College of Sport and Exercise Science

Institute for Health and Sport

# Multi-factorial modelling of player physical development within the Australian Football League (AFL) participation pathway

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This thesis is submitted in fulfilment of the requirements for admission to the degree of Doctor of Philosophy

Of

Victoria University

September, 2018

## ABSTRACT

National sporting organisations such as the AFL invest significant resources into establishing talent identification (TID) and talent development models to ensure the future success of their sport. The process usually involves predicting player potential through subjective assessments of game performances in combination with objective inputs inclusive of physical fitness testing, movement ability assessments, and match activity profiles. However, elite sporting performance is the product of a player's ability to overcome and master the dynamic interactions between organismic, task, and environmental constraints that may impede or facilitate physical fitness and skill development. Organismic constraints such as growth, maturity, and learning stages of individual players can all influence physical fitness, movement ability, and match activity profiles. Specific environmental constraints include differences in game play, skill level, game rules and policies, and field sizes. Task constraints are the limitations imposed by a set task, for example; the goals and rules of AFL, the sporting actions required, and the physical fitness qualities needed for high-level match performance. Of particular interest is the as relative age effect (RAE), a selection bias among players of differing skill and maturity levels caused when adolescent players are grouped into annual age-grouped teams. The extent to which these constraints contribute to variations in physical fitness and match activity between levels of junior AF competition is unclear. This thesis investigates the interactions between physical fitness characteristics, the RAE, and match activity profiles across multiple levels of the AFL participation pathway, and the subsequent implications for player TID and development.

The first study was a systematic review examining physical fitness measures of players across the AFL participation pathway levels to quantify longitudinal changes observed in physical fitness characteristics. Only studies examining physical fitness tests were included, with 27 meeting the inclusion/exclusion criteria. Sprint time (20-m) was the most reported test across the AFL participation pathway, followed by vertical jump (VJ), AFL agility, and 20-m multi-stage fitness test (MSFT). The fastest times for 20-m sprint were for elite AFL players (range 2.94 – 3.13 s), with local level players the slowest (3.22 – 4.06 s). State Junior Under (U) 18s had higher jumps than senior players; with the lowest jumps reported for Local U10s (range 31- 66 cm). Interestingly, no elite-level data were reported for the AFL agility or 20-m MSFT, with AFL agility times only reported for talent pathway levels (8.17 – 9.12 s). However, 20-m MSFT scores were reported across the junior levels of the AFL participation pathway (6.1 –

13.5 shuttles). Talent squad players exhibit similar test scores between competition levels irrespective of the physical fitness test, with the exception of 20-m sprint and VJ. It was suggested that physical tests can discriminate between local participation level players, but are less useful within the AFL talent pathway.

Study II examined the influence of age-policy changes on the RAE across the AFL talent pathway. The study design was a retrospective cross-sectional analysis of junior AFL players attending the annual National Draft, State, and State U16 combines between 1999 and 2016. Birth-date data was obtained for players attending the AFL State U16 ($n$ = 663), State ($n$ = 803), National ($n$ = 1111) combines, with comparisons made against corresponding aged-matched Australian general population birth-rates. Specifically, Under 16s and State players had greater birth frequencies (2% to 4.9%, $p < 0.05$) for earlier months in the selection year. Age-policy changes at the National level reduced birth distribution bias for some months; however the RAE remained for other months (March 3.9%, June 6.1%, and July 4.3%, $p \leq 0.05$). State U16s and National players had 2- 9% lower birth frequencies for the later months in the selection year compared general population. It seems that selection bias towards older players is instigated at the AFL's State U16, and maintained through to the State and National levels, with age-policy changes only partially successful at addressing the RAE at the National level.

Study III investigated the levels of association between physical fitness and match activity profiles of players within the AFL participation pathway. A total of 287 players across seven pathway levels were assessed on the 20-m sprint, AFL agility, VJ and running VJ, 20-m MSFT, and Athletic Abilities Assessment (AAA). Match activity profiles were obtained from global positioning system (GPS) measures; relative speed, maximal velocity, and relative high speed running (HSR). Correlational analyses revealed moderate relationships between sprint and jump test scores and match activity profiles in Local U12, Local U14, National U16 and National U18s ($r$ = 0.32-0.78, $p \leq 0.05$), but not jump tests in National U18s. AFL agility time was moderate-to-strongly associated with all match activity measures in Local U12, Local U14, Local U18, and National U16s ($r$ = 0.37-0.87, $p \leq 0.05$), and with relative speed in Local U18s ($r$ = 0.84, $p \leq 0.05$). Relative speed and HSR were moderate-to-strongly associated with 20-m MSFT in Local U14, Local U18, and National U18s, and AAA score in Local U12, and Local U18s ($r$ = 0.41-0.95, $p \leq 0.05$). Match activity profile demands increased between Local U12 and National U16s, then plateaued across the talent pathway levels. Physical fitness seemed to relate more strongly to match activity profiles in younger adolescent and National level players', therefore recruiters should consider the dynamic changes physical changes between AFL participation pathway levels.

The final study examined the utility of physical fitness and movement ability tests in differentiating and classifying players into specific AFL participation pathway levels. Players (*n* = 293) completed the same physical fitness tests battery as Study III; 5-m, 10-m and 20-m sprint, AFL agility, VJ, running VJ, 20-m MSFT, and AAA. A multivariate analysis of variance between AFL participation pathway levels for each test was conducted, and a non-linear analysis (classification tree) determined the extent players could be allocated to relevant levels. The magnitude of the difference between physical fitness and movement ability was age-level dependent, with the largest standardised effects between Local U12, Local U14s, and older levels for most physical fitness tests (Effect Size (ES): -4.24 to 4.65). The 20-m, 5-m, AFL agility, 20-m MSFT, overhead squat, and running VJ (right) all contributed substantially to the classification model, with over half of the players accurately classified into the appropriate AFL participation pathway levels (57%). The National U16 players were most accurately classified based these tests (87%); however, no National U18 players were classified. Talent selectors should consider differences in physical fitness and movement ability patterns between players when selecting players into the talent pathway; however other contextual factors (i.e., skills, psychological, and socio-cultural factors) are needed to establish a multi-component TID model in older levels of the talent pathway.

