on different ethnicity (Malina., 2004).

Within junior sports, player allocations are generally categorised by chronological cut-off dates and created on a 12-month calendar cycle time-frame. This provides equity challenges within these sub-groups, as up to 12 months differences can be present between those born at the cut-off point and those born later in the same year (Mujika et al., 2009). The term relative age effect (RAE) has been devised to specify the perceived unfair advantage of juniors born in the initial period of a cut-off cycle (Barnsley, Thompson, & Barnsley, 1985; Vaeyens, Philippaerts, & Malina, 2005). This phenomenon is based on the premise that while minimal chronological maturation differences may be present, there may be considerable biological maturation variance. The impact of this biological variation on physical characteristics such as anthropometric, running endurance, strength, power, running speed and motor control have been documented (Fransen et al., 2017; Gastin, Bennett, et al., 2013; Malina., 2004; Tribolet, Bennett, Watsford, & Fransen, 2018) and remains an important consideration within junior sport.

Investigations with junior soccer players have reported on the influence of RAE and player maturity on participation, retention and future career outcomes. Indeed an over-representation of players born in the early period of an age category has been reported for junior and professional soccer groups (Brewer, Balsom, & Davis, 1995; Helsen, Starkes, & Van Winckel, 1998; Mujika et al., 2009; Vaeyens et al., 2005). Interestingly, selection bias was reported within all age categories of soccer players aged 15 to 18 years, however, this was less evident when players reached their twenties (Helsen, Van Winckel, & Williams, 2005). This suggests a reduction in the influence of the RAE and likely physical differences in later adolescence (Fransen et al., 2017; Malina et al., 2015). Similarly, a selection bias towards greater biological maturity was reported for male junior ice hockey (Sherar et al., 2007) and basketball players (te Wierike, Elferink-Gemser, Tromp, Vaeyens, & Visscher, 2015). Within an Australian football context, performance in physical tests, an invitation to the national draft combine and subsequent draft selection appear biased towards early birth month individuals (Coutts, Kempton, & Vaeyens, 2014; Cripps et al., 2016; Pyne et al., 2006). Conversely, chronologically older individuals within these draft years were found to be born in the later months (Coutts et al., 2014) therefore highlighting the importance of retaining players within junior development pathways. It is clear that it is challenging to retain later maturing athletes within junior development programs, where selection options may be restricted due to inferior anthropometric or physical characteristics.

The process in which younger adolescents are profiled within age categories may, therefore, be a limiting factor within current junior development programs. Talent identification falls under broad categories involving physical, technical, tactical and psychological elements and all must be considered when assessing athletes (Meylan et al., 2010). With research demonstrating that selection and long-term retention of junior athletes are largely influenced by physical characteristics, biological bias must be considered within talent identification. An understanding of how differing maturity levels affect physical qualities including aerobic power, muscular strength and muscular endurance is critical (Vaeyens et al., 2008). The establishment of development programs from athlete profiling should be implemented with the understanding that the design can be influenced by the evolving maturation and trainability of the athlete. However, it appears that these biases are diminished as junior athletes reach later adolescence (Fransen et al., 2017; Malina et al., 2015). By identifying and reducing physical differences between junior and professional athletes, the successful transition of junior athletes to professional teams can be undertaken.

2.3.2 JUNIOR ATHLETE TALENT IDENTIFICATION AND DEVELOPMENT

Talent identification (TID) and development is a multi-million dollar industry within professional sport. Current practices are typically based around two key themes, subjective coach evaluations and objective tests of physical capacity, skill, psychological wellbeing and medical assessments (Vaeyens, et al., 2008). The basic scientific model adapted by Williams and Reilly (2000) (Figure 2.2) is a commonly proposed pathway for athlete excellence. Talent detection refers to the discovery of individuals from within a pool of potential athletes; TID refers to the assessment of athletes and detecting athletic potential at any moment in time by objective testing; talent development (TDE) refers to the provision of an environment for athletes to succeed; while talent selection refers to continuingly measuring athletes during the development pathway to assess their suitability for selection within a team or athletic program (Williams & Reilly, 2000).

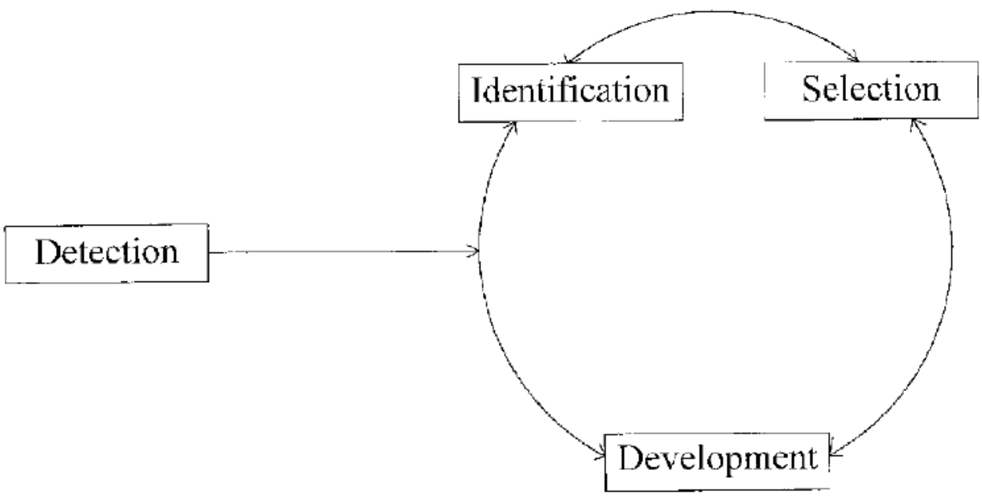

Figure 2.2: Key stages in identification and development process (Williams & Reilly 2000, adapted from Williams & Franks 1998).

A number of TID models have been proposed, including the differentiated model of giftedness and talent (DMGT2.0) (Figure 2.3). While initially developed for education purposes, this model offers a framework to base inferences and observations on TID in sport (Tranckle & Cushion, 2006). Two concepts are proposed by Gagne including 'Giftedness' which relates to innate characteristics such as inherited genes or variation in biological maturation, placing some athletes above their respective peers (Gagné, 2004). ‘Talent’ is the next concept and relates to a purpose-driven pursuit of skill mastery that interacts with individual player gifts (Gagné, 2004). Finally, ‘chance’ is proposed as the overarching factor that contributes to the interaction between giftedness and talent (Gagné, 2004). While coaches may view giftedness with potential in a given sport (Furley & Memmert, 2016), the non-linear and multidimensional nature of talent development within sports must be considered (Burgess & Naughton, 2010; Phillips, Davids, Renshaw, & Portus, 2010)

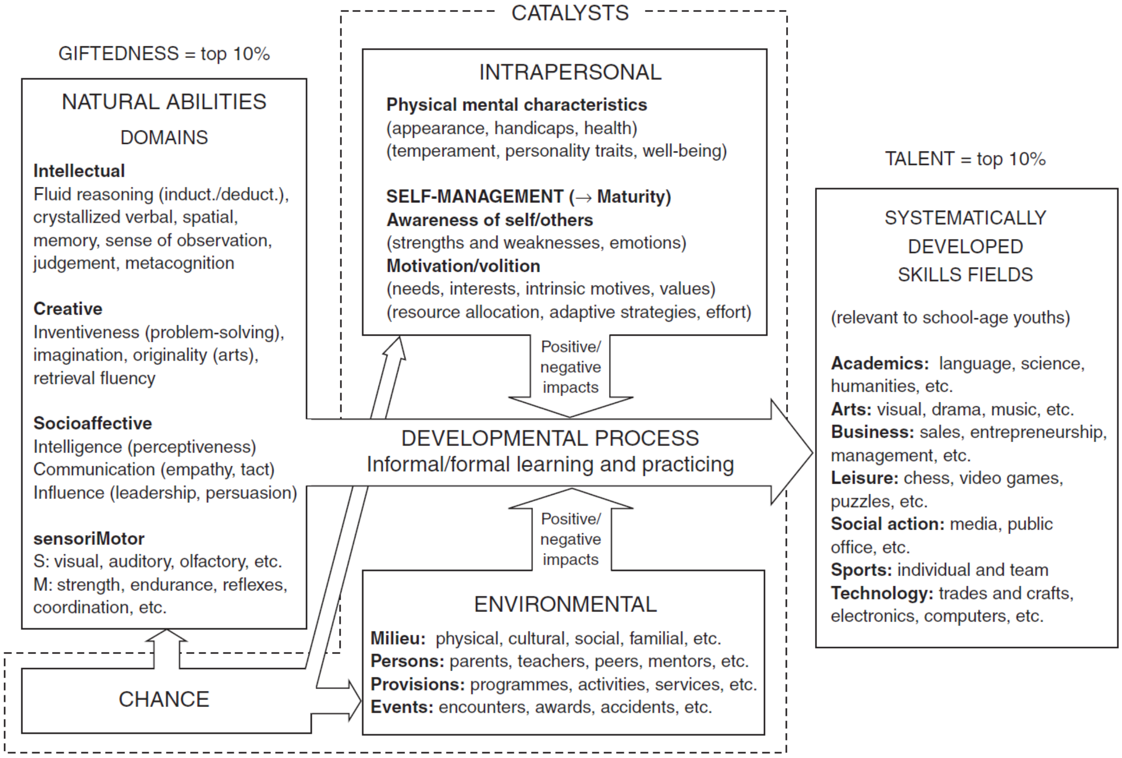

Figure 2.3: The Differentiated Model of Giftedness and Talent 2.0 (Gagne 2008).

A number of limitations are evident regarding cross-sectional TID and TDE models and how they attempt to predict future career success (Baker, Schorer, & Wattie, 2018). Although it is important to provide benchmark data, TID models may infer successful adult athlete data from measuring junior athletes (Morris, 2000). It is possible that junior athletes may not retain the preferred attributes during the maturation process (Ackland & Bloomfield, 1996). Further, the varying rates of maturation in adolescence can be problematic when assessing athletes through longitudinal TID models, with a number of variables within these models influenced by biological variation (Fransen et al., 2017; Malina et al., 2015). Finally, researchers and practitioners must be mindful of the potential to be uni-dimensional when considering TID models which focus on one single aspect of identification and development (Burgess & Naughton, 2010).

Discovering talented athletes, nurturing their development and minimising injury are integral components of any junior athlete development model (Burgess, Naughton, & Hopkins, 2012). Prior to the implementation of athlete development programs, comprehensive athlete profiling can provide the bases of these programs. Athlete profiling has enabled a greater understanding of the physical characteristics required for selection and career success within team sports (Sporis et al., 2009). Profiling can fall under the guise of various testing protocols, including anthropometric, physical, technical skill or measuring match-play demands. Physical testing generally involves assessments of strength, power, running endurance and running speed. Match-play activity profiles were initially recorded using TMA methods including video analysis (Barris & Button, 2008), however with the advent of GPS and accelerometers, greater volumes of data are now recorded and analysed (Coutts et al., 2010; Edgecomb & Norton, 2006; Johnston et al., 2015c; Kempton et al., 2015). Both physical and match-play activity profiling have been undertaken on elite cohorts in many sports, including running-based field sports such as Australian football (Gastin, Fahrner, et al., 2013; Johnston et al., 2015c; Johnston et al., 2012; Kempton et al., 2015; Rennie et al., 2018; Veale et al., 2010), rugby union (Cunniffe et al., 2009; Darrall-Jones et al., 2015), soccer (Sporis et al., 2009; Wehbe, Hartwig, & Duncan, 2014) rugby league (Austin & Kelly, 2014; Gabbett, 2002; Till et al., 2014) and Gaelic football (Malone et al., 2016; McIntyre & Hall, 2005; Shovlin et al., 2018). Given the unpredictable nature of these professional sports, the identification of key anthropometric and physical characteristics of professional athletes may provide a framework for junior development programs.

Recently, elite Academies have been conceived to develop elite-junior athletes, most notably with European soccer clubs. These academies were designed with the associated aim of creating early development institutions for nurturing talent identified athletes (Carling et al., 2009; Figueiredo et al., 2009a; Reilly, Bangsbo, & Franks, 2000). The importance of these Academies increased when the European Court of Human Rights in 1985 instituted 'The Bosman Ruling', allowing free movement of players between football clubs when their contracts had ceased (Williams & Reilly, 2000). This ruling made retaining players more difficult and therefore the onus was on football clubs to identify and develop junior athletes within their Academies. On an international level, the competition for success in Olympic sports has initiated many nations to invest heavily in TID and TDE programs. This includes Institutes of Sport in countries such as Australia and the United Kingdom, while non-traditional medal winning countries have also adapted these frameworks, including the ASPIRE Academy in Qatar. Although research suggests these specialised institutes may not deliver the pre-eminent model of athlete development, they provide smaller populated countries the chance to compete with larger populated countries (Vaeyens, Güllich, Warr, & Philippaerts, 2009). Additionally, athletes are afforded expert coaching, medical care and the ability to focus solely on their nominated sport, each of which are crucial elements of TDE.

Within Australian football, junior players are tested and selected by professional clubs through the National draft combine (Burgess, Naughton, & Hopkins, 2012). In order for an athlete to progress through the development pathway in Australian football, a number of stages exist depending on player's chronological age and ability (Figure 2.4). This framework provides a clear progression from junior participation to a professional Australian football club. The final stage of junior development involves the state or national level combines, where a series of anthropometric, physical, psychological, skill and medical assessments are undertaken (Burgess, Naughton, & Hopkins, 2012). These processes provide professional Australian football clubs the opportunity to profile prospective draftees. The draft combine is similar to that of the National Football League (NFL) in the USA (Sierer et al., 2008) and is the major outlet for TID in Australian football. With the recent establishment of club-based Academies in Australian football, there is now greater scope for organisations to identify and influence player development. These elite academies were firstly established in locations viewed as "non-traditional" AFL states, with the ultimate aim of increasing the player talent pool, however, they have now grown to include all states and territories in Australian. These Academies now provide a greater number of elite junior Australian footballer to profile and be considered for draft selection (Tribolet et al., 2018; Woods et al., 2017). While the current junior Australian football investigations have predominantly assessed within or across chronological age groups (Burgess, Naughton, & Hopkins, 2012; Cripps et al., 2016; Robertson et al., 2015; James P Veale & Alan J Pearce, 2009; Veale & Pearce, 2009; Veale et al., 2010; Woods et al., 2016; Woods et al., 2017; Woods, Joyce, et al., 2016; Woods, McKeown, et al., 2016; Woods, Raynor, et al., 2016; Woods et al., 2015), contemporary research is required in addition to existing investigations (Bilsborough et al., 2015; Burgess, Naughton, & Norton, 2012), comparing the physical and match-play profiles of junior and professional cohorts. Such information will inform coaches of the gaps between competition tiers and assist with player development frameworks.

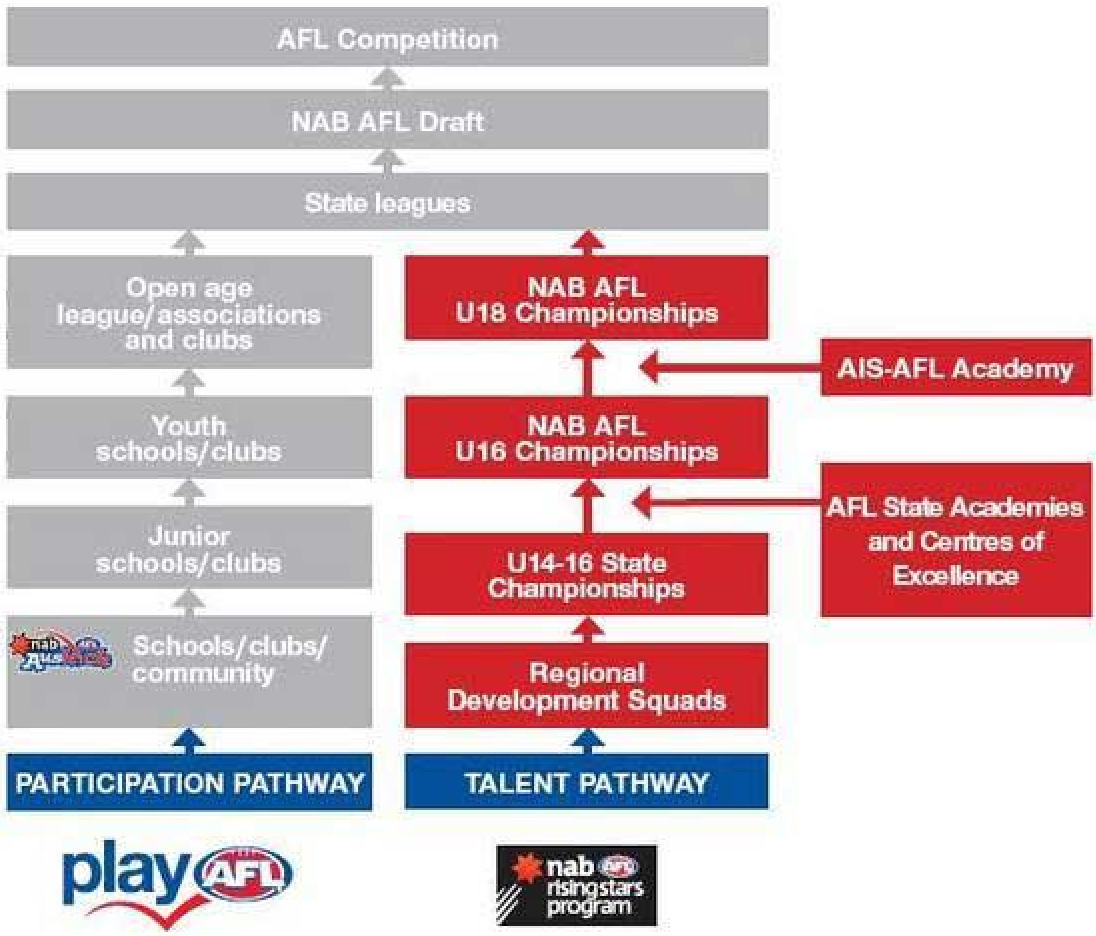

Figure 2.4: The development pathways for players to reach the elite level of the Australian Football League.

2.3.3 SUMMARY

While TID and TDE programs for junior athletes must incorporate a multidimensional approach, anthropometric and physical characteristics appear to be favored by coaches, particularly with younger adolescents. Within younger age-matched peer groups, differences in anthropometric and physical characteristics are clearly apparent. Despite these apparent differences, the biological variation within groups diminishes as athletes mature chronologically. Accordingly, it seems prudent to assess these older adolescents against professional cohorts (both sub-elite and elite level). This is particularly pertinent for potential recruits to professional teams. Currently, very few studies have directly identified key physical and activity profile differences between junior and senior Australian footballers of varying ages and playing experience. Therefore, further research is warranted to assess the fundamental physical characteristics of professional Australian footballers and provide benchmark data for comparison with elite-junior players. The subsequent sections of the review will examine the concept of physical profiling in detail, providing information regarding potential importance for TID and TDE.

2.4 ATHLETE PROFILING IN SPORT

Athlete profiling has been broadly utilised to identify and assess anthropometric, physical, technical and tactical skills of junior and professional athlete populations. Central to anthropometric or physical profiling are laboratory or field-based tests, including the measure of body mass, stature, body fat composition, aerobic capacity, anaerobic capacity, muscular strength and power. Within the context of field sports, the importance of measuring a range of physical capacities relates to the multifaceted activities required for success (Austin et al., 2011; Higham et al., 2016; Ingebrigtsen et al., 2015). Soccer, Gaelic football and Australian football are sports requiring intermittent locomotor activity, while interchangeably using the aerobic and anaerobic energy systems (Boone et al., 2012; Cullen et al., 2017; Gray & Jenkins, 2010). Conversely, rugby league, rugby union and American football are field sports involving brief locomotor movements with frequent collision activities, therefore requiring a greater expression of muscular strength and power (Darrall-Jones et al., 2015; Gabbett et al., 2008; Robbins, Goodale, Kuzmits, & Adams, 2013). By profiling all facets of physical capacity, a holistic understanding of individual athletes within a sport can be determined. Consequently, coaches can be provided with key data for appropriate training programs, team selection or assigning positions. The following section of the literature review will discuss anthropometric and physical profiling across junior and professional athletes over a broad range of sports.

2.4.1 ATHLETE PROFILING IN JUNIOR SPORT

Anthropometric Characteristics

The anthropometric profile of elite-junior athletes has been investigated for team sports including soccer (Figueiredo et al., 2010), Gaelic football (McIntyre & Hall, 2005), rugby union (Fontana, Colosio, Da Lozzo, & Pogliaghi, 2017) and rugby league (Tredrea, Dascombe, Sanctuary, & Scanlan, 2017). An uneven birth distribution has been found within elite-junior sports teams (Carling et al., 2009; Gonçalves, Severino, Silva, & Figueiredo, 2011; Tribolet et al., 2018), notably a greater number of players participating that are born in the first quarter of the year. A selection bias seems to exist towards superior physical and anthropometric characteristics within elite-junior populations (Fransen et al., 2017; Malina et al., 2015). This was reported for soccer players aged 11 to 14, where the selection of goalkeepers with greater body mass was preferred by coaches (Helsen et al., 2005). While such an occurrence may have greater prevalence in younger adolescent age categories (Malina et al., 2004; McCarthy & Collins, 2014), this concept can manifest within older adolescent cohorts. Elite under-19 year goalkeepers were reportedly taller and heavier than their non-elite counterparts (Rebelo et al., 2013). Alternatively, while greater stature was favored by recruiters within junior basketball, a relationship between height and motor abilities was not reported (Jakovljevic et al., 2016). It seems unique anthropometric characteristics are preferred within certain sports and are likely influenced by positional requirements or coach's preference.

Within elite-junior soccer, defenders and goalkeepers were reportedly taller and heavier, compared to midfielders and forwards positions (Gil, Gil, Ruiz, Irazusta, & Irazusta, 2007; Malina et al., 2005). While research suggests that a coaches subjective opinion and selection outcomes are biased by greater biological maturity (Fransen et al., 2017; Malina et al., 2015), the relationship to physical performance is less apparent with elite-junior athletes. The association between physical maturity and sprinting speed was reportedly non-linear with a cohort of 11 to 17-year-old soccer players (McCunn et al., 2017; Malina et al., 2017). Within this player group, mid-adolescent athletes recorded the poorest relationship between physical maturity and sprint speed. This cohort of players is within an important stage of adolescence, where a number of maturational changes occur regarding peak height velocity and weight gain (Beunen & Malina, 2007; Carvalho et al., 2011). As players develop chronologically, the current literature suggests homogenous maturational profiles are likely to occur within player groups (Fransen et al., 2017). Regarding more experienced junior athletes, the importance of developing physical characteristics such as running capacity, strength and power, may supersede anthropometric and morphological changes.

Aerobic & Anaerobic Characteristics

Field sports including soccer, Gaelic football, rugby union and rugby league require various aerobic and anaerobic demands during match-play. Popular assessments of aerobic and anaerobic capacity include multi-stage fitness tests (MSFT) (Figueiredo et al., 2009a; Till et al., 2017), continuous incremental running tests to exhaustion (Cullen et al., 2017), interval shuttle run tests (ISRT) (Elferink-Gemser et al., 2012) or maximal sprints tests over distances of 5,10, 20 or 40 meters (Carling et al., 2012). Within Gaelic football, VO_2max score had a positive relationship with total distance during match-play (Cullen et al., 2017). Additionally, these players undertook a locomotor activity at an intensity closer to their HR_{max} and VO_2max (Cullen et al., 2017). From a positional perspective, tactical requirements were suggested as the cause of midfielders recording greater running distance than other player groups (Cullen et al., 2017). Regarding two junior soccer investigations, players classified as elite athletes performed significantly better during the Yo-Yo IR1 and sprint tests, compared to a control group (Figueiredo et al., 2009a; Williams, 2016). It is expected that elite players will perform better during the Yo-Yo IR1 and 2 tests, as they are designed to simulate field sports locomotor activity (Bangsbo, Iaia, & Krustrup, 2008). A study analysing playing positions within soccer reported that goalkeepers performed poorest during endurance tests, while both midfielders and forwards exhibited the highest aerobic capacity (Gil et al., 2007; Rebelo et al., 2013). It is likely that positional demands within intermittent locomotor sports such as soccer and Gaelic football are the basis for these differences.

Within rugby union, junior players that recorded lower movement competency scores also performed poorest during a 40 m sprint and Yo-Yo IR1 test (Parsonage et al., 2014). While the running demands of rugby union are lower than soccer or Gaelic football, the findings suggest a link between basic movement competency and running capacity. A cohort of rugby league Academy players of varying training ages, improved Yo-Yo IR1 test scores, however minimal improvements in a 10 and 20 meter sprint times were revealed over two consecutive pre-season periods (Till et al., 2017). Interestingly players with greater experience covered more distance during the Yo-Yo IR1test (Till et al., 2017). It seems from the literature that performance during running tests can distinguish elite-junior athletes within a chronological age group.

Strength & Power Characteristics

Resistance training is routinely undertaken to increase the strength and power qualities of junior and professional athletes. A number of consensus papers relating to this issue now detail the performance and health benefits of this training modality for youth athletes (Lloyd et al., 2014; Valovich McLeod et al., 2011). Importantly, resistance training is considered a safe and effective method to increase bone health and muscular strength and power (Faigenbaum & Myer, 2010; Lloyd et al., 2014). Popular research methods to measure muscular strength of elite-junior athletes includes squats (Sander, Keiner, Wirth, & Schmidtbleicher, 2013), leg press (Christou et al., 2006), bench press, chin ups and the prone row (Till et al., 2017). Additionally, isometric strength testing using a hand grip dynamometer has been an effective measure to discriminate strength differences within elite-junior athlete groups (Palamas et al., 2015). Alternatively, popular measures of lower body muscular power include the broad, squat or countermovement jumps (Hammamiet al., 2016; Parsonage et al., 2014) or the medicine ball and barbell throw exercises for upper body power (Argus et al., 2009; Davis et al., 2008). These tests have been administered across a broad range of sports to profile an athlete's strength and power characteristics.

Rugby league is a sport requiring numerous expressions of muscular strength and power for tackling, wrestling and sprinting activates (Gabbett et al., 2012). Players who exhibited inferior upper-body strength reportedly had limited opportunities within elite-junior development pathways and were unlikely to progress to professional teams (Tredrea et al., 2017). However, rugby league players with low training age were able to elicit greater short-term strength gains than their counterparts with a superior training history (Till et al., 2017). Within soccer, Sander et al. (2013) demonstrated a positive relationship between strength training and increased maximum strength and sprint performance with adolescent players. High-speed movements are fundamental to success in field sports such as soccer (Chaouachi et al., 2009; Christou et al., 2006; Parsonage et al., 2014), therefore participation in resistance training programs are fundamental for physical development. Collectively, the findings have highlighted that initial improvement can occur from undertaking resistance training, however, to achieve sustained adaptations and morphological changes, continuous long-term strength training may be required.

Muscular power refers to the rate which muscles can perform work (Smith et al., 2014). The development of muscular strength can also assist with increased muscular force expression and performance tasks (Granacher et al., 2011; Harries, Lubans, & Callister, 2012; Suchomel, Nimphius, & Stone, 2016). It seems prudent that athletes train both of these physical characteristics to enhance performance outcomes. Elite-junior soccer players were able to improve lower-body peak power while undertaking a resistance training program (Chelly et al., 2009; Comfort, Stewart, Bloom, & Clarkson, 2014). A different cohort of junior soccer players improved countermovement jump height by 8% after an eight-week plyometric training intervention. It seems by influencing both elements of power (force and velocity), positive training adaptations can be elicited. Of equal importance may be the protective mechanisms of resistance training against injuries (Zwolski, Quatman-Yates, & Paterno, 2017). Acute muscular and overuse injuries have the potential to affect the short and long-term career prospects of junior athletes. Resistance training can reportedly reduce the risk of acute and overuse injuries (Emery, 2010; Valovich McLeod et al., 2011) and off-set bone fracture risk (Clark, Tobias, Murray, & Boreham, 2011), therefore providing elite-junior athletes with increased opportunity for participation and skill development within their chosen sport. Although the ability to train junior athletes may be limited compared to their senior, professional counterparts, a holistic approach incorporating all elements of physical capacity should be applied.

2.4.2 ATHLETE PROFILING IN ELITE SPORT

Anthropometric Characteristics

While the literature suggests certain anthropometric and physical characteristics are optimal for junior athlete identification and development, these characteristics may differ for adult, senior-level athletes, where homogenous maturation is evident (Fransen et al., 2017; Malina et al., 2015). Although this appears to be the situation for senior athletes, relative body composition heterogeneity may be apparent due to specific positional demands of a sport (Fransen et al., 2017). Regarding playing positions in soccer, goalkeepers, central defenders and forwards appear to possess greater body mass and stature than midfield players (Reilly, Bangsbo, et al., 2000; Sporis et al., 2009). Alternatively, specific playing positions within Gaelic football appear to favour homogenous anthropometric characteristics. Midfield players are reportedly taller and heavier and exhibit lower body fat percentages compared to all other playing positions (McIntyre & Hall, 2005).

The selection and allocation of positions within field sports with high collision incidences seem to be influenced by individual player's anthropometric characteristics. Within American football, longitudinal body weight and body composition changes were reported in both college and professional athletes (Anzell, Potteiger, Kraemer, & Otieno, 2013). Due to the data collection occurring over a 70 year period, it is likely that evolving training techniques and increased nutritional standards contributed to the differences reported. Players within a rugby union team were able to elicit short-term changes in fat-free mass after a 4-week pre-season training block (Argus et al., 2010). These changes in body composition are important for optimal performance in locomotor sports, as excess body fat can negatively influence running speed, endurance and increase energy expenditure requirements (Duthie et al., 2006). While biological maturation factors have limited impact on anthropometric characteristics of adult athletes, training individual physical characteristics may elicit morphological changes.

Aerobic & Anaerobic Characteristics

Similar to junior athletes, tests of aerobic and anaerobic capacity include incremental running assessments, time trials, shuttle runs and maximal speed. These tests involve a range of energy systems that are intermittently required during field sports. While soccer is a sport predominantly requiring the aerobic energy system, the contribution of the anaerobic energy system to high-intensity running and sprints underlines its importance to overall performance (Sporis et al., 2009; Williams & Reilly, 2000). Soccer players reportedly cover 9,500-12,000 meters during a 90-minute game, however, 40% of this distance can consist of high intensity running (>14$km \cdot h^{-1}$) (Rampinini et al., 2009). A number of investigations have assessed the aerobic capacity of soccer players and found VO_2max scores ranging from 58 to 64 $ml \cdot min^{-1} \cdot kg^{-1}$ (Boone et al., 2012; Tønnessen et al., 2013). Regarding playing positions, fullbacks and midfield players recorded the highest VO_2max scores, while goalkeepers reportedly had the lowest VO_2max, Additionally, fullback and midfield players recorded the highest running distance during match-play (Boone et al., 2012). Due to the relationship between, high-intensity match-play running (Jan Helgerud, Engen, Wisløff, & Hoff, 2001), competition level in soccer (Ingebrigtsen et al., 2012) and VO_2max scores, it seems prudent to measure this physical capacity regarding field sport athletes. Similar to soccer, midfield players within Gaelic football recorded the highest VO_2max scores during a continuous running test using a treadmill (McIntyre & Hall, 2005). The VO_2max scores were similar to that of soccer players, ranging from 57 to 66 $ml \cdot min^{-1} \cdot kg^{-1}$. A recent investigation of Gaelic footballers reported greater Yo-Yo IR2 running performance for midfield players, compared to all other positions (Shovlin et al., 2018). However, when analysing sprint performance, no differences were evident between the playing positions (Shovlin et al., 2018). Players within sports such as rugby union and rugby league perform work periods shorter in duration to soccer or Gaelic football (Austin et al., 2011; Gabbett et al., 2008). While the duration of these collision sports still requires players to develop the aerobic energy system, VO_2max scores for rugby league players (42 to 56 $ml \cdot min^{-1} \cdot kg^{-}1$) (Gabbett, 2005) appear to be lower than soccer and Gaelic football players. It seems that the activities undertaken during respective sports dictate training practices and the physical requirements of the athletes. As soccer and Gaelic football have a similar intermittent locomotor activity profile to Australian football, players are required to develop the aerobic and anaerobic energy systems for successful performance outcomes.

Strength & Power Characteristics

Similar to elite-junior athletes, resistance training is designed and applied to professional athletes with the aim of initiating morphological changes, improving performance and reducing injury incidences. The extent to which resistance training is performed is likely a consequence of the physical requirements of a sport and the athlete's needs. Soccer requires players to perform repeated powerful movements including sprinting, jumping and changes of direction (Reilly & Williams, 2003). Indeed soccer players can undertake 1000 to 1400 speed and power actions per match, depending on playing position or competition tier (Stølen, Chamari, Castagna, & Wisløff, 2005). While collision incidents are low in soccer, resistance training may benefit athletes through enhancing performance and reducing injury risk (Franco-Márquez et al., 2015; Hoff & Helgerud, 2004; Rodríguez-Rosell et al., 2016). When considering performance tasks and strength characteristics of semi-professional rugby league players, a positive relationship has been observed between upper and lower-body strength and tackling ability (Speranza, Gabbett, Johnston, & Sheppard, 2015). However, when assessing strength between playing positions in rugby league, there is conjecture within the literature regarding the prominence of muscular strength. No differences were found regarding relative isokinetic strength across playing positions (de Lacey, Brughelli, McGuigan, & Hansen, 2014), however, two retrospective investigations reported that forwards possess the highest muscular strength (Comfort, Graham-Smith, Matthews, & Bamber, 2011; King et al., 2009). While these findings may differ, it is clear that muscular strength and power are important for all playing positions in rugby league (Gabbett et al., 2008). The power profiling of rugby union players was assessed over a 13 week competition period. While a small reduction in the lower-body power was observed, upper-body power was maintained (Argus et al., 2009). Both rugby union and rugby league involve repeated locomotor and collision activities and therefore require players to continually express muscular strength and power throughout match-play (Argus et al., 2009; Speranza et al., 2015). Interestingly, players drafted from specific positional groups within the National Football League (USA) recorded higher vertical jump scores (Sierer et al., 2008). However, players classified within skill positions, including fullbacks, line-breakers, tight-ends and defensive-ends were not significantly different in lower-body power expression. Therefore, coaches must be careful when assessing athletes and understand the physical requirements of specific playing positions.