Physical development differences between players, age-grouped competition levels, and talent levels reported in these studies should be considered in the planning, implementation, and review of AFL development programs. Establishing associations between common physical fitness and movement ability tests used for TID in AFL and match activity profiles allows coaches and talent selectors to make more informed player selection decisions. Also, non-linear modelling facilitates TID decisions as it can highlight under or over-performing players; flagging them to selectors for further investigation of other contextual factors influencing a player's potential. Future studies should focus on including more areas that encompass TID and development (i.e., skills, psychological, and socio-economic attributes) to provide a comprehensive understanding of the interactions that determine a player's success at an elite level. This research is not limited to AFL, with the methods used having the potential to provide more informed TID and development processes across other sports.

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“I, Jade Alexandra Ziems Haycraft, declare that the PhD thesis by Publication entitled ‘Multi-factorial modelling of player physical development within the Australian Football League (AFL) participation pathway’ is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work”.

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|---|---|---|---|
| 1/3 | Physical characteristics of players within the Australian Football League participation pathways: a systematic review | Published | Haycraft, J.,Kovalchik, S., Pyne, D. B., & Robertson, S.(2017). "Physical characteristics of players within the Australian Football League participation pathways: a systematic review." Sports Medicine Open 3(1): 46. Impact factor: NA |
| 2/4 | The influence of age-policy changes on the relative age effect across the Australian Rules football talent pathway | Published | Haycraft, J.,Kovalchik, S., Pyne, D. B., Larkin, P., & Robertson, S.(2017). "The influence of age-policy changes on the relative age effect across the Australian Rules football talent pathway." Journal of Science and medicine in Sport 21(10): 1106-1111.Impact factor 3.5 |
| 3/5 | Relationships between physical testing and match activity profiles across the Australian Football League participation pathway. | Accepted for Publication | Haycraft, J., Kovalchik, S., Pyne, D. B., & Robertson, S. Relationships between physical testing and match activity profiles across the Australian Football League participation pathway. International Journal of Sports Physiology and Performance. In Second Review, Impact factor 2.7 |
| 4/6 | Classification of players across the Australian Rules football participation pathway based on physical characteristics | under review | Haycraft, J., Kovalchik, S., Pyne, D. B., & Robertson, S. Classification of players across the Australian Rules football participation pathway based on physical characteristics. International Journal of Sports Physiology and Performance, Impact Factor 2.7 |
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Status:

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| Sam Robertson | 4% | Reviewer, Provided Feedback, Edits | Sam Robertson Digitally signed by Sam Robertson Date: 2018.09.17 17:36:45 +10'00' | 18/9/2018 |
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Surname: Haycraft First name: Jade

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| Paul Larkin | 2% | Data cleaning and reviewer | Paul Larkin Digitally signed by Paul Larkin Date: 2018.09.18 15:46:05 +10'00' | 18/09/2018 |
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### 1. PUBLICATION DETAILS (to be completed by the candidate)

Title of Paper/Journal/Book: Haycraft, J., Kovalchik, S., Pyne, D. B., & Robertson, S. Relationships between physical testing and match activity profiles across the Australian Football League participation pathway. *International Journal of Sports Physiology and Performance.* 1-23. doi: https://doi.org/10.1123/ijspp.2018-0488

Surname: Haycraft | First name: Jade

College: College of Sport and Exercise Science | Candidate's Contribution (%): 90%

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| Sam Robertson | 5% | Analysis, Reviewer, Provided Feedback, Edits | Sam Robertson Digitally signed by Sam Robertson Date: 2018.09.17 20:30:18 +10'00' | 18/9/18 |
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Surname: Haycraft First name: Jade

College: College of Sport and Exercise Science Candidate's Contribution (%): 90%

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Accepted and in press: ☐ Date:

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I declare that the publication above meets the requirements to be included in the thesis as outlined in the HDR Policy and related Procedures – policy.vu.edu.au.

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| Stephanie Kovalchik | 1% | Analysis | Stephanie Kovalchik Digitally signed by Stephanie Kovalchik Date: 2018.09.18 13:56:31 +10'00' | 18/9/18 |
| David Pyne | 4% | Reviewer, Provided Feedback, Edits | David Pyne Digitally signed by David Pyne Date: 2018.09.18 12:24:33 +10'00' | 18/9/18 |
| Sam Robertson | 5% | Analysis, Reviewer, Provided Feedback, Edits | Sam Robertson Digitally signed by Sam Robertson Date: 2018.09.17 20:31:20 +10'00' | 18/9/18 |
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ACKNOWLEDGMENTS

Associate Professor Sam Robertson, it has been an incredible journey over the past years. Thank you for your guidance, understanding, support, expertise, and drive that have pushed me to finish this thesis, and continually seek new knowledge. It has been a true honour being your student.

Dr Stephanie Kovalchik, thank you for agreeing to be my supervisor, and assisting me with your incredible knowledge. I appreciate your kindness and patience when working together and I submit this thesis having gained so much from you.

Dr David Pyne, I am extremely appreciative of the time you volunteered to read endless manuscripts and provide valuable feedback on everything from my candidature to the final thesis, especially considering there was no obligation to do so. Thank you.

Professor Damian Farrow & Dr Paul Larkin thank you for your incredible leadership with the AFL research board project. Your effort in organising every testing day from club recruitment to schedules was greatly appreciated.

Thank you to the coaches, talent managers, team managers, and players across the AFL participation pathway that welcomed the research team into their clubs. This research would not have been complete without your effort.

To all the student interns that volunteered their time to assist with data collection, the sport science industry, and this research would not be the same without your invaluable commitment and time.

To members of my family, Mum & Dad, Rainer, Lucienne, and Tess thank you for supporting and encouraging me through the years. Dad, I especially hope you enjoy reading this like all the others. Kaye & John, thank you also for your ongoing support.

To my husband Tyson, you have been on this long academic voyage with me since year 12. You have always been incredibly patient, understanding, and supportive through the long days I have had to spend focusing on study and my career. I could not have got this far without you and look forward to sharing future successes with you.

Finally, to the memory of my grandfather Don Haycraft, who was always supportive of me in anything I chose to pursue in life, even if it seemed ridiculous. Who was extremely excited when I chose to pursue a career in sport science, and was there to begin the Ph.D. journey but was not able to reach the finish line with me.

## LIST OF PUBLICATIONS & SUBMISSIONS

Haycraft, J., Kovalchik, S., Pyne, D. B., & Robertson, S. (2017). Physical characteristics of players within the Australian Football League participation pathways: a systematic review. *Sports Medicine Open*, 3(1), 46-62. doi:10.1186/s40798-017-0109-9

Haycraft, J., Kovalchik, S., Pyne, D. B., Larkin, P., & Robertson, S. (2018). The influence of age-policy changes on the relative age effect across the Australian Rules football talent pathway. *Journal of Science and Medicine in Sport*, 21(10), 1106-1111. doi: https://doi.org/10.1016/j.jsams.2018.03.008

Haycraft, J., Kovalchik, S., Pyne, D. B., & Robertson, S. Relationships between physical testing and match activity profiles across the Australian Football League participation pathway. *International Journal of Sports Physiology and Performance*. In Press (Ahead of Print). doi: https://doi.org/10.1123/ijspp.2018-0488. © Human Kinetics

Haycraft, J., Kovalchik, S., Pyne, D. B., & Robertson, S. Classification of players across the Australian Rules football participation pathway based on physical characteristics. *International Journal of Sports Physiology and Performance.* In Review.

## LIST OF ABBREVIATIONS

**AAA –** Athletic Abilities Assessment

**ABS –** Australian Bureau of Statistics

**AF –** Australian Football

**AFL –** Australian Football League

**AIS –** Australian Institute of Sport

**ASC –** Australian Sports Commission

**CI –** Confidence Interval

**COD –** Change of Direction

**CV –** Coefficient of Variation

**DOB –** Date of Birth

**ES –** Effect Size

**FMS** – Functional Movement Screen

**FTEM –** Foundations, Talent, Elite, Mastery Framework

**GC –** Gold Coast Suns

**GPS –** Global Positioning System

**GWS –** Greater Western Sydney

**HSR –** High Speed Running

**IR –** Intermittent Recovery

**MANOVA** - Multivariate Analysis of Variance

**MSFT –** Multi-stage Fitness Test

**NSO –** National Sporting Organisation

***n*** – Sample Size

**OR –** Odds Ratio

***p*** **–** Spearman’s Rank Correlation Coefficient

**PRISMA –** Preferred Items for Systematic reviews and Meta-analyses

**Q -** Quartile

***r*** – Correlation Coefficient

**RAE** – Relative Age Effect

**RM** – Repetition Max

**RVJ** – Running Vertical Jump

**SANFL** – South Australian Football League

**TAC** – Transport Accident Commission

**TEE** – Technical Error of Measurement

**TID** – Talent Identification

**U** – Under

**VFL** – Victorian Football League

**VJ** – Vertical Jump

**$VO_2max$** – Maximal Oxygen Uptake

**WAFL** – Western Australian Football League

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# CHAPTER 1 – Introduction

## 1.1. Introduction

Talent development refers to the combination of elements that encourage, drive and support athletes long-term striving to achieve sporting excellence. It is a dynamic process involving relationships between technical and tactical skills, physical and psychological characteristics, and socio-cultural influences (Burgess & Naughton, 2010; Gulbin, Croser, Morley, & Weissensteiner, 2013). In contrast, talent identification (TID) is cross-sectional in nature and defined as the recognition of athletes that have the potential to reach, and succeed at the highest level of elite sport (Abbott & Collins, 2002; Vaeyens, Lenoir, Williams, & Philippaerts, 2008; Williams & Reilly, 2000). A key role of national sporting organisations (NSO's) such as the Australian Football League (AFL) is to develop appropriate talent development and TID models that ensure the future success of their sport. The AFL has invested significant resources into creating a participation pathway consisting of two streams; i) the local participation pathway, and ii) the talent pathway (see Figure 1.1.) (Australian Football League [AFL], 2016). Currently, the AFL's TID approach consists of subjective assessments of player performances during games, with objective assessments such as physical and skills testing evaluated by talent scouts, selectors, and coaches (Burgess, Naughton, & Norton, 2012; Woods, Joyce, & Robertson, 2016). Despite a body of work examining the physical fitness requirements of developing and elite Australian football (AF) players, no studies have systematically compared differences in physical fitness and match activity profiles across the entire AFL participation pathway. With physical fitness testing used for TID and player selection into elite AFL and talent pathways, it is important to determine if physical fitness testing is a valid assessment for differentiating between talented and non-talented players at key TID stages across the AFL participation pathway.