Collectively, the research profiling junior and professional athletes have demonstrated the diverse range of physical characteristics required for development stages and individual sports. These findings can aid coaches with drafting prospective athletes, team selection or assigning positions. Along with a multitude of research assessing a variety of team sport athletes, there is a growing body of literature reporting on the profiling of athletes in Australian football. The following section provides an overview of this research.

2.4.3 ATHLETE PROFILING IN JUNIOR AUSTRALIAN FOOTBALL

Anthropometric Characteristics

The anthropometric characteristics of junior Australian footballers have been described in the context of age classifications (Cripps et al., 2016; Veale et al., 2010), team and draft prediction (Burgess, Naughton, & Hopkins, 2012; Keogh, 1999; Robertson et al., 2015; Woods et al., 2015), performance during match-play (Gastin & Bennett, 2014; Gastin, Bennett, et al., 2013; James P Veale & Alan J Pearce, 2009) and the relationship to injury (Chalmers et al., 2013; Lathlean, Gastin, Newstead, & Finch, 2018). Similar to other field sports, a positive correlation exists between stature, body mass and team selection within Australian football (Keogh, 1999; Pyne et al., 2006; Woods et al., 2015). While the influence of biological maturation diminishes in later adolescence (Fransen et al., 2017; Malina et al., 2015), anthropometric and morphological differences can still be apparent within player cohorts (Woods et al., 2015). While it may create a restrictive approach to athlete development pathways, there appears to be a selection bias towards players regarded as exhibiting superior physical capacity within Australian football.

From a selection perspective, nomadic players are generally smaller and lighter and undertake more low to high-speed running during match-play (Gastin, Bennett, et al., 2013; Young & Pryor, 2007). Interestingly, stature was explanatory of the selection of talent identified under-18 players, while increased body mass was associated with talent identified under-16 player (Veale, Pearce, Koehn, & Carlson, 2008; Woods et al., 2017). Regarding match-play performance, under-15 players with advanced biological maturity displayed greater stature and body mass and undertook more high-speed running distance and efforts (Gastin & Bennett, 2014). However, when viewing anthropometric data within an injury context, junior players with a higher body mass index displayed a greater injury severity risk (Chalmers et al., 2013). It appears these risks can be offset by increasing aerobic capacity and muscular strength. While early maturation seems to suggest superior performance and selection outcomes within junior sports (Fransen et al., 2017; Gastin & Bennett, 2014; Gastin, Bennett, et al., 2013), this phenomenon seems to decrease as adolescents mature chronologically and biologically (Tribolet et al., 2018). Regarding junior players transitioning to professional Australian football teams, anthropometric and body composition characteristics are likely different between experienced and less experienced players (Bilsborough et al., 2015; Veale et al., 2010). It is unlikely that these differences can be minimised during one pre-season period (Burgess, Naughton, & Norton, 2012), exposing new draftees to an elevated injury risk with increased training loads. Therefore, implementing appropriate training strategies and monitoring systems, including resistance training to develop neuromuscular and morphological characteristics, within an individual's draft year may encourage positive selection and transition outcomes to professional teams. Unfortunately, minimal research has investigated this concept in an Australian football context to date.

Aerobic & Anaerobic Characteristics

Australian football has been defined as an intermittent, locomotor field sport, with common running tests providing a broad understanding of an athlete's aerobic and anaerobic capacity. While exploring these measures with junior Australian footballers, there appears to be conjecture regarding running ability and anthropometric characteristics. Similar to junior basketballers (E Silva, Figueiredo, Moreira Carvalho, & Malina, 2008), biological maturity was a key predictor of the success across a broad range of physical performance tests with a cohort of 16-year-old Australian footballers (Cripps et al., 2016). However, a poor relationship between maturity and estimated VO_2max scores was reported (Cripps et al., 2016), and supported by a previous investigation (Gastin & Bennett, 2014). From a match-play performance perspective, Gastin and Bennett (2014) reported a strong relationship between estimated VO_2max scores from the multi-stage fitness test and high-intensity running distance during Australian football match-play. Interestingly, time recorded for a 20m sprint was explanatory of talent identified under-16 and under-18 players (Woods et al., 2017) indicating the importance of this physical capacity.

Further, physical characteristics that indicated career success included superior anaerobic capacity, sprints during match-play and 5m, 10m, 20m sprint times (Burgess, Naughton, & Hopkins, 2012). Whilst the match-play running demands of junior (Burgess, Naughton, & Norton, 2012; Henderson et al., 2015; Veale & Pearce, 2009; Woods et al., 2016) and senior (Black et al., 2016; Coutts et al., 2010; Delaney et al., 2017; Johnston et al., 2015c; Rennie et al., 2018) Australian football players are known, few studies have directly compared aerobic and anaerobic capacity between competition tiers. While it is important to recognise the match-play demands of junior and elite Australian football, a thorough understanding of the baseline running characteristics of junior Australian footballers can contribute to the optimisation of training practices and player selection.

Strength & Power Characteristics

The ability to express strength and power is required for a number of Australian football match-play activities, including jumping, sprinting, tackling and fending opponents (Hrysomallis & Buttifant, 2012). Due to the plethora of physical match-play demands, challenges for sports scientists and high-performance managers persist to prepare all the physical characteristics required for match-play. Whilst strength differences are common between junior and senior players, a group of elite under-18 Australian footballers recorded significantly lower movement competency scores compared to their senior counterparts (Woods, McKeown, et al., 2016). Movement competency has been traditionally assessed using the Functional Movement Screen (FMS^{TM}), a test aiming to identify muscular asymmetries and dysfunction using a battery of assessments (Cook, et al., 2006a; Cook, et al., 2006b). While this movement assessment has shown moderate to good intra- and inter-tester reliability (McCunn, et al., 2016; Moran, et al., 2016), the ability to predict injury was reported as poor (Newton et al., 2017). The recently designed Athletic Ability Assessment (AAA) was designed to assess movements more commonly associated with strength and conditioning exercises, with good intra- and inter-tester reliability reported (McKeown, et al., 2014).

Within the junior development pathway, it appears the stronger players are afforded greater selection opportunities (Keogh, 1999). It is likely that coaches view athletes with advanced physical characteristics as better able to cope with the physical requirements of match-play. Therefore, if resistance training opportunities are restricted within junior programs, selection will likely be limited for physically immature players. While increased muscular strength is likely a consequence of advanced biological maturity, junior players can prompt significant body composition, strength and power changes through resistance training (Christou et al., 2006; Granacher et al., 2011; Keiner et al., 2013). It is important to note that while strength differences are apparent between junior and professional Australian footballers (Bilsborough et al., 2015), new draftees may be exposed to match-play within their first year (Burgess, Naughton, & Hopkins, 2012). Therefore, the transition to professional Australian football will be further supported by undertaking resistance training prior to the draft selection.

Muscular power is a physical characteristic that has also differentiated across competition tiers (Bilsborough et al., 2015) and within chronologically age-matched player groups (Keogh, 1999; Veale et al., 2008; Woods et al., 2015). The vertical jump is one such performance measure related to talent identified junior Australian footballers. As it relates to the expression of horizontal power and match-play running, a strong relationship between vertical jump and sprint performance has been reported (Köklü, Alemdaroğlu, Özkan, Koz, & Ersöz, 2015). These are two activities frequently performed in Australian football and can occur during key moments of match-play (Gray & Jenkins, 2010). While the strength and power characteristics of professional Australian footballers has been extensively examined, fewer studies have investigated junior players, specifically comparing the differences to professional player cohorts. In addition, it is unknown whether junior Australian footballers can elicit changes in muscular strength and power through a properly prescribed training intervention during the pre-season or in-season periods. Such information would be useful to sports scientists and strength and conditioning coaches to enable optimal training prescription throughout the competitive year.

2.4.4 ATHLETE PROFILING IN PROFESSIONAL AUSTRALIAN FOOTBALL

Anthropometric Characteristics

It appears that anthropometry and body composition can distinguish elite Australian footballers from their sub-elite and junior counterparts (Bilsborough et al., 2015; Gastin, Fahrner, et al., 2013; Mooney et al., 2011; Young et al., 2005). Anthropometric characteristics likely influence team selection at the elite level to a lesser extent than for junior cohorts, however, do differ according to positional requirements (Pyne et al., 2006). Stature can vary within forward and defender positional groups, while nomadic players are generally smaller than key forward, defender and ruck positions (Pyne et al., 2006; Young & Pryor, 2007). Regarding four groups of Australian footballers of varying chronological ages, the most experienced elite senior players (≥4 years) were heavier and exhibited higher absolute fat-free soft tissue mass (Bilsborough et al., 2015). An investigation using players classified as "young" or "old" based on chronological age reported that older players had greater stature, body mass and a higher sum of seven skinfolds (Hrysomallis & Buttifant, 2012). Interestingly, this older player cohort was able to maintain strength and power characteristics over a competition period (Hrysomallis & Buttifant, 2012), potentially indicating that more experienced players can retain muscle mass despite the likely presence of residual fatigue through the competition period. Again, players classified as more experienced exhibited greater body mass, however, similar stature was reported when compared to a less experienced player group (Black et al., 2016). It appears that increased body mass is a discriminant factor regarding experience in Australian football and is likely augmented by greater resistance training experience. When assessing the relationship between body composition and performance tests, a group of selected players exhibited a lower sum of 7 skinfolds, superior repeat sprint ability, 3 km time trial performance and 40 m sprint times to their non-selected counterparts (Le Rossignol, Gabbett, Comerford, & Stanton, 2014). Despite these findings highlighting the differences in body mass and fat-free mass across professional player cohorts, physical performance tests may provide a superior indicator of selection or career outcomes.

Aerobic & Anaerobic Characteristics

Physical characteristics associated with success in Australian football include speed, acceleration and repeat sprint ability (Gray & Jenkins, 2010). While these explosive movements can occur during important stages of match-play, the development of aerobic fitness is also important due to match-play duration being up to and beyond 100 minutes (Aughey, 2010; Mooney et al., 2011) along with the notion of recovery being an aerobically driven process. Indeed, players can cover over 13 km and work at average intensities above 128 $m \cdot min^{-1}$ during match-play (Coutts et al., 2015; Johnston et al., 2016). Australian footballers reportedly cover more high-speed running distances than players in rugby league and soccer codes (Varley, Gabbett, & Aughey, 2014), therefore, it seems practical to train this energy system in an attempt to influence match performance outcomes.

Australian footballers have recorded VO_2max scores ranging from 61 ± 3.3 to 63 ± 4.8 $ml \cdot kg^{-1} \cdot min^{-1}$ (Aughey, 2013; Pyne et al., 2006; Young & Pryor, 2007) and are comparable with soccer (Mohammedet al., 2018) and hockey players (Manna, Khanna, & Dhara, 2009). From a match-play perspective, players with greater VO_2max scores recorded superior running distance and performed more high-speed running distance (Ryan et al., 2017). While VO_2max appears to be an important attribute of Australian footballers, repeated sprint and shuttle run tests provide alternative measures of running capacity, particularly in the context of the type of running experienced during match-play. One such test of repeated running ability is the Yo-Yo IR2 and has demonstrated a strong relationship with HSR and ball disposals during match-play (Mooney et al., 2011). These findings suggested that the ability to undertake repeated HSR may increase physical and technical skill performance, however, a specific investigation of this concept failed to demonstrate a relationship between a Yo-Yo test and a coaches performance rating or player impact scores (Mooney et al., 2011). Conversely while developing repeated running ability and maximum speed are undoubtedly important due to the intermittent running nature of Australian football match-play, aerobic capacity demonstrated a strong relationship with player impact scores during match-play (Gastin, Fahrner, et al., 2013). Despite these mixed findings, the available investigations indicate the importance of developing the aerobic and anaerobic energy systems. Accordingly, it appears Australian footballers should be specifically tested and trained for these multifaceted match-play running requirements.

Strength & Power Characteristics

The ability to express muscular strength and power is important for many sports and can distinguish across player groups in Australian football (Bilsborough et al., 2015; Caia et al., 2013; Hrysomallis & Buttifant, 2012; Keogh, 1999; Young et al., 2005). Despite limited research comparing strength and power characteristics of junior and professional Australian footballers, it appears there are significant differences between these competition tiers (Bilsborough et al., 2015). Similar to physical capacity measures noted earlier, biological maturity, training history and training load likely contribute to these differences. The differences between players classified as elite and sub-elite were reportedly greater than experienced and less experienced players within a professional team (Bilsborough et al., 2015; Caia et al., 2013). It seems players can improve strength and power capacity in a relatively short time-frame within a professional Australian football environment.

Regarding playing positions, key forward and back positions reportedly possess superior levels of strength compared to nomadic players (Young et al., 2005). These positions require upper body strength to execute wrestling, fending and tackling to gain possession from the opposition. Therefore, the importance of increasing muscular strength appears to vary across playing positions within Australian football. The ability to maintain strength and power over an entire season appears to be imperative for maintaining performance (Hrysomallis & Buttifant, 2012) and minimising injury risks (Lovell et al., 2018). Importantly, it seems that players can maintain this physical capacity throughout a season with the correct approach to resistance training (Hrysomallis & Buttifant, 2012; McGuigan et al., 2009). Naturally, consideration must be given to relatively younger players recording lower levels of strength and power (Hrysomallis & Buttifant, 2012) however such instances must be rectified in an attempt to heighten performance output and improve player resilience.

It seems older players are better able to express force during upper and lower-body power assessments (Bilsborough et al., 2015; Hrysomallis & Buttifant, 2012; Young et al., 2005). This is important as both these physical characteristics are positively related to accelerating, sprinting and tackling proficiency (Cunningham et al., 2013; Speranza et al., 2015). These activities can occur during important contested and uncontested periods in Australian football. While new draftees within Australian football have an increased opportunity for muscular strength and power development, it also seems these athletes need to time to adjust to increased training loads, match-play intensity, injury risks and residual fatigue. While a modified training approach is likely for this player cohort, regular strength and power assessments can assist with program design and implementation and therefore lead to a successful transition to a professional team. There remains an absence of research specifically recording the time-course of strength and power adaptations in junior Australian footballers as they transition to sub-elite or elite competition tiers. Further, information about benchmarking with older, more experienced players remains in its infancy, therefore, additional research would aid in the understanding of this important concept.

2.4.5 SUMMARY

Athlete profiling has been undertaken for a broad range of physical characteristics and sports, providing coaches with detailed knowledge of potential recruits, assisting with selection and recruitment and directing training practices. It is clear that each sport is multifaceted and requires a diverse range of physical requirements for successful match-play outcomes. Collision sports such as rugby league and rugby union favour strength and power characteristics, while locomotor sports such as Australian football, soccer and Gaelic football require aerobic and anaerobic energy system development. The transition from junior to elite level competition is clearly challenging, partially due to the substantial gap in physical capacity between these competition tiers. The transition between tiers likely involves a substantial increase in training load, match-play intensity and subsequent injury risks. Collectively, these reasons highlight the need for further profiling research within and across competition tiers of Australian football, primarily to assist with benchmarking athletes against known high standards and to ensure that appropriate training practices are implemented for optimal athlete development. The process by which athletes develop the required physical characteristics are varied and can involve field or gym-based training methods, with a number of considerations noted in the following section of this review.

2.5 TRAINING PRACTICES FOR FIELD SPORTS: A BRIEF OVERVIEW

Although a number of studies have described and compared anthropometric and physical characteristics with regards to match-play performance (Cullen et al., 2017; Gastin, Fahrner, et al., 2013; Mooney et al., 2011), selection (Gabbett, Georgieff, & Domrow, 2007; Robertson et al., 2015; Tredrea et al., 2017; Woods et al., 2015; Young et al., 2005) or career outcomes (Burgess, Naughton, & Hopkins, 2012; Gabbett et al., 2009; Pyne et al., 2005), far fewer investigations have assessed the adaptive responses of team sport athletes to running or resistance training. As such, the ability to prescribe, monitor and measure the outcomes of training is key to assessing their effectiveness for athlete development or the overall health of a physical performance program. The majority of research in this area has been conducted with professional athletes, however, it appears that the correct prescription of running training or resistance training programs can also lead to meaningful improvements in junior athlete cohorts. The following section outlines the research in this area to-date, noting scope for further investigation.

2.5.1 PROFESSIONAL ATHLETES

Typical running-based training methods with professional athletes involve sprints, repeated sprints or aerobic running drills. Within soccer, training interventions to stimulate aerobic and anaerobic adaptations have typically involved small-sided games (Fanchini et al., 2011; Fransson et al., 2018; Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011; Hill-Haas, Dawson, Coutts, & Rowsell, 2009; Özcan, Eniseler, & Şahan, 2018; Rampinini et al., 2007) or short and long interval running (da Silva et al., 2015; de Villarreal, Suarez-Arrones, Requena, Haff, & Ferrete, 2015; Dellal et al., 2008; Impellizzeri et al., 2006). Conversely, sports requiring repeated short, intense movements such as volleyball have utilised alternative training approaches to condition their athletes. A jump-specific training program to improve jumping, movement speed and the ability to repeatedly perform these movements reported a moderate improvement in these activities (Sheppard, Gabbett, & Borgeaud, 2008). Using a game-specific training approach, professional rugby league players elicited improvements in agility performance, vertical jump and relative VO_2max scores (Gabbett, 2006b). Conversely, superior maximal aerobic speed scores calculated following a pre-season training period were related to the distance covered during match-play (Swaby, Jones, & Comfort, 2016). It is clear that a properly prescribed and applied training program can elicit positive adaptations as measured through testing and subsequent match performance.

Separate to targeted running programs, strength and power training programs are generally prescribed to stimulate neuromuscular or morphological changes (Carr, McMahon, & Comfort, 2017; Helgerud, Rodas, Kemi, & Hoff, 2011; Styles, Matthews, & Comfort, 2016) and reduce injury incidence in athletes (Askling, Karlsson, & Thorstensson, 2003; Bennell et al., 1998; Brooks, Fuller, Kemp, & Reddin, 2006; Holcomb, Rubley, Lee, & Guadagnoli, 2007). Carr et al. (2017) implemented a season-long strength training protocol with first-class county cricket players, involving two training sessions per week during the off-season and one session per week during the pre-competition and competition phases. Strength (+15%) and power (+4.3%) were increased during the off-season and pre-season periods, however, a decline in these capacities was noted during the competition phase. A number of investigations have detailed strength and power changes over a competitive season with various field sport athletes. Australian footballers (Hrysomallis & Buttifant, 2012), American footballers (Hoffman & Kang, 2003) and rugby union players (Argus et al., 2009) all maintained maximal strength, with no significant improvements evident over a competitive season. Conversely, a group of basketballers displayed improved upper-body strength over a similar time period (Hoffman & Kaminsky, 2000). Interestingly, these investigations revealed that the greatest strength changes were elicited by the least experienced athletes. Therefore it seems important to monitor strength and power adaptations throughout a season as opposed to solely during the preparation period. It appears difficult to maintain baseline physical capacity levels from the pre-season through to the competition phase which may be due to restricted training opportunities in the competition phase, therefore the physical capacity of professional athletes may plateau over this time period. Further, the importance of an elite training environment has been shown with athletes competing at a higher competition level displaying greater strength and power (Argus et al., 2012). While older athletes with higher training ages and superior maturation may display greater absolute physical capacity, junior athletes may indeed have greater scope for neuromuscular development (Argus et al., 2012).

2.5.2 JUNIOR ATHLETES

While research with junior athletes has extensively focused on presenting normative anthropometric or physical data (Canhadas et al., 2010; Carling et al., 2009; Cullen et al., 2013; Cullen et al., 2017; Darrall-Jones et al., 2015; Gabbett, 2002; Gil et al., 2007; le Gall et al., 2010; Perroni, Vetrano, Camolese, Guidetti, & Baldari, 2015; Rebelo et al., 2013; Till et al., 2015; Till et al., 2014; Veale et al., 2010; Woods et al., 2017), contemporary research is required to assess the effectiveness of training practices with this cohort. Junior athletes are likely unable to cope with the training load and volume prescribed to senior athletes, however, the provision of similar training modalities may indeed be effective. The development of aerobic capacity with under 17 junior soccer players utilised a sport-specific training approach, whereby players were required to dribble a football on a specifically designed circuit for four 4 minute periods, with VO_2max improving by 9% (McMillan et al., 2005, Helgerud, Macdonald, & Hoff, 2005). An alternate group of junior soccer players used a 4 by 4-minute interval running protocol and demonstrated an average relative VO_2max increase of 10% after 8 weeks of training (Jan Helgerud et al., 2001). Key outcomes of this investigation were the increased match running performance of the training group combined with improved VO_2max scores (Jan

Helgerud et al., 2001). Additionally, junior soccer players showed VO_2max improvements after undertaking a high-intensity intermittent running approach (>80% HR_{max}) over 8 weeks (Gaetano & Rago, 2014). It is clear that sport-specific running protocols can be effective at eliciting positive VO_2max and match-play running changes with junior athletes.

An investigation across competition tiers within rugby league noted greater improvements in VO_2max scores for junior players compared to their professional counterparts after a 14-week pre-season training program (Gabbett, 2006b). Both groups recorded comparable physical capacities prior to the training program and undertook similar training modalities. The greater VO_2max changes were likely due to the reduced training age of the junior players, providing scope for increased neuromuscular and cardiovascular adaptations (Gabbett, 2006b). In addition, a group of under-15 year rugby league players recorded superior VO_2max changes compared to an under-18 year group after a 10-week training program (Gabbett, Johns, & Riemann, 2008). Interestingly, players undertook the same training program, consisting of specific strength and conditioning drills, combined with technical skill training (Gabbett, 2006b; Gabbett et al., 2008). Both these investigations speculated that a reduced training age provided greater scope for improvement when a similar training stimulus is administered (Gabbett et al., 2008). Ultimately a cardiovascular training stimulus was provided to ensure optimal physical and technical skill output during match-play. While intermittent bouts of high intensity running are common to field sports (Cunningham et al., 2018; Hulin, Gabbett, Johnston, & Jenkins, 2018; Scott et al., 2017; Silva et al., 2018; Veugelers, Naughton, Duncan, Burgess, & Graham, 2016) and when enhanced can improve technical skill performance (Mooney et al., 2011), increasing aerobic capacity appears to limit performance decrements (Delextrat & Martinez, 2014; Hoff & Helgerud, 2004; Impellizzeri et al., 2008; Tosun, Hürmüz, & Gökmen, 2017).

It appears that muscular strength and power differences are greatest between junior and professional athlete cohorts (Argus et al., 2012; Gabbett et al., 2009). As such, a number of investigations have shown the effectiveness of resistance training programs to improve the strength and power qualities of junior athletes (Christou et al., 2006; Comfort et al., 2014; Coutts, Murphy, & Dascombe, 2004). A six-week training program involving 16 elite-junior rugby league players improved upper-body strength and power (Riviere, Louit, Strokosch, & Seitz, 2017). The study design involved two training sessions per week, using a variable or traditional resistance training approach, with greater adaptations reported in the variable resistance trained group (Riviere et al., 2017). Two further investigations using a training group and control group performing regular skills training, reported greater strength and power changes with the addition of resistance training to normal technical skills training (Christou et al., 2006; Keiner et al., 2013). While specific neuromuscular adaptations to resistance training with junior populations have been documented (Ozmun, Mikesky, & Surburg, 1994; Ramsay et al., 1990), these findings demonstrate that a dual training stimulus can be effective at eliciting muscular adaptations. Resistance training using high loads (85-100% of 1 Repetition Maximum) improved peak power, sprint times, squat jump height and 5-jump distance with junior soccer players (Chelly et al., 2009). While establishing the safety of prescribing relatively heavy loads for junior athletes, this investigation also demonstrated the wide-ranging performance benefits of resistance training for junior athletes. From a performance perspective, tennis players improved over a number of performance tasks after a 6-week neuromuscular training program involving plyometric, strength and jump components. It seems physical and performance improvements can be gained by junior athletes participating in appropriately designed and implemented training programs, however, this concept has not been investigated in detail with junior Australian footballers and therefore requires further research.

By examining running, strength or power training programs across a range of sports, a clear understanding of successful training modalities can be established. From the studies available, there appears to be a paucity of investigations regarding junior Australian footballers. While a broad understanding of the anthropometric and physical characteristics associated with success has been established, further investigations to establish appropriate training modalities to develop these characteristics are required. By understanding the current gaps in physical capacity between elite-junior and professional players, training within the elite-junior development pathway can be specifically directed for improved draft outcomes or successful transition to professional teams.

2.6 SUMMARY

Team sports including Australian football require a multifaceted approach to physically develop junior athletes and prepare these athletes to optimally transition to the elite level. Currently, the availability of physical and match-play data is commonplace for a number of sports, including Australian football. While the prevalence of the current investigations are based on individual player cohorts, an area yet to gain in-depth attention is the comparison from junior through to elite senior Australian footballers. This may be due to the absence of, or limited access to elite-junior athlete populations and the ability to standardise test design across these tiers of competition.

Within Australian football, a large portion of anthropometric and physical profiling data has been reported in relation to team selection, draft outcomes or career success. These investigations have provided a broad understanding of the physical characteristics required for junior, sub-elite senior and elite senior Australian footballers. Despite these investigations, a paucity of research exists regarding direct comparisons from elite-junior through to elite senior players. While it is negligent to assume junior athletes can train at the same volume or intensity as their elite senior counterparts, understanding the gap between these competition levels can aid with the prescription of safe and effective training programs and optimize the transition to professional Australian football. Although several authors recently investigated and compared the physical demands of sub-elite and elite senior match-play, this review of the literature highlighted a paucity of studies involving junior players. While an original investigation by Burgess et al. (2012) provided a frame of reference to compare elite-junior and professional Australian footballers, contemporary research is required to provide an updated examination. By providing an analysis of the anthropometric, physical and match-play profiles of elite-junior, sub-elite senior and elite senior players, an enhanced understanding of the transition from elite-junior to professional Australian football will be identified.

The following five chapters present information about five applied studies that have attempted to provide further enquiry into these topics.

CHAPTER THREE

DIFFERENCES IN PHYSICAL CAPACITY BETWEEEN JUNIOR AND SENIOR AUSTRALIAN FOOTBALLERS

As per the manuscript published in the *Journal of Strength and Conditioning Research*:

Kelly, S.J, Watsford, M.L., Austin, D.J., Spurrs, R.W., Pine, M.J., Rennie, M.J. Differences in Physical Capacity between Junior and Senior Australian Footballers. *Journal of Strength and Conditioning Research.* 2017; 31(11):3059-3066.

ABSTRACT

The purpose of this study was to profile and compare anthropometric and physical capacities in elite-junior and senior Australian football (AF) athletes of various chronological ages and stages of athletic development. Seventy-nine junior and professional senior AF athletes undertook eleven assessments to profile and compare differences in anthropometric and physical capacities. Junior athletes were divided into two groups based on chronological age (under-16 and -18 years) with senior contracted athletes grouped according to years since drafted to a professional team (1-2 years, 3-7 years and 8+ years). Parametric data was assessed using a one-way analysis of variance (ANOVA), while nonparametric data was assessed using a Kruskal Wallis ANOVA. The magnitude difference between groups was measured using effect size (Cohen's d). Significant differences were evident between under 16 group and all senior groups for anthropometric ($p = 0.0012$-0.019/$d = 1.25$-2.13), absolute strength ($p = 0.0011$-0.01/$d = 1.82$-4.46) and relative strength ($p = 0.0011$-0.027/$d = 0.84$-3.55) measures. The under 18 group displayed significantly lower absolute strength ($p = 0.0011$-0.012/$d = 1.82$-3.79), and relative strength ($p = 0.0011$-0.027/$d = 0.85$-4.00) to the 3 to 7 and 8+ groups. Lower power output was also evident between the under 16 group and senior groups for upper and lower body measures ($p = 0.0011$-0.017/$d = 1.03$-2.99). Minimal differences were evident between all groups for running assessments, however, the under 16 group were significantly slower compared with the 8+ group for the 3km time trial ($p < 0.02$/$d = 1.31$). Both junior groups covered significantly less distance during the Yo-Yo IR2 ($p < 0.02$/ $d = 1.19$ and 1.60) in comparison to the 8+ group. It is evident from this study that there are significant differences in strength and power between junior and senior AF athletes.

Key Words: Australian football, physical profiling, athlete development, strength, power

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CHAPTER FOUR

MATCH-PLAY ACTIVITY PROFILES AND ENERGY COST OF ELITE-JUNIOR, SUB-ELITE AND ELITE SENIOR AUSTRALIA FOOTBALLERS

As per the manuscript published in *PLOS ONE:*

Kelly, S.J, Watsford, M.L., Austin, D.J., Spurrs, R.W., Pine, M.J., Rennie, M.J. Match-play activity profiles and energy cost of elite-junior, sub-elite and elite senior Australian footballers. PLOS ONE, 14(2): e0212047. https://doi.org/10.1371/journal.pone.0212047

Abstract

Aims

Currently, minimal research has quantified physical requirement differences in match-play between youth and senior Australian football players. The aim of the current research was to describe and compare the movement profiles and energy cost of youth, sub-elite and elite senior Australian football match-play.

Methods

Fifty-seven Australian footballers playing in an elite senior (20), sub-elite senior (16) and elite youth competition (21) participated in this study. Distance, speed based indices and metabolic power measures recorded via Global Positioning System (GPS) devices were compared across three competition tiers. Kicks and handballs were collected via a commercial statistics provider (Champion Data©) and compared across the competition tiers.

Results

Youth players recorded less field time (elite: ES = 1.37/sub-elite: ES = 1.68), total distance (elite: ES = 1.64 /sub-elite: ES = 1.55) and high speed running (elite: ES = 0.90/sub-elite: ES = 0.26) compared to the elite and sub-elite players. The average energy cost of elite (ES = 2.19) and sub-elite (ES = 1.58) match-play was significantly higher than youth match-play.

Conclusions

A progressive increase regarding physical demands was evident across AF competition tiers. The findings suggest that sub-elite match-play can provide a viable pathway for youth players to develop physical capacity and technical skills before transitioning to elite senior match-play.

Keywords: high speed running, energy cost, youth development pathway

Introduction

Team sports movement demand information is commonly collected by video-based analysis and more recently Global Positioning Systems (GPS) and accelerometer based microtechnology. This has provided quantitative data relating to training and match workloads within field sports. This data has recently been integrated with technical skills, providing holistic insights into player performance (1-3). Physical performance within Australian football (AF) match-play has previously been reported for elite senior (Australian Football League) (4, 5), sub-elite senior (state reserve competition league) (6, 7) and elite-junior players (national under 18-year competition) (3, 8, 9). Despite the increased availability of match-play data regarding AF players, little objective research has directly compared across competition tiers from junior through to elite senior players. With the evolving nature of professional AF match-play (6, 8), challenges persist regarding optimal development and management strategies for junior players. Therefore, contemporary data is required to guide best practices regarding the junior development pathway within AF.

Previous research investigating the gap in match-play demands between junior and professional AF players reported a divergence in match-play intensity between these competition tiers over a number of competitive seasons (8). Elite senior AF match-play is more intense and comprises of greater high-speed running and higher energy expenditure than sub-elite senior match-play (6, 7, 10). From a technical skills perspective, it appears that senior players classified as lower calibre perform at a high intensity during match-play (2). This poses a number of challenges regarding the optimisation of physical and technical skill development of junior and sub-elite players. Although a 1 to 4 year period is typically required before players make their debut within AF, there is increasing evidence that newly drafted players are exposed to professional match-play earlier in their careers (8). This is period is likely hastened when players are selected earlier during the national draft. There may be risks that young players have not acquired adequate physical readiness to cope with the increased physical demands of professional AF (8). Inferior strength and movement competency are evident between junior AF players (11-13), increasing potential injury incidences of younger players exposed to an increased training workload or match-play intensity. Therefore, the benefits of quantifying differences in physical demands between junior, sub-elite senior and elite senior AF match-play are twofold. Firstly, it can direct training practices within the junior development pathway and secondly provide a framework to optimally prepare junior players for professional AF match demands.

While a broad understanding of the physiological and anthropometric characteristics of junior AF players is known (14-16), further research is required to directly quantify differences across competition tiers in AF. Therefore, this study aimed to describe and compare match-play movement demands, energy cost and the number of kick and handball involvements across three AF competition tiers. Given that the differences between the physical demands of elite and sub-elite match-play have been widely examined (6, 7, 17), this research was primarily undertaken to identify differences between junior and elite senior players and junior and sub-elite senior players. A progressive increase in match-play intensity across three AF competition tiers was hypothesised. Specifically, more high speed running (HSR), high accelerations (HA), high decelerations (HD) and a higher match-play energy cost would be evident in the elite and sub-elite senior competition tiers. Given professional AF players will likely have greater technical skill proficiency, it was expected that elite and sub-elite senior players would accrue a greater number of kick and handball involvements.

Materials and Methods

Study Design

To investigate differences in match-play movement demands and metabolic power indices across three AF competition tiers, this cross-sectional study was undertaken during one competitive in-season period. The study involved 17 elite senior, 17 sub-elite senior and 8 national U18 competition games. Data files were delimited to players classified as nomadic and other rotating positions, to standardize the collection procedures (4). Team selection varied weekly according to injury status and player form, with data analysis undertaken on players who participated in >75% of the total field time (4). Exclusion criteria included fixed forward, back and ruck positions, injuries to players and data files that were <74.99% of the total field time.

Participants

A total of 57 players from three tiers of AF participated in this research study. The distribution of players included; 20 elite senior (24.9 ± 3.8 years, 87.8 ± 9.4 kg, 185.2 ± 6.9 cm), 16 sub-elite senior (21.7 ± 2.7 years, 84.9 ± 5.5 kg, 184.6 ± 6.1 cm) and 21 junior players (17.9 ± 1.6 years, 80.8 ± 4.1 kg, 182.7 ± 4.2 cm). Written informed consent was obtained from participants and the organisations involved, with ethical approval granted by the Human Research Ethics Committee at the University of Technology Sydney (UTSHREC: 2014000427).

Data Analysis

Movement demands were recorded using commercially available 10Hz GPS devices (Catapult Innovations, Melbourne Australia), with players assigned the same device for each match, thus ensuring improved reliability within the data (4). The reliability and validity of these GPS devices have been reported elsewhere and deemed acceptable for data pooling (18, 19). The distribution of 467 data files included; 237 elite senior, 103 sub-elite senior and 77 junior competition files. Devices were placed in a custom designed pouch, positioned between the scapulae within the player's jersey as previously described (4).