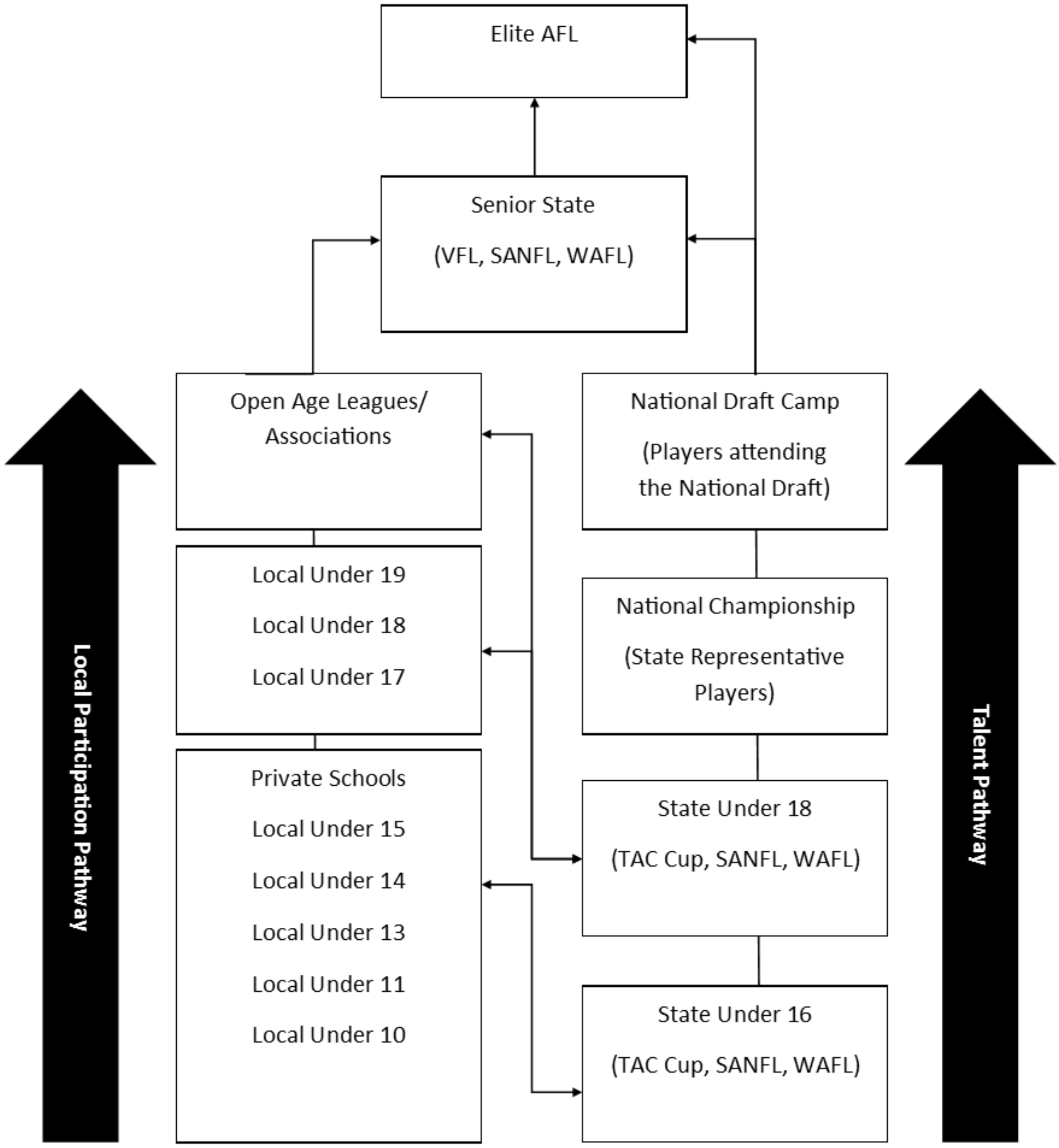


**Figure 1.1.** The AFL participation pathway adapted from AFL Development (AFL, 2016). The participation pathway has two distinct development pathways; the local participation and talent pathways. Players may move between the local participation and talent pathways during their development. Elite level players are selected from Senior State and junior National Draft Camp/Championship squads via the annual AFL National Draft. AFL: Australian Football League; TAC: Transport Accident Commission (Victorian State Junior Football League); VFL: Victorian Football League; SANFL: South Australian National Football League; WAFL: Western Australian Football League.

The dynamic nature of athletic talent development requires AF players to continually cultivate solutions to overcome physical or skill challenges caused by a myriad of limitations presented during sports performance. Newell's model of constraints (Figure 1.2.) is based on the notion that optimal movement patterns are the product of ideal coordination and control of specific activities to overcome the interaction of constraints that regulate a given movement/performance (Newell, 1986). The three categories of constraints that may impede or facilitate physical and skill development are; organismic, task, and environmental (Davids, Glazier, Araújo, & Bartlett, 2003; Newell, 1986, 1991, 2003). Organismic constraints are defined as those relating to the individual athlete such as growth, maturity, and stages of learning which can influence a players' physical fitness characteristics and stability of competition at junior levels (Davids, Araújo, Hristovski, Passos, & Chow, 2012; Wattie, Schorer, & Baker, 2015). Environmental constraints refer to the general or task-specific external factors that influence individual development. Examples of environmental constraints include; the physical environment, socio-cultural influences, policies, relationship networks (i.e., family, friends, coaches, and teachers), differences in game play between levels, skill level of team and opponents, game policies, and field sizes (Berry, Abernethy, & Cote, 2008; Silva et al., 2014; Tangalos, Robertson, Spittle, & Gastin, 2015). The placement of children into annual age-grouped teams is also an environmental constraint that can create selection bias in physically demanding sports like AFL (Baxter-Jones, 1995; Cobley, Baker, Wattie, & McKenna, 2009; Mann & van Ginneken, 2017; Wattie et al., 2015). This phenomenon referred to as the relative age effect (RAE) is a demographic characteristic where a bias exists towards selecting athletes born earlier in a defined age group year comparative to those born later (Andronikos, Elumaro, Westbury, & Martindale, 2016; Coutts, Kempton, & Vaeyens, 2014; Simmons & Paull, 2001).