Following each match, data was downloaded using Catapult Sprint (version 5.1.6; Catapult Innovations), with bench time and time between quarters excluded via the manufacturer's software. All data was exported to Microsoft Excel (Microsoft 2010, Redmond, USA) for further analyses. Non-individualised speed, acceleration and deceleration zones were established from classifications used in previous research (7, 21). Variables were expressed per minute of game time due to player rotations, providing individual total field times.

Movement demand and workload variables documented in previous AF studies were examined (4, 7), including total distance, average speed per minute and Playerload™ per minute. Velocity based measures were examined for distance, time spent and the number of efforts in two zone classifications, including low speed running (LSR, 0.0-14.4 $km{\cdot}h^{-1}$) and high speed running (HSR, 14.4-20.0 $km{\cdot}h^{-1}$) (7). Distance, time spent and number of efforts within acceleration and deceleration zone classifications were investigated according to previous research (21) for low decelerations (LD, -0.65 to -1.46 $m{\cdot}s^{-2}$), moderate decelerations (MD, -1.47 to -2.77 $m{\cdot}s^{-2}$), high decelerations (HD, <-2.78 $m{\cdot}s^{-2}$), low accelerations (LA, 0.65 to 1.46 $m{\cdot}s^{-2}$), moderate accelerations (MA, 1.47 to 2.77 $m{\cdot}s^{-2}$) and high accelerations (HA, >2.78 $m{\cdot}s^{-2}$) .

Metabolic power variables from the 10Hz GPS devices were collected, ensuring only data containing the highest resolution was analysed (22). These variables were calculated using an algorithm established previously (23) and included average energy expenditure

($kJ \cdot kg^{-1}$), estimated distance and total time and number of efforts in low power (LP, 0-19.99 $W \cdot kg^{-1}.min^{-1}$), high power (HP, 20-39.99 $W \cdot kg^{-1}.min^{-1}$) and very high power (HP, >40 $W \cdot kg^{-1}.min^{-1}$) zone classifications (7). Total kick (number of times a player disposed of the ball by foot) and handball (number of times a player disposed of the ball by hand) involvements were obtained from the provider of match statistics for the Australian football league (AFL) (Champion Data©, Victoria, Australia) and analysed per minute of game time.

Statistical Analysis

Descriptive statistics for all variables were reported as mean and 95% CI (lower and upper), with data assessed for normality and sphericity. A linear mixed model was used to account for pseudo-replication within the dataset. Individual players were included as a random effect, while the level of competition was defined as a fixed effect. Bonferroni post hoc comparisons were used to identify differences between groups. The analysis was undertaken using the Statistical Package for Social Sciences (version 21, IBM, Armonk, NY). Standardised effect size (ES) were computed and interpreted as <0.2, trivial; 0.21-0.6, small; 0.61-1.20, moderate; 1.21-2.0 large; >2.1 very large (24). An alpha level of $P<0.05$ was used for all statistical tests.

Results

Results for velocity, workload and technical skill variables across the competition tiers are reported in Table 4.1. Both senior player group's played more field time (d = 1.37/1.68) and covered a great total distance (d = 1.55/1.63) during match-play. Interestingly, when the total distance (d = 0.11/0.15) and Playerload™ (d = 0.21/0.53) were analysed relative to game time, differences between the junior players and senior player groups diminished. The senior player groups also performed more HSR distance (d = 0.26/0.90), time (d = 0.35/1.01) and efforts (d = 0.32/1.06). Regarding technical skill measures, notable differences were solely evident for handballs (d = 0.40) between sub-elite senior and junior players.

Table 4.1: Physical performance and technical skills for elite-junior, elite and sub-elite Australian footballers. Values are mean (95% CI).

	Elite-junior	Elite	Elite-junior vs Elite (Effect Size d)	Sub-Elite	Elite-junior vs Sub-Elite (Effect Size d)
Field Time	85.66 (83.55-87.77)	101.12 (100.08-102.16)[a]	1.37	106.35 (104.84-107.87)[ab]	1.68
Total Distance Covered (m)	10940 (10661-11219)	13193 (13047-13339)[a]	1.64	13189.34 (12967-13412)[a]	1.55
Average Speed ($m.min^{-1}$)	125.72 (122.73-128.70)	130.68 (129.28-132.08)[a]	0.15	126.53 (124.37-128.69)[b]	0.11
Player Load$\cdot min^{-1}$	12.39 (11.95-12.82)	13.74 (13.53-13.94)[a]	0.53	13.03 (12.71-13.35)[ab]	0.21
Low Speed Distance Covered ($m\cdot min^{-1}$)	89.04 (86.31-91.76)	86.41 (85.16-87.67)	0.62	89.77 (87.80-91.75)[b]	0.38
High Speed Distance Covered ($m\cdot min^{-1}$)	24.38 (22.67-26.10)	30.47 (29.62-31.32)[a]	0.90	25.64 (24.30-26.97)[b]	0.26
Low Speed Time ($\%\cdot min^{-1}$)	89.09 (88.35-89.83)	85.48 (85.11-85.86)[a]	0.96	87.92 (87.34-88.50)[ab]	0.30
High Speed Time ($\%\cdot min^{-1}$)	8.52 (7.93-9.11)	10.95 (10.65-11.24)[a]	1.01	9.13 (8.66-9.59)[b]	0.35
High Speed Efforts ($n\cdot min^{-1}$)	1.50 (1.42-1.57)	1.79 (1.75-1.83)[a]	1.06	1.51 (1.46-1.57)[b]	0.32
Kicks ($n\cdot min^{-1}$)	0.098 (0.087-0.108)	0.109 (0.103-0.115)	0.14	0.105 (0.097-0.114)	0.43
Handballs ($n\cdot min^{-1}$)	0.073 (0.062-0.084)	0.085 (0.079-0.091)	0.20	0.095 (0.086-0.104)[a]	0.40

[a] Significantly different to elite-junior AFL players (*P*<0.05)
[b] Significantly different to elite AFL players (*P*<0.05)

Data pertaining to accelerations, decelerations and metabolic power indices are presented in Tables 4.2 and 4.3. The elite senior players performed more distance (d = 0.67/1.98) and spent more time (d = 0.16/1.68) undertaking accelerations and decelerations. Conversely, junior players recorded a greater number of moderate and high acceleration (d = 0.35/1.00) and deceleration (d = 0.60/0.63) efforts. It was clear that mean energy cost of the elite (d = 2.19) and sub-elite match-play (d = 1.58) was considerably higher than junior match-play. Additionally, the estimated distance covered during elite (d = 1.73) and sub-elite (d = 1.12) match-play was considerably higher than junior match play. Finally, the junior players spent less time and recorded fewer efforts within low to high metabolic power zones, with differences ranging from small to very large.

Table 4.2: Acceleration and Deceleration data for elite-junior, elite and sub-elite Australian footballers. Values are mean (95% CI).

	Junior	Elite Senior	Elite-junior vs Elite (Effect Size d)	Sub-Elite Senior	Elite-junior vs Sub-Elite (Effect Size d)
Distance Covered ($m \cdot min^{-2}$)					
High Decelerations	1.16 (1.10-1.22)	1.34 (1.31-1.37)[a]	0.71	1.14 (1.10-1.18)[b]	0.05
Moderate Decelerations	3.39 (3.27-3.51)	3.69 (3.63-3.75)[a]	0.80	3.33 (3.24-3.42)[b]	0.32
Low Decelerations	7.66 (7.33-7.98)	10.43 (10.26-10.61)[a]	1.96	8.44 (8.19-8.69)[ab]	0.90
Low Accelerations	8.80 (8.45-9.16)	11.72 (11.54-11.90)[a]	1.98	9.86 (9.62-10.11)[ab]	0.99
Moderate Accelerations	4.12 (3.97-4.27)	4.68 (4.60-4.75)[a]	0.98	4.18 (4.07-4.28)[b]	0.42
High Accelerations	1.66 (1.56-1.75)	1.92 (1.87-1.96)[a]	0.67	1.38 (1.31-1.45)[ab]	0.43
Time Spent ($\% \cdot min^{-2}$)					
High Decelerations	0.86 (0.80-0.93)	1.25 (1.21-1.28)[a]	1.32	0.86 (0.81-0.92)[b]	0.17
Moderate Decelerations	2.34 (2.27-2.41)	2.44 (2.40-2.47)[a]	0.44	2.28 (2.22-2.33)[b]	0.19
Low Decelerations	5.71 (5.56-5.87)	6.79 (6.70-6.88)[a]	1.68	6.02 (5.90-6.13)[ab]	0.89
Low Accelerations	5.65 (5.49-5.82)	6.70 (6.61-6.80)[a]	1.60	6.12 (5.99-6.23)[ab]	0.59
Moderate Accelerations	2.56 (2.48-2.64)	2.63 (2.58-2.67)	0.16	2.60 (2.53-2.66)	0.54
High Accelerations	1.27 (1.20-1.35)	1.46 (1.42-1.50)[a]	0.46	1.12 (1.07-1.18)[ab]	0.14
Number of Efforts ($n \cdot min^{-2}$)					
High Decelerations	0.55 (0.52-0.58)	0.46 (0.44-0.47)[a]	0.63	0.52 (0.49-0.54)[b]	0.38
Moderate Decelerations	1.01 (0.94-1.06)	0.86 (0.83-1.01)[a]	0.60	0.98 (0.93-1.02)[b]	0.25
Low Decelerations	2.82 (2.71-2.93)	3.26 (3.19-3.33)[ab]	1.30	2.95 (2.87-3.02)	0.80
Low Accelerations	2.81 (2.69-2.93)	3.24 (3.16-3.31)[a]	1.12	3.09 (3.02-3.17)[a]	0.85
Moderate Accelerations	1.04 (1.01-1.12)	0.95 (0.91-0.99) [a]	0.35	1.12 (1.07-1.17)[a]	0.50
High Accelerations	0.49 (0.46-0.52)	0.36 (0.35-0.37)[a]	1.00	0.38 (0.36-0.40)[a]	0.58

[a] Significantly different to elite-junior AFL players (*P*<0.05)
[b] Significantly different to elite AFL players (*P*<0.05)

Table 4.3: Metabolic power data and energy cost for elite-junior, elite and sub-elite Australian footballers. Values are mean (95% CI).

	Junior	Elite Senior	Junior vs Elite Senior (Effect Size d)	Sub-Elite Senior	Junior vs Sub-Elite (Effect Size d)
Peak Metabolic Power ($W{\cdot}kg^{-1}$)	195.48 (189.63-210.32)	168.74 (162.36-175.23)[a]	0.41	165.29(155.48-175.10)[a]	0.19
Average Energy Expenditure ($kJ{\cdot}kg^{-1}$)	47.81(46.38-49.22)	62.55 (61.85-63.15[a]	2.19	59.61 (58.57-60.65)[ab]	1.58
Estimated Distance (ED)	13856 (13469-14244)	16959 (16788-17130)[a]	1.73	16373 (16099-16646)[ab]	1.12
Estimated Distance Index	1.269 (1.262-1.276)	1.283 (1.280-1.287)[a]	0.49	1.248 (1.242-1.253)[ab]	0.27
Time Spent ($W{\cdot}kg^{-1}{\cdot}min^{-1}$)					
Low Power	73.06 (71.28-74.84)	82.73 (81.85-83.60)[a]	0.91	90.91 (89.55-92.28)[ab]	1.45
High Power	7.10 (6.67-7.53)	10.31 (10.08-10.54)[a]	1.76	8.87 (8.52-9.23)[ab]	1.04
Very High power	1.85 (1.70-1.99)	2.71 (2.63-2.77)[a]	1.57	2.15 (2.04-2.26)[ab]	0.67
% Time Spent ($W{\cdot}kg^{-1}{\cdot}\%min^{-1}$)					
Low Power	85.51 (84.81-86.22)	82.25 (81.88-82.63)[a]	1.16	85.86 (85.27-86.44)[b]	0.23
High Power	8.00 (7.51-8.49)	10.29 (9.99-10.47)[a]	1.18	8.58 (8.20-8.95)[b]	0.38
Very High power	2.05 (1.91-2.19)	2.67 (2.60-2.74)[a]	1.10	2.06 (1.95-2.17)[b]	0.10
Number of Efforts ($W{\cdot}kg^{-1}{\cdot}n{\cdot}min^{-1}$)					
Low Power	353.75 (340.49-367.01)	508.83 (501.57-516.08)[a]	2.37	475.78 (464.66-486.91)[ab]	1.60
High Power	158.46 (150.75-166.17)	223.36 (219.38-227.34)[a]	1.96	195.99 (189.81-202.16)[ab]	1.18
Very High power	56.34 (51.56-61.13)	81.47 (79.07-83.86)[a]	1.38	66.08 (62.31-69.84)[ab]	0.64

[a] Significantly different to elite-junior AFL players (*P*<0.05)
[b] Significantly different to elite AFL players (*P*<0.05)

Discussion

This study provided a comparative analysis of match-play across three AF competition tiers. Match-play movement demand differences between elite senior and sub-elite senior competitions have been documented (6, 7), however, minimal research has incorporated junior AF players within the analysis (8). The main findings of the present study revealed a higher total game time for elite senior and sub-elite senior match-play and an overall progressive increase in HSR, HA, HD and energy cost across the competition tiers. These findings provided similar outcomes to previously observed match-play data between competition tiers within AF (6, 7). While physical performance differences were in congruence with the hypothesis, it appears that more kick and handball involvements are accrued in both sub-elite and elite match-play. Therefore, these findings illustrate a potential match-play pathway for junior players transitioning to professional AF, through sub-elite competitions.

Elite senior match play had the greatest workload and involved more HSR than the other competition tiers. Similar findings were reported between junior and elite senior AF players over a number of competitive seasons. Junior game speed within this research remained similar over a five year period, while elite senior match-play yielded a 25% increase (8). Elite senior players in the current investigation recorded 22%, 25% and 18% more HSR distance, time and efforts per minute, compared to the junior players. Alternatively, sub-elite players performed 5%, 7% and 1% more HSR distance, time and efforts per minute compared to the junior players. Importantly the capacity to perform HSR has been positively correlated with team selection in AF (25) and playing at a higher competition tier in futsal (26). Conversely, previous AF research reported that higher calibre players, as rated by skill coaches, performed less HSR than the lower calibre players within the same team.. It was suggested that as a result of greater field time, higher caliber players displayed increased fatigue (2). Due to the greater running volumes and intensities in both senior competition tiers, it seems prudent that junior players concurrently develop the aerobic and anaerobic energy systems. Further investigation regarding training practices to improve these physical characteristics is therefore warranted.

The findings regarding kicks and handballs indicated that both sub-elite and elite senior match-play afforded an opportunity to develop these technical skills. The number of total team kicks compared to the opposition has been reported to be a key indicator of performance success with AF (27), highlighting the importance of developing this skill. Regarding the competition tiers, it is likely that the interplay between internal (experience, technical ability, decision making) and external (opposition, team tactics, game state) factors (1), influenced technical skill proficiency differently for each group. Investigations within AF (1) and soccer (28) match-play reported a strong relationship between the early onset of fatigue and a reduction in technical skill performance. Within AF research reported higher caliber players accrued more skill involvements, while also undertaking less high intensity running (2). These players displayed a higher chronological age (2), indicating a relationship between technical skill acumen and match-play experience within AF. The current research suggests that junior players have not developed the required physical capacity to maintain skill proficiency during match-play.

Currently, there is minimal research highlighting the relationship between acceleration and deceleration efforts during field sports match-play (29, 30). Consequently, there is minimal data on the acceleration and deceleration profiles during elite-junior AF match-play. Elite senior players in the current investigation covered 15% more distance and spent 13% to 36% more time performing HA and HD movements, compared to the junior players. Similar findings have been reported between elite and sub-elite senior AF players for distance and time spent in HA and HD zones (7). This may reflect the superior capacity of elite senior players to perform and sustain moderate to high-intensity acceleration and deceleration movements. Interestingly, the junior players recorded 17% to 30% more HD and HA efforts compared to sub-elite and elite senior players. It seems junior players have developed a capacity to undertake HA efforts, however appear to have a diminished ability to sustain these rapid velocity changes. Due to the considerable energy cost of acceleration and deceleration movements (31), it is recommended that training practices with junior players replicate the various velocity, acceleration and deceleration movements evident in this research. Small-sided games are one such training modality utilized within soccer to stimulate match-play specific physical and technical skill development (32, 33). The recent advent of metabolic power data derived from microtechnology has revealed that small-sided games elicit a high volume of acceleration and deceleration movements (33). Small-sided games may replicate intense periods of match-play and therefore provide a beneficial training stimulus for AF players. Despite the regular implementation of this training modality within AF, little is currently known about the physical benefits of small-sided games. Future research should measure how this training modality can positively develop the physical capacity of junior AF players.

Although the authors acknowledge the questions surrounding the reliability and validity of microtechnology to accurately quantify metabolic power (23, 34), this was one of the first studies to provide data on the energy cost of junior AF match-play. Both senior match-play tiers resulted in a substantially higher mean energy cost. Although the authors recognize this absolute measure was likely biased by the greater field times evident for the senior competition tiers, these findings provide some practical implications for junior player development. The mean match-play energy cost for sub-elite and elite senior players was similar to an AF (57-66 $kj \cdot kg^{-1}$) (10) and soccer (66 $kj \cdot kg^{-1}$) (23) investigation. Conversely, an alternative AF study reported a higher mean match-play energy cost ranging from 74-76 $kj \cdot kg^{-1}$ (7). With the increased physical demands evident in elite senior AF (8), training practices within the junior develop pathway should continually evolve to prepare young players for the higher energy cost of senior match-play. Additionally, elite junior players may benefit from being progressively exposed during training practices, to the movement profiles commonly reported within elite senior AF. The hierarchical trend within the current investigation, outlines the challenges that exist transitioning junior players to elite senior AF.

A notable strength of this investigation was the recruitment of one professional AF team (elite and sub-elite cohort) who were exposed to a homogeneous training environment, while also using an established and embedded elite-junior development program. This provided the authors with a large cohort for cross-sectional analysis. As with all match analyses, the findings within this investigation reflect the tactical decisions of the coaching staff during match-play, and therefore caution is warranted when extrapolating the results to different AF teams or competition tiers. This was one of the first studies to identify and compare movement demands from junior through to elite senior match-play, with many relevant outcomes established. Future research should examine specific training practices to prepare junior players transitioning to professional AF teams.

Conclusion

A number of differences were evident for field time, HSR, HA, HD and match-play energy cost across competition tiers within AF. It was evident that sub-elite senior match-play allowed for increased field time, a reduction in running demands and similar technical skill involvements to elite senior match-play. Therefore, sub-elite senior match-play justifiably offers a match-play conduit to develop physical capacity and technical skill acumen during the transition from junior to elite senior AF match-play.

Acknowledgments

The authors would like to thank the players and staff of the Sydney Swans football club for their participation and cooperation throughout this research. The authors received no financial assistance for this research.

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CHAPTER FIVE

ACTIVITY PROFILE DIFFERENCES BETWEEN ELITE-JUNIOR AND PROFESSIONAL AUSTRALIAN FOOTBALLERS DURING SUB-ELITE MATCH-PLAY

As per the manuscript currently under review at the *International Journal of Sports Physiology and Performance:*

Kelly, S.J, Watsford, M.L., Rennie, M.J, Spurrs, R.W., Austin, D.J., Brosann, R. Activity profile differences between elite-junior and professional Australian footballers during a sub-elite match-play.

Abstract

Purpose: To assess differences in the physical characteristics of selected and non-selected Academy-level youth Australian Football (AF) players. A secondary purpose was to compare the match activity profiles of the selected youth Academy players and professional AF players competing in the same matches. *Methods:* Part 1 of the study examined 47 youth Academy players using anthropometric and physical assessments to determine body composition, running capacity and muscular strength and power. Part 2 of the study utilised Global Positioning Systems microtechnology to measure match activity profiles of 23 youth and 19 professional players during 21 matches in a National, sub-elite competition. Absolute and relative physical performance measures included field time, total distance, Playerload^{TM}, low-speed running (LSR), high-speed running (HSR) and low, moderate and high accelerations and decelerations. Kicks and handballs accrued during match-play were also compared across the youth and professional players. *Results:* Compared to the non-selected players, selected players were most likely older and very likely had greater body mass. Furthermore, they likely possessed greater running capacity and very likely possessed greater muscular strength. The selected players were most likely younger and likely displayed lower body mass and stature compared to the professional players. The professional players recorded greater absolute metrics including field time, total distance and Playerload^{TM}, however, selected youth players exhibited higher average speed, HSR and high acceleration and deceleration distance and efforts. *Conclusions:* Superior body mass, running capacity and muscular strength were indicative of youth player selection in an elite junior Academy. Relative, but not absolute physical performance outputs were higher in selected youth players when compared to professional AF players within the same match.

Keywords: selected youth players, physical profile, activity profiles.

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Kelly, S.J, Watsford, M.L., Rennie, M.J, Spurrs, R.W., Austin, D.J., Brosann, R. submitted, Activity profile differences between elite-junior and professional Australian footballers during a sub-elite match-play.

CHAPTER SIX

CHANGES IN THE PHYSICAL PROFILE OF FIRST YEAR AUSTRALIAN FOOTBALL PLAYERS DURING PRESEASON TRAINING

As per the manuscript under review at the *Journal of Strength and Conditioning Research:*

Kelly, S.J, Watsford, M.L., Rennie, M.J, Spurrs, R.W., Austin, D.J., Epakis, C. Changes in the Physical Profile of First Year Australian Football Players During Preseason Training.

ABSTRACT

This study described the anthropometric and physical changes of first year Australian football players. Twenty-seven first year Australian football players (mean ± SD age: 18.7 ± 1.9 years, body mass: 85.2 ± 8.7 kg, stature: 188.6 ± 6.8 cm) volunteered to participate in the investigation. The players were drafted to one professional Australian football club over a 3 year period and undertook nine assessments to profile and assess changes in anthropometric (body mass and stature) and physical capacities (running capacity, strength and power). The data was collected over the first 3-month pre-season period, where the recently drafted athlete arrived at a professional Australian football club. A test (early November) and re-test (early February) protocol was used to assess for possible changes over this time-frame. Significant increases were evident in body mass ($p<0.05$) and distances during the Yo-Yo IR2 test ($p<0.05$). No change was apparent for the 3km time trial test ($p=0.14$). Additionally, significant upper and lower body strength increases were apparent for the bench press ($p<0.05$), bench row ($p<0.05$), chin up ($p<0.05$), back squat ($p<0.05$) and Romanian deadlift ($p<0.05$). Finally, a significant increase in vertical jump height was found ($p<0.05$). It appears that first year Australian footballers can improve anthropometric and physical characteristics during their first pre-season period, likely due to training load increases from previous junior development programs. Therefore, this investigation provides insight into the development of new draftees within a professional Australian football team.

Keywords: Australian football, pre-season, anthropometric profile, physical profile,

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Kelly, S.J, Watsford, M.L., Rennie, M.J, Spurrs, R.W., Austin, D.J., Epakis, C. submitted, Changes in the Physical Profile of First Year Australian Football Players During Preseason Training.

CHAPTER SEVEN

EFFECTS OF A 12-WEEK RESISTANCE TRAINING PROGRAM ON THE STRENGTH AND POWER CHARACTERISTCS OF ELITE-JUNIOR AUSTRALIAN FOOTBALL PLAYERS

As per the manuscript under review at the *Journal of Science and Medicine in Sport:*

Kelly, S.J, Watsford, M.L., Rennie, M.J, Spurrs, R.W., Austin, D.J., Kenna, D. Effects of a 12-week resistance training program on the strength and power characteristics of elite-junior Australian football players.

Abstract

Objectives: This study investigated whether a 12-week resistance training intervention could improve the strength and power characteristics of junior Australian football players.

Design: Cohort study

Methods: Twenty-one male elite junior Australian football players were assessed for five strength and three power measures prior to and following a resistance training intervention. Players were allocated into a training group (n =11) or a control group (n =10) prior to the first testing period. The training group participated in a 12-week gym based resistance training intervention and concurrent technical skills training, while the control group participated in technical skills training only.

Results: The findings revealed significant pre- and post-test interactions between the groups with large effect sizes for a number of strength (η_p^2 = 0.15-0.39) and upper body power measures (η_p^2 = 0.27-0.32). Within-group analysis for the training group revealed moderate to large increases for a number of upper and lower body strength (ES = 1.01-1.32) tests and moderate to very large increases for upper and lower body power (ES = 0.62-2.40) tests. Conversely, the control group recorded very few positive changes with a moderate increase detected for the weighted chin (ES = 0.80), CMJ peak power (ES = 0.64) and the bench throw (ES = 0.76).

Conclusions: Compared to technical skills training alone, the addition of short-term resistance training appears to provide a safe and effective method to advance strength and power adaptations in adolescent athletes.

Key Words: Australian Football; upper body strength and power; lower body strength and power; adolescent athletes

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Kelly, S.J, Watsford, M.L., Rennie, M.J, Spurrs, R.W., Austin, D.J., Kenna, D. submitted, Effects of a 12-week resistance training program on the strength and power characteristics of elite-junior Australian football players.

CHAPTER EIGHT

GENERAL DISCUSSION

8.1 GENERAL DISCUSSION

Athlete profiling incorporates a number of elements including anthropometry, physical characteristics, technical skill and tactical performance and appraisal. Within an Australian football context, a number of investigations have assessed these elements of profiling with individual junior (Bilsborough et al., 2015; Burgess, Naughton, & Hopkins, 2012; Robertson et al., 2015; Tribolet et al., 2018; Veale et al., 2010; Woods et al., 2017; Woods, Joyce, et al., 2016; Woods et al., 2015; Woods et al., 2017; Young & Pryor, 2007) and elite player cohorts (Bilsborough et al., 2015; Caia et al., 2013; Gastin, Fahrner, et al., 2013; Hrysomallis & Buttifant, 2012; Mooney et al., 2011; Veale et al., 2010; Young et al., 2005), however, very few investigations have directly assessed elite-junior Australian footballers alongside a professional player cohort. The available research within Australian football, soccer, rugby league and rugby union suggests that a gap in physical and technical capacity exists between these competition tiers. However methods to mitigate these differences and optimally transition junior athletes to professional levels of competition have not been identified. Therefore, this thesis aimed to investigate the gap in physical and match-play activity profile characteristics across three tiers of Australian football and suggest strategies to optimally physically develop and progress athletes through junior pathway programs.

A series of applied research studies were conducted to improve the understanding of the anthropometric, physical and match-play activity profile characteristics of junior Australian footballers, while assessing the magnitude of the difference to professional Australian footballers. The five studies followed a logical sequence by first assessing the anthropometric and physical characteristics across elite-junior and professional player cohorts, and thereafter the match-play activity profiles of three competition tiers in

Australian football were assessed. Following this, the physical characteristics of selected and non-selected elite-junior players were determined and subsequently the match-play activity profiles of this elite-junior cohort were compared to professional players. Changes in the anthropometric and physical characteristics of newly drafted players were then assessed over the pre-season period to track this young cohort's transition into a professional environment. The final study served to improve the strength and power characteristics of elite-junior Australian footballers. These were key physical characteristics that distinguished elite-junior and professional players within the previous investigations. Collectively, the five studies provided a unique approach to profile the anthropometry, physical and match-play activity profile characteristics of elite-junior Australian footballers. Such information contributes to current understanding regarding the development of this player cohort. Each subcomponent of the five studies are discussed herein with respect to the main findings of topical importance.

The findings from *Study One* demonstrated absolute and relative strength and power differences between junior and senior Australian footballers. Additionally, the results indicated that elite-junior Australian footballers exhibit comparable aerobic running capacity to their elite senior counterparts. Despite previous Australian football research highlighting the physical profile of junior (Bilsborough et al., 2015; Burgess, Naughton, & Hopkins, 2012; Robertson et al., 2015; Veale et al., 2008; Woods et al., 2015; Young & Pryor, 2007) and elite players (Bilsborough et al., 2015; Hrysomallis & Buttifant, 2012; McGuigan et al., 2009; Pyne et al., 2005; Young et al., 2005), the findings from this study are unique, as they provide an in-depth analysis of physical capacity across a greater spectrum of elite-junior and elite players.

The results revealed differences between the two junior player groups and the three elite player groups for anthropometric, strength and power characteristics. Strength differences between junior and elite players were consistent with previous research (Bilsborough et al., 2015; Gabbett, 2002; Veale et al., 2010) and while influenced by training loads, these were likely augmented by biological growth and maturation factors (Fransen et al., 2017; Malina et al., 2015). .

Regarding strength outcomes, absolute and relative measures progressively increased from the under 16 player group, through to the 8+ year group. These findings were consistent with investigations across chronological age groups in Australian football (Young & Pryor, 2007), rugby league (Till et al., 2014), rugby union (Darrall-Jones et al., 2015) and soccer (Vandendriessche et al., 2012). In agreement with research monitoring muscular power changes (Hrysomallis & Buttifant, 2012; Till, Cobley, O'Hara, Chapman, & Cooke, 2013), the findings indicated that greater chronological age, biological maturation and training age all influence power adaptations. Therefore, given the relationship between muscle cross-sectional area and power production (Hulthen et al., 2001), it is reasonable to speculate that a higher power output would be achieved by elite players. Overall, the strength the power results confirmed previous findings (Argus et al., 2012; Bilsborough et al., 2015), with superior characteristics for chronologically older athletes. Less variance was evident between the groups for the running measures, with the 8+ year players yielding superior results compared to both junior player groups for the Yo-Yo IR2 test, however, no differences were evident for the time trial performances. Given the intermittent running requirements of Australian football and the similarity of match-play activity profiles with this test (Bangsbo et al., 2008), these findings regarding the intermittent running test are not surprising.

The major findings from this study reveal clear disparities between junior and elite Australian footballers for anthropometric and physical characteristics, notably muscular strength and power. These findings suggest the development of running capacity within elite-junior programs is relatively advanced compared with strength and power characteristics. The findings from this study have identified differences in anthropometric and physical characteristics between junior and elite senior Australian footballers and established key characteristics for coaches and strength and conditioning coaches to develop with their junior player groups.

Building on the concept of between-tier comparisons developed in *Study One*, *Study Two* provided a comparative analysis of match-play activity profiles across three Australian football competition levels, including elite junior, sub-elite and elite. Activity profile differences between elite and sub-elite competitions have been documented (Aughey, 2013; Brewer et al., 2010; Johnston et al., 2015c), however, few investigations have incorporated elite junior players (Burgess, Naughton, & Norton, 2012). The main outcomes revealed higher total game time for elite and sub-elite players and a progressive increase in HSR, HA, HD and energy cost across the competition tiers. While physical performance differences were in congruence with the hypothesis, sub-elite and elite players accrued more kick and handball involvements. The findings indicated that the sub-elite competition tier offers a physical and technical development pathway for junior players transitioning to elite Australian football match-play.

Elite senior match-play involved greater total distance, Playerload^{TM} and HSR, compared to the alternate competition tiers. Elite players recorded 22%, 25% and 18% more HSR distance, time and efforts per minute when compared to the junior players. Alternatively, sub-elite players only performed 5%, 7% and 1% more HSR distance, time and efforts per minute compared to the junior players. The capacity to undertake HSR is positively related to team selection in Australian football (Le Rossignol et al., 2014) and playing at a higher competition tier in futsal (Dogramaci et al., 2011). It is clear that coaches and strength and conditioning coaches should aim to develop the running capacity of junior players, notably their ability to perform HSR. From a technical skills perspective, sub-elite and elite players accrued more kicks and handballs and therefore it appears these competition tiers provide greater opportunity to develop skill components of Australian football. Interestingly, the total number of kicks accrued during match-play has been suggested to be a key indicator of success within Australian football (Robertson et al., 2016).

Prior to this investigation, minimal data has been presented on the acceleration and deceleration profiles of junior match-play, despite these metrics being recorded in several sub-elite and elite match-play investigations (Johnston et al., 2015; Johnston et al., 2015c; Sullivan et al., 2014). Elite players in the current investigation covered 15% more distance and spent 13% to 36% more time performing HA and HD movements, compared to the junior players. This may reflect the superior opportunity for training at the elite level, subsequently enabling elite players to perform and sustain moderate to high-intensity acceleration and deceleration movements during match-play. Conversely, in terms of the number of efforts, junior players recorded 17% to 30% more HD and HA efforts compared to both professional player groups. It seems youth players have developed a capacity to undertake HA efforts, however, a limited capacity to sustain these rapid velocity changes may be related to differences regarding training volume and intensities. It is also important to consider the limitations associated with the assessment of HA and HD efforts, with relatively poor reliability previously reported for these measures (Johnstonet al., 2015; Johnston, Watsford, Pine, & Spurrs, 2014). Accordingly, the HA and HD results should be interrupted with caution. Finally, elite and sub-elite match-play resulted in a higher mean energy cost, however when interpreting these findings the reader must recognise the longer game time of both professional player cohorts. The mean match-play energy cost for sub-elite and elite players was similar to previous investigations within Australian football (57-66 $kj \cdot kg^{-1}$) (Coutts et al., 2015) and soccer (66 $kj \cdot kg^{-1}$) (Osgnach et al., 2010). As evident by the greater energy requirements of the elite and sub-elite competition tiers, challenges are apparent to condition new draftees for the increased demands of sub-elite and elite competitions with particular focus required on the volume of activity undertaken during match-play.

This was one of the first studies to identify and compare match-play activity profiles of elite junior, sub-elite senior and elite senior athletes, with many practical outcomes established for junior player development. Differences were evident for field time, HSR, HA, HD and match-play energy cost across the competition tiers, with elite match-play evidently the most intense. Compared with elite match-play, sub-elite match-play allows for increased game time, lower running demands and similar technical skill involvements. Participation in sub-elite match-play provides a feasible match-play pathway for elite-junior Australian footballers aiming to develop physical capacity and technical skill acumen. While caution is warranted due to the increased physical nature of senior match-play, the transitions process from junior pathways to professional Australian football programs may be eased.