Task constraints are limitations imposed by the task such as; differences in game rules, player positions, quality of physical fitness of team/opposition, and tiers of competition (Davids et al., 2012; Vilar, Araújo, Davids, & Button, 2012; Wattie et al., 2015). However, constraints are not mutually exclusive from each other, as effective movement patterns for sports performance are the result of interactions between constraining factors (Newell, 1991, 2003; Wattie et al., 2015). Over the span of a player's career, the dynamical systems created by constraint interactions requires them to continually evolve to meet changing sport demands (Newell, 2003). How a player's physical fitness and match activity profile adapts to changes as they progress through the AFL participation pathway however is yet to be established.

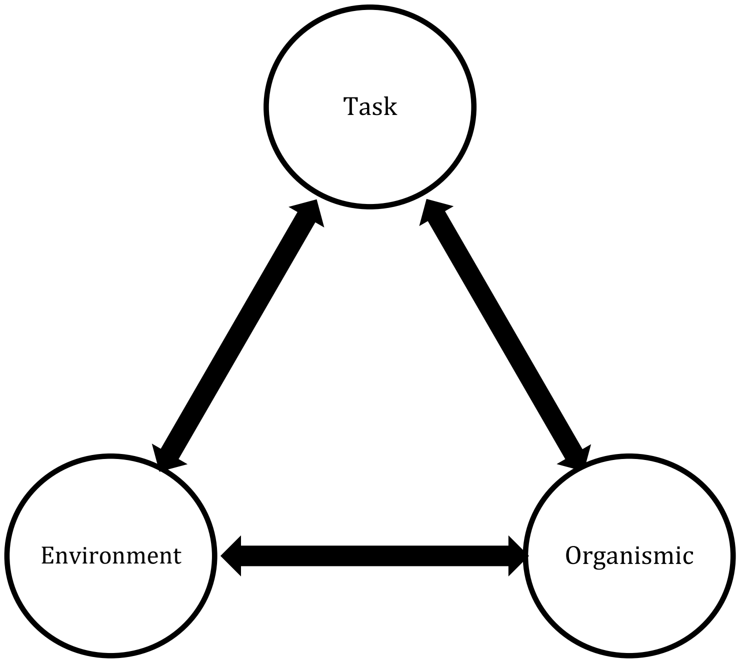


**Figure. 1.2.** Newell's model of interacting constraints (Newell, 1986). The model is depicted as a triangle to represent how a change in any one of the three constraints has a flow-on effect on the other two constraints.

Australian football is an invasion team sport that requires players to display high levels of physical fitness in aerobic capacity, speed, agility, power, and strength (Gray & Jenkins, 2010). Game motion analyses indicate that AF is intermittent in nature and characterised by both high-intensity (high-speed running, sprinting, acceleration, agility), and low-intensity activities (standing, walking, jogging) (Boyd, Ball, & Aughey, 2013; Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004; Gray & Jenkins, 2010; Hiscock, Dawson, Heasman, & Peeling, 2012; Veale, Pearce, & Carlson, 2007; Wisbey, Montgomery, Pyne, & Rattray, 2010). The physical fitness characteristics of the sport have been well documented, with talent pathway players annually tested at the AFL State and National Under (U) 16 and U18 Draft Combines (Pyne, Gardner, Sheehan, & Hopkins, 2005, 2006; Woods, Raynor, Bruce, McDonald, & Collier, 2015). The AFL Draft Combine testing battery includes sprinting, vertical jumps, agility, and multi-stage fitness tests (MSFT) (Pyne et al., 2005; Robertson, Woods, & Gastin, 2015; Woods et al., 2015; Woods, Raynor, Bruce, McDonald, & Robertson, 2016; Young & Rogers, 2014), with small-to-moderate relationships reported between these tests and career progression at the elite level (Pyne et al., 2005, 2006). In parallel with these testing programs, global positioning system (GPS) monitoring has become popular for establishing match activity profiles during competition, with widespread use in talent squads and senior elite competition (Bauer, Young, Fahrner, & Harvey, 2015; Brewer, Dawson, Heasman, Stewart, & Cormack, 2010; Burgess et al., 2012; Coutts et al., 2010; Gastin, Bennett, & Cook, 2013). Yet there is no research that has directly compared the magnitude of difference or strength of relationships between physical fitness tests and match activity profiles across all AFL participation pathway levels. Furthermore, the ability of physical fitness tests to classify players into specific AFL levels is unclear. This is essential for informing training and physical preparation guidelines for junior AF players at differing levels of the AFL participation pathway, whilst providing recruiters with more informed TID and talent development recommendations.

To address the abovementioned questions pertaining to talent development in Australian Football, this thesis comprises both a systematic review and a series of experimental studies. The systematic review will summarise relevant literature pertaining to physical fitness characteristics of players across the AFL participation pathway levels. A retrospective cross-sectional examination will then be conducted to determine the prevalence of RAE, and the effect of age policy changes on reducing selection bias of players attending the AFL State and National combines. A comparison of the differences in the strength of relationship between physical fitness and match activity profiles of players across the AFL participation pathway will be conducted. This data will provide insights into the key physical fitness attributes that influence match activity profiles of players at each level of the AFL participation pathway. Finally, different physical fitness profile combinations exhibited by players within levels of the AFL participation pathway will be examined, allowing players to be classified into correct competition levels. Physical fitness models will be established to provide practical evidence-based guidelines for coaches, talent selectors, and physical preparation staff within the AFL participation pathway to systematically inform training and selection priorities of AF players.