Following *Study Two,* the next investigation was designed with two purposes in mind; firstly comparing the anthropometric and physical profiles of age-matched elite-junior Australian footballers who were either selected or not selected to play in professional football and secondly to compare the activity profiles of the selected elite-junior players and professional Australian footballers with the same matches of a National sub-elite competition. The findings indicated that the elite-junior players selected to play professional football had greater body mass, high-speed intermittent running capacity and muscular strength characteristics. When considering the match-play outcomes, the professional players played more game time and covered more total distance, however, the elite-junior players recorded superior average speed, LSR and HSR distance and acceleration and deceleration metrics relative to field time. Although this investigation was in agreement with previous research regarding the selection of junior players (Robertson et al., 2015; Woods et al., 2015), this was the first investigation to evaluate the concept of elite-junior players competing in the same senior competition tier and directly compare between elite-junior players and professional players in this context.

The findings of the current investigation were in agreement with research demonstrating a selection bias towards greater body mass in elite-junior Australian footballers (Robertson et al., 2015; Woods et al., 2015). While superior anthropometric and morphological characteristics may be viewed as necessary to cope with the physical demands of Australian football, positional demands and individual player requirements seem likely to have a greater influence on selection. In agreement with a prior research (Woods et al., 2015), this investigation reported superior running capacity for selected players. This was particularly notable during the Yo-Yo IR2, a test correlated with players ability to undertake HSR during match-play (Mooney et al., 2011). The selected players were also significantly stronger than their non-selected peers. Due to the gap reported between elite-junior and elite players for these physical characteristics, it seems important that coaches and strength and conditioning coaches apply training strategies to develop such components of fitness with junior player cohorts.

The second part of this investigation demonstrated chronological and anthropometric differences between selected elite-junior and professional players. The professional player's recorded greater match-play time and total distance covered, while the elite-junior players recorded greater distances relative to game time. Importantly, the work-rate recorded for junior athletes in the current study was higher than prior investigations involving junior Australian footballers (Burgess, Naughton, & Norton, 2012; Henderson et al., 2015). Elite-junior players also recorded more LSR and HSR distance and efforts, however, the professional players spent more time undertaking LSR and HSR. Comparable to velocity measures, the junior players covered more distance, spent more time and performed more efforts in all acceleration and deceleration zones.

The trend regarding running intensity within Australian football match-play suggests an incremental increase from elite- junior to the professional competitions (Burgess, Naughton, & Norton, 2012; Johnston et al., 2015c). Therefore, with the outcomes of this investigation revealing that elite-junior players work at higher intensities during sub-elite match-play, it seems important for their development to participate in this competition tier. Regarding technical skills, it was evident that sub-elite players accrued more kicks and handballs per minute of match-play and likely resulted from the greater technical and tactical skill development of these older and more experienced players. Therefore, the findings indicate a positive relationship between technical skill acumen, chronological age and match-play experience. Accordingly, it appears that the sub-elite match-play pathway should not be overlooked for the optimal development of junior athletes in Australian football. Such a premise may also be evident in other sports, with targeted research projects required to directly assess this concept.

The findings from this investigation demonstrated that elite-junior players selected to a sub-elite competition, exhibited superior body mass, aerobic running capacity and strength characteristics. These findings were significant as *Study One* demonstrated a large difference in muscular strength and neuromuscular power between elite-junior and professional players. It seems physical capacity bias selection even with these biological mature adolescent athletes. Thereafter, the match-play activity profiles of these selected elite-junior players were superior to that of professional players when viewed relative to match time and higher than previous elite under-18 match-play investigations. Due to the apparent differences in match-play time and intensity metrics form *Study Two*, it appears that sub-elite match-play can aid in the physical and technical development junior players. In the short-term, it may provide a transitional pathway to prepare junior players for the increased demands of elite match-play.

While *Studies One, Two and Three* involved the assessment of players within the junior player development pathway, *Study Four* assessed the anthropometric and physical characteristics newly drafted Australian football players over a 13-week pre-season period. Improvements in body mass, intermittent running capacity as measured through the Yo-Yo IR2 test, and strength and power characteristics were apparent. Despite the small increase in body mass, moderate to large strength increases were apparent, suggesting that short-term neuromuscular adaptations can occur in the absence of morphological changes.

It seems young Australian football players are increasingly exposed to elite match-play (Burgess, Naughton, & Norton, 2012), therefore, close monitoring of the tolerance and adaptation to training load is imperative. Pre-season is the optimal time to develop these physical changes, as opportunities may be limited during competition periods. The small increase in body mass apparent within this investigation was likely an interplay between the resistance training undertaken by first-year players potentially being counterbalanced by increased running loads. The importance of developing anthropometric characteristics are numerous, with positive relationships evident with team selection (Pyne et al., 2006; Woods et al., 2015), draft (Burgess, Naughton, & Hopkins, 2012) and performance (Gastin, Fahrner, et al., 2013) outcomes. While aiding performance, enhanced physical characteristics, notably muscular strength, can improve player resilience and potentially reduce injury risk (Fortington et al., 2016; Gastin, Fahrner, et al., 2013). From a running perspective, greater improvement was apparent for the Yo-Yo IR2 compared to the 3km time trial. Interestingly *Study One* showed minimal differences between elite-junior and professional players for time-trial tests, however, some differences were apparent for the Yo-Yo IR2. While elite-junior Australian footballers appear to exhibit high aerobic capacity, the movement profile of the Yo-Yo IR2 may be more challenging with the repeated high-intensity efforts and change of direction movements. Therefore, the first year players likely adapted to increased participation in this type of training within the pre-season period. From a practical perspective, time trial tests may be better utilised at the beginning of pre-season to assess athletes returning from conditioning-specific off-season programs, with Yo-Yo IR2 providing a better estimate of physiological development through pre-season training, where concurrent conditioning and skills training are performed.

These findings provided one of the first insights into the development of new draftees within a professional Australian football team. The investigation specifically aimed to provide further background within junior player profiling. While this investigation revealed that elite-junior players elicit short-term adaptations to a professional training environment, it is advised that coaches pursue a long-term approach to the physical development of less experienced players. With elite-junior players exhibiting significantly lower muscular strength and neuromuscular power to professional players within *Study One* this gap is unlikely to be bridged over one season. However, optimal training sequencing to account for the likely increased residual fatigue experienced by new draftees appears essential for physical development. Therefore, tracking short-term training adaptations during pre-season can assist with delivering individual player training prescriptions and an increased likelihood of a positive transition to a professional team. Overall *Studies One to Four* demonstrated clear physical characteristic disparities between junior and senior Australian footballers. While the authors found the development of physical characteristics within a professional Australian football team are accelerated, it was decided to implement a training intervention with junior Australian footballers based of the previous four investigations

Therefore S*tudy Five* examined the effect of a 12-week resistance training intervention on the strength and power characteristics of junior Australian football players. It was hypothesised that the addition of a resistance training intervention would increase the expression of strength and power compared to players undertaking skills training only. A large interaction effect was evident between the training and control groups for upper- and lower-body strength and upper-body power.

The specific results revealed that upper- and lower-body strength increased by 9.59%-40.6% for the training group and -0.05%-11.9% for the control group, respectively. Conversely, upper- and lower-body power improved by 2.75%-25.9% for the training group and 3.89%-14.2% for the control group. While the strength changes were lower in magnitude than previously reported for adolescent athletes (Velez, Golem, & Arent, 2010), improvements were nonetheless elicited during this short training intervention.

The findings supported previous research, whereby adolescent athletes concurrently undertaking resistance and technical skill training elicited strength increases (Chelly et al., 2009; Christou et al., 2006; Sander et al., 2013). It seems short-term resistance training interventions can alter strength and upper-body power and affect greater changes than undertaking technical skills training only (Faigenbaum et al., 2015; Sander et al., 2013). An interesting finding related to power differences between groups being solely evident for the upper-body power measure. As Australian football involves a diverse range of lower body movements, including plyometric activities, specific resistance training may be required to develop upper-body power.

There were a number of practical observations evident in the findings, including players within the training group displaying greater strength and upper-body power. Additionally, participants remained injury free throughout the 12-week training intervention period. The significance of these findings can be viewed by the findings within *Studies One* and *Four*. The ability to reduce the strength and power differences between elite-junior and professional players will likely ease the transition period required for new draftees. Additionally, as *Study Four* found that strength and power changes can be elicited within a professional team environment, the three to four year period that is perceived as the time required to attain optimal strength and power characteristics may be moderated. Overall, the findings from this investigation provide coaches within the elite-junior development pathway with an evidence-based approach to alter strength and power characteristics.

The studies within this thesis identified key physical differences between junior and elite senior Australian footballers. *Studies One, Two and Three* exposed differences in physical capacity across a broad spectrum of junior and senior and competition tiers within

Australian football. In addition to these descriptive findings, *Study Four* identified the physical development of elite junior players drafted to a professional Australian football team during this important stage of athlete development. Lastly *Study Five* demonstrated the positive application of a training intervention to the development of junior athletes, with the specific aim of reducing identified physical differences to an elite senior player cohort.

8.2 Research Contributions

An important aspect of junior athlete development has been the use of profiling to further understand the unique characteristics of selection, draft, performance or career outcomes. While research has provided an understanding of the physical and technical skill demands of Australian football, the five studies contained within this thesis provided a further in-depth understanding of differences between junior and senior player cohorts and practical training strategies that can be applied within the junior development pathway. Each study endeavoured to address the theme as set out in the theoretical framework, providing a clear understanding of the physical characteristics required for professional Australian football.

The findings of *Studies One* and *Two*, identified differences in physical characteristics between junior, sub-elite and elite Australian footballers. Currently the physical development programs implemented for junior players are likely determined by biological and training age considerations. The novel findings of this investigation identified key physical and match-play running characteristics that can assist training practices and player development. *Study Three* findings were twofold; firstly demonstrating anthropometric and physical characteristics that indicate positive selection outcomes or junior players and secondly, players who exhibited these characteristics were able to undertake the match running demands of a sub-elite senior match-play. *Study Four* demonstrated that the development of anthropometric and physical characteristics of first-year players can be elicited within an initial pre-season period. The authors acknowledge that first-year players will likely benefit from being trained with a long-term development perspective, however tracking short-term requirements may aid with training prescription. While these findings are no doubt positive, the findings of *Studies One, Two* and *Three* suggests developing of these physical characteristics prior to draft selection. The findings of *Study Five* demonstrated the successful implementation of a training intervention to develop key physical characteristics that distinguished junior and elite senior Australian footballers.

This investigation supplements the body of literature regarding short and long term physical development of junior Australian footballers. While this investigation did not specifically investigate the National draft, the development of junior players utilising these novel findings may positively influence draft outcomes. Importantly, this investigation extents across a junior and senior player cohort and provides a holistic understanding of player development. Finally, to assist with a targeted player development approach, this investigation identifies training and match-play selection methods that coaches can engage for junior player development. As noted within the thesis, each of these studies has either been published or are under review for publication. It is anticipated that their publication will reach a wide audience and practitioners from a number of field sports will be able to apply the concepts developed in these studies. Furthermore, the outcomes of the research have been applied to an Academy system, with a number of alterations to training and selection practices implemented as a result of the findings.

8.3 PRACTICAL APPLICATIONS

The five studies of this thesis have provided a number of practical findings that will be useful for coaches, strength and conditioning coaches and recruiters within junior and professional Australian football teams. These practical applications relate to the anthropometric, physical and technical constructs of junior player profiling.

- The major differences in physical capacity between junior and professional Australian footballers are strength and power characteristics. Coaches within the youth development pathway should implement resistance training interventions to reduce these gaps, thus assisting the transition of junior players to professional teams (*Study One*).
- Sub-elite match-play appears to offer a viable pathway for junior Australian footballers to develop physical and technical attributes required during match-play (*Study Two*).
- It seems prudent for coaches and recruiters to assess potential draftees during sub-elite match-play, where junior players can work at higher intensities. This environment likely affords a greater ability to differentiate high calibre junior players (*Study Two*).
- Superior anthropometric and physical characteristics in youth players appear to aid with selection outcomes (*Study Three*).
- The running profile of junior Australian football players is superior to professional players competing in the same sub-elite match when viewed relative to match time. Therefore, this match-play pathway may assist the physical and technical development of junior players and support the transition to elite match-play (*Study Three*).

- Pre-season training elicits substantial improvements in recently drafted Australian footballers. Given the likely large differences in training load between typical elite-junior and professional players, it is important to carefully prescribe and closely monitor training and be prepared to adjust the loads if required (Study Four).
- Information is now available about the target levels that junior Australian footballers should be aiming for in terms of developing anthropometric and physical characteristics prior to the draft selection. Such benchmarking can provide a training focus with the aim of optimising the transition period to elite Australian football (*Study Four*).
- Relatively short time-frame resistance training interventions can improve upper- and lower-body strength and upper-body power in junior Australian football players (*Study Five*).

8.4 DIRECTIONS FOR FUTURE RESEARCH

Throughout the development of this thesis and quest to deliver on the theoretical framework, several research questions have formed based on the findings of each investigation and further discussions with the relevant stakeholders. While the five studies endeavored to contribute to the literature on physical profiling and development of junior Australian footballers, it is recommended that future research expands on the findings and explores the following areas.

- It appears important to establish training modalities to reduce the differences in strength and power between junior and professional Australian footballers and ensure that such modalities can be implemented across a broad range of junior development programs.

- Explore training practices that can help a non-selected players prepare for the demands of elite match-play
- Given the possibility that sub-elite match-play provides an ideal conduit for development, a detailed examination of how participation in sub-elite match-play can aid with the transition of junior players to elite Australian football match-play is required.
- A detailed investigation of training load variations across players of varying experience and how these may influence the physical development of younger players during pre-season and competition periods would be beneficial to provide information to junior development programs.
- The provision of a more detailed analysis of the pre-season development of first-year Australian footballers would enable a better understanding of this crucial transition period. The inclusion of a greater number of physical tests and more testing periods over this time frame would provide the required detail.
- The investigation of whether long-term resistance training interventions can elicit positive morphological adaptations with junior Australian footballers. It appears that there are many possible benefits to arise from such training.
- More information is required about the optimal resistance training frequency for junior Australian footballers along with the quantification of the required training dosage to elicit optimal adaptations.

8.5 CONCLUSION

Athlete profiling provides an important mechanism to shape the development of athletes within field sports and can be assessed across a broad range of characteristics. The sequence of studies presented in this thesis, along with the respective results that have been discussed, provide pertinent information on the anthropometric and physical profile of junior Australian footballers. This was specifically undertaken by assessing junior player cohorts against a high calibre professional player group, using a number of test modalities. The results from these investigations inform coaches and professionals within Australian football about key differences between the physical and match-play activity profiles of junior and professional players and present strategies to overcome these differences. Furthermore, along with elite-junior and professional athletes, this thesis incorporated players classified as sub-elite and therefore provided an understanding of all competition levels within the Australian football development pathway. Importantly, this investigation demonstrated the success of a training intervention involving targeted improvements in observed physical characteristics (strength and power expression) that clearly distinguished between elite-junior and professional Australian footballers. While this research focused on Australian footballers, the methodologies within this investigation are general in nature and can, therefore, be implemented across a broad range of field sports. The findings can undoubtedly assist coaches and strength and conditioning coaches across junior athlete development pathways within field sports, with the ultimate aim to optimally transition junior athletes to professional teams.

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APPENDICES

APPENDIX A: UNIVERSITY ETHICS APPROVAL

Dear Applicant

Thank you for your response to the Committee's comments for your project titled, "Long term athlete development in Australian rules football: Physiological profiling and relationship between testing and match performance." Your response satisfactorily addresses the concerns and questions raised by the Committee who agreed that the application now meets the requirements of the NHMRC National Statement on Ethical Conduct in Human Research (2007). I am pleased to inform you that ethics approval is now granted.

Your approval number is UTS HREC REF NO. 2013000348

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

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

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

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

Yours sincerely,

Professor Marion Haas

Chairperson

UTS Human Research Ethics Committee

C/- Research & Innovation Office
University of Technology, Sydney
T: (02) 9514 9645
F: (02) 9514 1244
E: Research.Ethics@uts.edu.au
I: http://www.research.uts.edu.au/policies/restricted/ethics.html
P: PO Box 123, BROADWAY NSW 2007
[Level 14, Building 1, Broadway Campus]
CB01.14.08.04
REF: E11

Dear Applicant

Thank you for your response to the Committee's comments for your project titled, "Improving Strength and Power in elite-junior Australian footballers". Your response satisfactorily addresses the concerns and questions raised by the Committee who agreed that the application now meets the requirements of the NHMRC National Statement on Ethical Conduct in Human Research (2007). I am pleased to inform you that ethics approval is now granted.

Your approval number is UTS HREC REF NO. 2014000847

Your approval is valid five years from the date of this email.

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

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

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

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

Yours sincerely,

Professor Marion Haas

Chairperson

UTS Human Research Ethics Committee

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University of Technology, Sydney

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I: http://www.research.uts.edu.au/policies/restricted/ethics.html

P: PO Box 123, BROADWAY NSW 2007

[Level 14, Building 1, Broadway Campus]

CB01.14.08.04

Ref: E13

APPENDIX B: RESEARCH CONSENT FORM

INFORMED CONSENT FORM:
INVOLVEMENT OF SYDNEY SWANS ACADEMY ATHLETES

I, ______________________________ *(parent/guardian name)* authorise the participation of ______________________ (*athlete name*) in the research project "**Long term athlete development in Australian rules football: Physiological profiling and relationship between testing and match performance**", being conducted by Stephen Kelly of the University of Technology, Sydney.

I understand that the purpose of this study is to determine the physical differences between elite senior and junior Australian footballers as assessed by a number of physical tests for aerobic and anaerobic capacity in addition to strength and power assessments. I understand that the specific aim of this study is to quantify the magnitude difference between two elite-junior and three elite senior Australian footballers of varying age and training experience. I understand that this research will involve participants less than 18 years of age.

I understand that my child's participation in this research will involve completing sub and maximal aerobic and anaerobic capacity assessments, which will involve sections of high and very high intensity activity. Additionally, my child will be required to undertake strength and power assessments that will require varying degrees of difficultly and skill to complete. I understand that it will be ensured that my child completes a standardised warm-up and cool down during testing, with proper technique shown where applicable.

I am aware that I can contact Stephen Kelly (Mobile: ; Email: Stephen.J.Kelly@student.uts.edu.au) or his supervisor A/Prof. Mark Watsford (Phone: 02 9514 5379; Email: Mark.Watsford@uts.edu.au) on behalf of my child, if I have any concerns about the research. I also understand that I am free to withdraw my child's participation from this research project at any time they wish and without giving a reason. I acknowledge and accept that my child's participation is entirely voluntary, and that UTS has accepted my child's participation in good faith without express implied warranty. I understand that the research data gathered from this project will be accessible only to researchers of this study, and agree that the data may be published in a form that does not identify the athletes in any way.

I agree that Stephen has answered all my questions fully and clearly.

____ ____/____/____

Signed by Parent/Guardian

____ ____/____/____

Signed by Sydney Swans Academy Athlete

____ ____/____/____

Witnessed by

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

UNIVERSITY OF TECHNOLOGY SYDNEY

INFORMED CONSENT FORM:
INVOLVEMENT OF SYDNEY SWANS ATHLETES

I, ___________________________ *(name)* of the Sydney Swans Football Club, authorise my participation of in the research project "**Long term athlete development in Australian rules football: Physiological profiling and relationship between testing and match performance**", being conducted by Stephen Kelly (E-mail: Stephen.J.kelly@student.uts.edu.au) of the University of Technology, Sydney.

I understand that the purpose of this study is to determine the physical differences between elite senior and junior Australian footballers as assessed by a number of physical tests for aerobic and anaerobic capacity in addition to strength and power assessments. I understand that the specific aim of this study to quantify the magnitude difference between two elite-junior and three elite senior Australian footballers of varying age and training experience. .

I understand that the my participation in this research will involve completing sub and maximal aerobic and anaerobic capacity assessments, which will involve sections of high and very high intensity activity. Additionally I will be required to undertake strength and power assessments that will require varying degrees of difficultly and skill to complete. It will be ensured that you complete a standardised warm-up and cool down during testing, with proper technique shown where applicable.

I am aware that I can contact Stephen Kelly (Mobile: [redacted]; Email: Stephen.j.kelly@student.uts.edu.au) or his supervisor A/Prof. Mark Watsford (Phone: 02 9514 5379; Email: Mark.Watsford@uts.edu.au) if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish and without giving a reason. I acknowledge and accept that my participation is entirely voluntary, and that UTS has accepted my participation in good faith without express implied warranty. I understand that the research data gathered from this project will be accessible only to researchers of this study and agree that the data may be published in a form that does not identify me in any way.

I agree that Stephen has answered all my questions fully and clearly.

____________________________________ ____/____/____

Signed by

______________________________________ ____/____/____

Witnessed by

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

UNIVERSITY OF TECHNOLOGY SYDNEY

INFORMED CONSENT FORM: INVOLVEMENT OF SYDNEY SWANS ACADEMY ATHLETES

I, ______________________________ *(parent/guardian name)* authorise the participation of ______________________ (*athlete name*) in the research project "**Long term athlete development in Australian rules football: Physiological profiling and relationship between testing and match performance**", being conducted by Stephen Kelly of the University of Technology, Sydney.

I understand that the purpose of this study is to determine the movement demands of elite-junior Australian footballers as assessed during match-play using Global positioning systems (GPS). I understand that the specific aim of this study is to quantify the match running demands of elite-junior Australian footballers during 8 games. I understand that this research will involve participants less than 18 years of age.

I understand that my child's participation in this research will involve wearing a GPS unit positioned between the shoulder blades during match-play. I understand the risks involved with wearing this unit, although no injuries have been reported when wearing GPS units during training or match-play. It will be ensured that the unit placed between my child's shoulder blades will be securely positioned within a padded vest under their playing jersey.

I am aware that I can contact Stephen Kelly (Mobile: [redacted]; Email: Stephen.J.Kelly@student.uts.edu.au) or his supervisor A/Prof. Mark Watsford (Phone: 02 9514 5379; Email: Mark.Watsford@uts.edu.au) on behalf of my child, if I have any concerns about the research. I also understand that I am free to withdraw my child's participation from this research project at any time they wish and without giving a reason. I acknowledge and accept that my child's participation is entirely voluntary, and that UTS has accepted my child's participation in good faith without express implied warranty. I understand that the research data gathered from this project will be accessible only to researchers of this study, and agree that the data may be published in a form that does not identify the athletes in any way.

I agree that Stephen has answered all my questions fully and clearly.

____ ____/____/____

Signed by Parent/Guardian

____ ____/____/____

Signed by Sydney Swans Academy Athlete

____ ____/____/____

Witnessed by

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

UNIVERSITY OF TECHNOLOGY SYDNEY

Consent Form for Sydney Swans Academy Athlete/Parent-Guardian

I, ______________________________ *(name)* of the Sydney Swans Football Club, authorise the participation in the research project "**Improving strength and power in elite-junior Australian footballers**", being conducted by Stephen Kelly (E-mail: Stephen.J.kelly@student.uts.edu.au) of the University of Technology, Sydney. Funding for this research has been provided by Sydney Swans Football Club.

I understand that the specific aim of this study is to increase the strength and power capacity of junior Australian footballers. I understand that the purpose of this study is to decrease the physical differences between elite senior and junior Australian footballers as assessed by a number of physical tests for strength and power output. I understand that this research will involve participants less than 18 years of age.

I understand that my child has been asked to participate in this research because their status as an elite-junior Australian footballer. I understand that my child's participation in this research will require undertaking physical testing and completing a supervised strength and power training program that will require varying degrees of difficulty and skill. Testing and completion of the strength and power training program will be undertaken over an 8 week period. I understand that there is a moderate risk of injury involved with strength and power exercises, however muscular injuries will been minimised by ensuring that my child completes a standardised warm-up and cool down during testing and training, with proper technique shown where applicable. I understand that submaximal loads will be lifted during testing and training periods, minimising risks of joint and muscular injury. Additionally spotters will be used to assist with an exercise where applicable, during lifts requiring greater technique and strength.

I am aware that I can contact Stephen Kelly (Mobile: [redacted]; Email: Stephen.j.kelly@student.uts.edu.au) or his supervisor A/Prof. Mark Watsford (Phone: 02 9514 5379; Email: Mark.Watsford@uts.edu.au) if I have any concerns about the research. I also understand that I am free to withdraw my child's participation from this research project at any time I wish and without giving a reason. Additionally I understand there will be no repercussion regarding my child's position within the Sydney Swans academy by not participating within this research. I acknowledge and accept that my child's participation is entirely voluntary, and that UTS has accepted my child's participation in good faith without express implied warranty. I understand that the research data gathered from this project will be accessible only to researchers of this study.

I agree that Stephen Kelly has answered all my questions fully and clearly. I agree that the research data gathered from this project may be published in a form that does not identify my child in any way.

____ ____/____/____

Signature (participant)

____ ____/____/____

Signature (researcher or delegate)

NOTE:

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

APPENDIX C: INFORMATION SHEET FOR PARTICIPANTS

UNIVERSITY OF TECHNOLOGY SYDNEY

INFORMATION FOR PARTICIPANTS- Study 1

Long term athlete development in Australian rules football: Physiological profiling and relationship between testing and match performance (REF: 2013000348)

1. Who is doing this research?
   My name is Stephen Kelly (Phone: ; E-mail: Stephen.J.Kelly@student.uts.edu.au) and I am currently a higher degree research student at University of Technology Sydney. My chief supervisor during the current research will be A/Prof. Mark Watsford (Phone: 02 9514 5379; E-mail: Mark.Watsford@uts.edu.au).

2. What is this research about?
   The following study will involve the assessment of elite Australian rules footballer's physical and anthropometric profile across a number of playing ages. Player profiling has enabled a greater understanding of the physical characteristics required for success at the elite level in individual or team sports. This research project will give an insight into whether a significant difference exists between two elite-junior and 3 elite senior Australian football groups of varying age and experience. Specifically, the outcomes of this study will provide valuable information to coaches and conditioning staff at Football clubs for the assessment of future training practices, development of elite-junior players to elite senior player level and design of training sessions. In addition, the results from this study will establish further research to be conducted in the area, with the aim of improving the understanding of the application and improving player development within Australian football. The results will be presented in a thesis, journal articles and conference papers, as part of the requirements for the Doctor of Philosophy degree.

3. If I say yes, what will this research involve?
   If you undertake this research, testing will involve the collection of physical testing data during training sessions. The test data will be recorded by the researcher ensuring confidentiality. The use of physical testing is a common method of assessing elite team sport athletes, with the strictest safety guidelines adhered to at all times.

4. Are there any inconvenience/risks involved in this research?
   In this study we would ask you to follow your normal training session and testing procedures as required by the club, although you need to ensure that certain tasks are followed with extra diligence:

- Inform the club and researcher of any pre-existing injuries.
- Ensure that you follow the correct preparation practices as set out by the Sydney Swans Football Club to minimise risk of injury
- Undertake a comprehensive pre testing warm-up to minimise the risk of injury
- Dress in suitable clothing for the testing sessions (shorts, jersey, football boots).
- Report any complications or difficulty during testing and training.

5. Why have I been asked to participate in this research?
   You have been requested to be a part of this study, due to your status as an elite Australian rules footballer.

6. Do I have to participate in this research?
   Although all tests undertaken during this study are part of your normal training schedule, you may withdraw at any time without explanation. There will be no consequences for your non-participation in the current study. If you have any questions or concerns regarding the current study, you can contact either myself (Stephen Kelly) or the chief supervisor (Dr. Mark Watsford), whose details are above. Alternatively, if you would like to talk to someone who is not connected with the research, you may contact the Research Ethics Officer on 02 9514 9772, and quote this reference number (2013000348).

THANK YOU FOR TAKING PART IN THIS STUDY. PLEASE DO NOT HESITATE TO ASK ANY QUESTIONS AT ANY TIME.

UNIVERSITY OF TECHNOLOGY SYDNEY

INFORMATION FOR PARTICIPANTS- Study 2 and 3

Long term athlete development in Australian rules football: Physiological profiling and relationship between testing and match performance (REF: 2013000348)

1. Who is doing this research?

   My name is Stephen Kelly (Phone: [redacted]; E-mail: Stephen.J.Kelly@student.uts.edu.au) and I am currently a higher degree research student at University of Technology Sydney. My chief supervisor during the current research will be A/Prof. Mark Watsford (Phone: 02 9514 5379; E-mail: Mark.Watsford@uts.edu.au).

2. What is this research about?
   The following study will involve the assessment of elite Australian rules footballer's activity profile during competitive junior matches. Global Positioning System (GPS) is a relatively new method of time-motion analysis that enables the monitoring of player movements and the development of a better understanding of team sports. In order to collect data on athlete movement demands a GPS unit needs to be worn so that the movements of the player can be tracked and recorded. This research project will give an insight into whether or not a link exists between player performance and athlete movement demands. Specifically, the outcomes of this study will provide valuable information to coaches and conditioning staff at football clubs for the assessment of player performance and design of training sessions. In addition, the results from this study will establish further research to be conducted in the area, with the aim of improving the understanding of the applications GPS and best practice for physical testing and how it can improve player performance in Australian football. The results will be presented in a thesis, journal articles and conference papers, as part of the requirements for a Doctor of Philosophy degree.

3. If I say yes, what will this research involve?
   If you undertake this research, testing will involve the collection of movement demand data through GPS worn between participant's shoulder blades during match-play. The GPS data will be recorded by the researcher and stored on a password secured computer, ensuring confidentiality. The recording of movement demand data is a common method of assessing elite senior and junior team sport athletes, with the strictest safety guidelines adhered to at all times. Additionally, movement demand data will be collected using GPS units, which you are required to wear by the club. The use of GPS is a relatively safe method to record athlete

movement demands as they are small, non-invasive and designed to break before any harm is done to the wearer.

4. Are there any inconvenience/risks involved in this research?
   In this study we would ask you to follow your normal match day procedures as required by the club, although you need to ensure that certain tasks are followed with extra diligence:

- Attend each game of the TAC cup competition, arrive approximately1 hours before the start of the match at the necessary venue in order to collect data on player movement demands.
- Ensure that you follow the correct preparation practices as set out by the NSW Rams to minimize risk of injury

- Put on a purposely made vest under your playing jersey with a pouch for the GPS unit, 20 minutes prior to the start of the match.
- Report any complications or difficulty when wearing the GPS unit

5. Why have I been asked to participate in this research?
   You have been requested to be a part of this study, due to your status as an elite-junior Australian rules footballer.

6. Do I have to participate in this research?
   Although wearing GPS units are part of a normal match schedule, you may withdraw at any time without explanation. There will be no consequences of your non-participation in the current study. If you have any questions or concerns regarding the current study, you can contact myself (Stephen Kelly) or chief supervisor (Dr. Mark Watsford), whose details are above. Alternatively, if you would like to talk to someone who is not connected with the research, you may contact the Research Ethics Officer on 02 9514 9772, and quote this reference number (2013000348).

THANK YOU FOR TAKING PART IN THIS STUDY. PLEASE DO NOT HESITATE TO ASK ANY QUESTIONS AT ANYTIME

UNIVERSITY OF TECHNOLOGY SYDNEY

INFORMATION SHEET FOR PARTICIPANTS

Improving Strength and Power in elite-junior Australian footballers

(UTS HREC 2014000847)

WHO IS DOING THE RESEARCH?

My name is Stephen Kelly (Phone: ; E-mail: Stephen.J.kelly@student.uts.edu.au) and I am a higher degree research student at the University of Technology Sydney. My chief supervisor during the current research will be Dr. Mark Watsford (Phone: 02 9514 5379; E-mail: Mark.Watsford@uts.edu.au).

WHAT IS THIS RESEARCH ABOUT?

The proposed study will include the assessment of elite-junior Australian footballers (AF), over an 12-week strength and power training program. This will also involve a pre- and post-testing period within the regular training program. This will enable a greater understanding of the effectiveness of a structured and progressive strength and power training program on the development of junior AF athletes. One of my previous research projects identified that junior AF athletes exhibited significantly lower strength and power when compared to senior AF players. This research project will investigate whether these differences in strength and power can be reduced. Specifically, the outcomes of this study will provide valuable information to coaches and conditioning staff at Football clubs for the direction of future training programs and practices. In addition, the results from this study will establish further research to be conducted in the area, with the aim of improving player development within junior AF.

IF I SAY YES, WHAT WILL IT INVOLVE?

If the participant undertakes this research, testing will involve the collection of physical testing data (2 x 90 minute sessions at the Football Club) and an 8 week training program to be undertaken at the immediate completion of normal academy training sessions. Each training session as part of the 8 week program will last approximately 45- 60 minutes.

Participants will have experience with all exercises within the training program, with loads progressively increased over the 8 weeks. The test data will be recorded by the researcher ensuring confidentiality. The use of physical testing is a common method of assessing elite team sport athletes, with the strictest safety guidelines adhered to at all times.

ARE THERE ANY RISKS/INCONVENIENCE?

There is a moderate risk of muscular and joint injury during strength and power testing and training program which would cause discomfort to the participant. This will be minimised through a comprehensive warm-up, familiar training protocols, the use of spotters to aid with technical exercises and the use of a 3-5 repetition maximum load to failure during testing.

There will be no extra travel requirements or monetary loss on participants, due to the testing and training program occurring during normal training times for Sydney Swans academy players.

WHY HAVE I BEEN ASKED?

The participant has been requested to be a part of this study, due to their status as an elite-junior Australian footballer. The benefits of participating in this study for individual junior Australian footballers will include increases in strength and power capacity and the associated relationship with performance benefits and short and long-term injury reduction. AF is a game requiring a number of physical capacities including tackling, acceleration, sprinting and jumping movements (Gray & Jenkins 2010; Hrysomallis & Buttifant 2012). Therefore high levels of strength and power are required by athletes competing in this sport. Furthermore, strength training has a positive correlation with reducing injury incidence in junior athletes (Emery 2010)

DO I HAVE TO SAY YES?

Although all tests undertaken during this study are part of a normal training schedule for the athlete, participants may withdraw at any time without explanation.

WHAT WILL HAPPEN IF I SAY NO?

There will be no consequences for future participation within the Sydney Swans academy, if the participant decides to discontinue or choose not to be involved within the study.

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

Participant's involvement within this study is voluntary and therefore can change their mind about participating within this study and with draw without having to provide an explanation.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If the participant has any questions or concerns regarding the study, they can contact either myself (Stephen Kelly) or the chief supervisor (A/Prof. Mark Watsford), whose details are above. Alternatively, if you would like to talk to someone who is not connected with the research, you may contact the Research Ethics Officer on 02 9514 9772, and quote this reference number (2014000847)