## 1.2. Objectives of the Thesis

### 1.2.1. Aims

This doctoral investigation forms part of a larger AFL collaborative project that aims to establish an athlete development matrix inclusive of technical (skill) and tactical (decision making), sociocultural, and psychological influences on player development. The primary purpose of this thesis is to model physical fitness attributes of Australian football players at each stage of the AFL participation pathway, accounting for the relative age effect and relationships between fitness and attributes and match activity profiles. A secondary objective of this thesis is to comprehensively profile the associations between physical fitness testing and match activity within junior levels of the AFL participation pathway. A third objective is to provide an improved talent identification processes for talent selectors and coaches.

### 1.2.2. Objectives

- To undertake a systematic review of physical fitness testing studies pertaining to AFL with an emphasis on longitudinal changes in the physical fitness of AF players.
- To determine the prevalence of the relative age effect within AFL talent pathway levels, and evaluate the effectiveness of age policy changes to address talent selection bias.
- To establish the relationships between physical fitness tests and measures of physical match activity profiles within and between different levels of the AFL participation pathway.
- To identify the key physical fitness metrics that classify AF players into specific AFL participation pathway levels.

## 1.3. Chapter Organisation

Chapter 1 introduces details regarding the rationale and specific aims for the research conducted for this dissertation.

Chapter 2 provides a broad overview of talent identification and development of athletes, the sport of AFL, and the current AFL participation pathway. Specifically, this chapter provides a critical analysis of different sport development models proposed in literature and their similarities/differences compared to the AFL participation pathway. The influence of Newell’s constraints model on talent identification and development across the AFL participation pathway is also explored, with a specific focus on the relationship between AFL development level, physical fitness, match activity profiles.

Chapter 3 is a systematic review examining physical fitness measures of players across the AFL participation pathway levels previously reported in scientific literature. A specific focus of the chapter is the longitudinal changes observed in physical fitness characteristics as players' transition through the AFL local participation and talent pathways to elite levels of competition. Furthermore, this study outlined common physical fitness tests used in AFL and determined competition levels that have not previously established physical fitness characteristics. As such, another purpose of this study was to inform data collection for these levels in Chapters 4 and 5.

Chapter 4 is a retrospective cross-sectional study spanning 17 years that highlights the prevalence of selection bias (i.e., relative age effect), partially caused by competition age groupings and player's birth month distribution. A specific focus of the chapter is on determining the extent to which age policy changes implemented by the AFL reduces selection bias in talent pathway levels of the AFL participation pathway.

Chapter 5 examines the relationships between physical fitness tests and physical match activity profiles across local participation and talent pathway levels of the AFL participation pathway. The physical fitness and movement ability tests selected in this study were identified in Chapter 3 as common tests used for talent identification within the AFL. Specifically, physical fitness and movement characteristic data within the local participation pathway levels had not yet been reported and were the main focus of this study. There were two aims of this study; i) to determine the magnitude of relationships between physical fitness tests and match activity measures for each level of the AFL participation pathway, and ii) to establish how physical match activity profiles change as players progress through the pathway. Additionally, the physical fitness data collected in this chapter also formed part of the data used in Chapter 6.

Chapter 6 is a cross-sectional analysis of the physical fitness and movement characteristics of players across the entire AFL participation pathway. The aim of this study was to use non-linear analyses to develop a physical fitness and movement ability matrix that allow players to be correctly classified into specific AFL competition levels. Data collected in Chapter 5 was also used in this chapter, however where possible the data collection was extended to allow larger sample sizes for each AFL participation pathway level.

Chapter 7 contains a general discussion of all the reviews and experimental studies and discusses the practical implications of this thesis, as well as providing recommendations for future research.

Chapters 3 and 4 in this thesis are published in peer-reviewed journals, with chapters 5 and 6 currently under review at peer-reviewed journals. Thus, the definitions of key terms, importance of the areas of research, and research aims may be repeated in several chapters.

## 1.4. References


Abbott, A., & Collins, D. (2002). A theoretical and empirical analysis of a 'state of the art' talent identification model. *High Ability Studies, 13*(2), 156-178. doi:10.1080/1359813022000048798

AFL Development. (2016). Participation and talent pathways. Retrieved from http://www.aflcommunityclub.com.au/index.php?id=559

Andronikos, G., Elumaro, A. I., Westbury, T., & Martindale, R. J. J. (2016). Relative age effect: implications for effective practice. *Journal of Sports Sciences, 34*(12), 1124-1131. doi:10.1080/02640414.2015.1093647

Bauer, A. M., Young, W., Fahrner, B., & Harvey, J. (2015). GPS variables most related to match performance in an elite Australian football team. *International Journal of Performance Analysis in Sport, 15*(1), 187-202. doi:10.1080/24748668.2015.11868786

Baxter-Jones, A. D. (1995). Growth and development of young athletes. *Sports Medicine, 20*(2), 59-64.

Berry, J., Abernethy, B., & Cote, J. (2008). The contribution of structured activity and deliberate play to the development of expert perceptual and decision-making skill. *Journal of Sport and Exercise Psychology, 30*(6), 685-708. doi:10.1123/jsep.30.6.685

Boyd, L. J., Ball, K., & Aughey, R. J. (2013). Quantifying external load in australian football matches and training using accelerometers. *International Journal of Sports Physiology and Performance, 8*(1), 44-51. doi:10.1123/ijspp.8.1.44

Brewer, C., Dawson, B., Heasman, J., Stewart, G., & Cormack, S. (2010). Movement pattern comparisons in elite (AFL) and sub-elite (WAFL) Australian football games using GPS. *Journal of Science and Medicine in Sport, 13*(6), 618-623. doi:10.1016/j.jsams.2010.01.005

Burgess, D., & Naughton, G. (2010). Talent development in adolescent team sports: a review. *International Journal of Sports Physiology and Performance, 5*(1), 103-116. doi:10.1123/ijspp.5.1.103

Burgess, D., Naughton, G., & Norton, K. (2012). Quantifying the gap between under 18 and senior AFL football: 2003 and 2009. *International Journal of Sports Physiology and Performance, 7*(1), 53-58. doi:10.1123/ijspp.7.1.53

Cobley, S., Baker, J., Wattie, N., & McKenna, J. (2009). Annual age-grouping and athlete development. *Sports Medicine, 39*(3), 235-256. doi:10.2165/00007256-200939030-00005

Coutts, A. J., Kempton, T., & Vaeyens, R. (2014). Relative age effects in Australian Football League national draftees. *Journal of Sports Sciences, 32*(7), 623-628. doi:10.1080/02640414.2013.847277

Coutts, A. J., Quinn, J., Hocking, J., Castagna, C., & Rampinini, E. (2010). Match running performance in elite Australian Rules football. *Journal of Science and Medicine in Sport, 13*(5), 543-548. doi:10.1016/j.jsams.2009.09.004

Davids, K., Araújo, D., Hristovski, R., Passos, P., & Chow, J. Y. (2012). Ecological dynamics and motor learning design in sport. In N. J. Hodges & A. M. Williams (Eds.), *Skill Acquisition in Sport: Research, Theory and Practice* (2nd ed., pp. 112-130). New York: Routledge.

Davids, K., Glazier, P., Araújo, D., & Bartlett, R. (2003). Movement systems as dynamical systems. *Sports Medicine, 33*(4), 245-260. doi:10.2165/00007256-200333040-00001

Dawson, B., Hopkinson, R., Appleby, B., Stewart, G., & Roberts, C. (2004). Player movement patterns and game activities in the Australian Football League. *Journal of Science and Medicine in Sport, 7*(3), 278-291. doi:10.1016/S1440-2440(04)80023-9

Gastin, P. B., Bennett, G., & Cook, J. (2013). Biological maturity influences running performance in junior Australian football. *Journal of Science and Medicine in Sport, 16*(2), 140-145. doi:10.1016/j.jsams.2012.05.005

Gray, A. J., & Jenkins, D. G. (2010). Match analysis and the physiological demands of Australian football. *Sports Medicine, 40*(4), 347-360. doi:10.2165/11531400-000000000-00000

Gulbin, J. P., Croser, M. J., Morley, E. J., & Weissensteiner, J. R. (2013). An integrated framework for the optimisation of sport and athlete development: A practitioner approach. *Journal of Sports Sciences, 31*(12), 1319-1331. doi:10.1080/02640414.2013.781661

Hiscock, D., Dawson, B., Heasman, J., & Peeling, P. (2012). Game movements and player performance in the australian football league. *International Journal of Performance Analysis in Sport, 12*(3), 531-545. doi:10.1080/24748668.2012.11868617

Mann, D. L., & van Ginneken, P. J. M. A. (2017). Age-ordered shirt numbering reduces the selection bias associated with the relative age effect. *Journal of Sports Sciences, 35*(8), 784-790. doi:10.1080/02640414.2016.1189588

Newell, K. M. (1986). Constraints on the development of coordination. In M. Wade (Ed.), *Motor Development in Children: Aspects of Coordination and Control* (pp. 341-361). Amsterdam: Martin Nijhoff.

Newell, K. M. (1991). Motor skill acquisition. *Annual Review of Pychology, 42*(1), 213-237. doi:10.1146/annurev.ps.42.020191.001241

Newell, K. M. (2003). Change in motor learning: A coordination and control perspective. *Motriz, Rio Claro, 9*(1), 1-6.

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2005). Fitness testing and career progression in AFL football. *Journal of Science and Medicine in Sport, 8*(3), 321-332. doi:10.1016/S1440-2440(05)80043-X

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2006). Positional differences in fitness and anthropometric characteristics in Australian football. *Journal of Science and Medicine in Sport, 9*(1), 143-150. doi:10.1016/j.jsams.2005.10.001

Robertson, S., Woods, C., & Gastin, P. (2015). Predicting higher selection in elite junior Australian Rules football: The influence of physical performance and anthropometric attributes. *Journal of Science and Medicine in Sport, 18*(5), 601-606. doi:10.1016/j.jsams.2014.07.019

Silva, P., Aguiar, P., Duarte, R., Davids, K., Araújo, D., & Garganta, J. (2014). Effects of pitch size and skill level on tactical behaviours of association football players during small-sided and conditioned games. *International Journal of Sports Science and Coaching, 9*(5), 993-1006.

Simmons, C., & Paull, G. C. (2001). Season-of-birth bias in association football. *Journal of Sports Sciences, 19*(9), 677-686. doi:10.1080/02640410152475801

Tangalos, C., Robertson, S., Spittle, M., & Gastin, P. B. (2015). Predictors of individual player match performance in junior Australian football. *International Journal of Sports Physiology and Performance, 10*(7), 853-859. doi:10.1123/ijspp.2014-0428

Vaeyens, R., Lenoir, M., Williams, A. M., & Philippaerts, R. M. (2008). Talent identification and development programmes in sport. *Sports Medicine, 38*(9), 703-714.

Veale, J., Pearce, A. J., & Carlson, J. S. (2007). Player movement patterns in an elite junior Australian Rules Football Team: An exploratory study. *Journal of Sport Science and Medicine, 6*(2), 254-260.

Vilar, L., Araújo, D., Davids, K., & Button, C. (2012). The role of ecological dynamics in analysing performance in team sports. *Sports Medicine, 42*(1), 1-10. doi:10.2165/11596520-000000000-00000

Wattie, N., Schorer, J., & Baker, J. (2015). The relative age effect in sport: A developmental systems model. *Sports Medicine, 45*(1), 83-94. doi:10.1007/s40279-014-0248-9

Williams, A. M., & Reilly, T. (2000). Talent identification and development in soccer. *Journal of Sports Sciences, 18*(9), 657-667. doi:10.1080/02640410050120041

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

Woods, C., Joyce, C., & Robertson, S. (2016a). What are talent scouts actually identifying? Investigating the physical and technical skill match activity profiles of drafted and non-drafted U18 Australian footballers. *Journal of Science and Medicine in Sport, 19*(5), 419-423. doi:10.1016/j.jsams.2015.04.013

Woods, C., Raynor, A. J., Bruce, L., McDonald, Z., & Collier, N. (2015). Predicting playing status in junior Australian football using physical and anthropometric parameters. *Journal of Science and Medicine in Sport, 18*(2), 225-229. doi:10.1016/j.jsams.2014.02.006

Woods, C., Raynor, A. J., Bruce, L., McDonald, Z., & Robertson, S. (2016b). The application of a multi-dimensional assessment approach to talent identification in Australian football. *Journal of Sports Sciences, 34*(14), 1340-1345. doi:10.1080/02640414.2016.1142668

Young, W., & Rogers, N. (2014). Effects of small-sided game and change-of-direction training on reactive agility and change-of-direction speed. *Journal of Sport Sciences, 32*(4), 307-314. doi:10.1080/02640414.2013.823230

# CHAPTER 2 – Review of Literature

## 2.1. Introduction

National sporting organisations such as the AFL invest significant resources into establishing appropriate TID and talent development models with the aim of ensuring the future success of their sport (Abbott & Collins, 2002; Pankhurst & Collins, 2013). In AFL, TID is cross-sectional in nature and involves the recognition of players that have the potential to reach, and succeed in elite competition (Abbott & Collins, 2002; Vaeyens, Lenoir, Williams, & Philippaerts, 2008; Williams & Reilly, 2000). This process involves the prediction of an athlete's potential success through subjective assessments of game performances, in combination with objective inputs such as physical fitness, match activity profiles, and skills testing (Burgess, Naughton, & Norton, 2012; Woods, Joyce, & Robertson, 2016b). However, players' are forced to continually evolve their physical fitness and skills to meet changing demands of their sport (Newell, 2003). Optimal sporting movement/performance patterns become the product of a player's ability to overcome and master the dynamic interactions between their athletic ability, their environment, and the task demands of the game (Newell, 1986). There are three categories of constraints that may impede or facilitate physical fitness and skill development: organismic, task, and environmental (Davids, Glazier, Araújo, & Bartlett, 2003; Newell, 1986, 1991, 2003). Organismic constraints such as growth, maturity, and learning stages of individual players all influence an individual's physical fitness, match activity profiles (Davids, Araújo, Hristovski, Passos, & Chow, 2012; Wattie, Schorer, & Baker, 2015). Changes in individual players' physical characteristics can disrupt skill proficiency, leading to increased physical demands during a game to counterbalance skill errors (Davids et al., 2012; Davids et al., 2003; Wattie et al., 2015). Environmental constraints in the AFL participation pathway include differences in game play, skill level, game policies, and field sizes (Berry, Abernethy, & Cote, 2008; Silva et al., 2014; Tangalos, Robertson, Spittle, & Gastin, 2015). Of particular interest is the placement of adolescents into annual age-grouped teams to balance competition between players of similar skill and maturity, which has contributed to selection bias among players of differing skill and maturity levels within the same age group (Baxter-Jones, 1995; Cobley, Baker, Wattie, & McKenna, 2009; Mann & van Ginneken, 2017; Wattie et al., 2015). Task constraints are the limitations imposed by a set task, for example; the goals and rules of the sport, the sporting actions required, and the physical fitness qualities needed for performance (Newell, 1991, 2003; Wattie et al., 2015). The extent to which these differences contribute to physical fitness and match activity variation between levels of junior AF competition is unclear.

This review will focus on the participation pathways, physical fitness characteristics, RAE, and match activity profiles that apply to AFL player development and TID. While a body of research has investigated the physical fitness in AF players, these studies have yet to be consolidated into one systematic review. Furthermore, selected details of physical fitness and match activity profiles of AF players have been reported, however a cross-sectional analysis comparing these characteristics across the entire AF participation pathway has not been conducted. Additionally, non-linear data analysis methods have the potential to identify multiple physical fitness and movement ability patterns specific to each level of the AFL participation pathway that may have not been identified previously with linear methods.

The primary aim of this literature review is to provide a brief background on the different models used for TID and development, and compare these to processes currently used within the AFL participation pathway. Secondly, an overview of the interactions between organismic, environment, and task constraints pertaining to AFL will be provided, with specific focus on the theoretical constructs underpinning physical fitness and movement ability testing, and match activity profiling for TID. Finally, a review will be conducted to summarise relationships regarding fitness testing and match activity profiles used for TID/selection between AFL participation pathway levels.

## 2.2. Overview of Australian Rules Football

2.2.1. Game CharacteristicsAustralian Football is a popular field-based team sport originating in Victoria in 1858 and as of 2018 is played in numerous structured leagues across Australia and internationally (Gray & Jenkins, 2010). The elite competition, the AFL, is held in Australia and includes 18 teams competing over 24 rounds, with a premiership side determined via a finals series. The popularity of AF sees over 1.5 million players participate in 237 domestic leagues, with over 2900 clubs across Australia (Australian Football League [AFL], 2017). Moreover, AF has expanded internationally with over 170,000 players competing in international competitions around the world (AFL, 2017). The game layout is an invasion sport comprising of four 20 to 30 min quarters, where two teams of 22 players (18 on field, 4 as interchange players) aim to score (Gray & Jenkins, 2010; Norton, Craig, & Olds, 1999). Players are typically grouped into three position types; forwards, backs, and nomadic players (Gray & Jenkins, 2010; Pyne, Gardner, Sheehan, & Hopkins, 2006). Forwards are offensive players and backs defensive; however these positions usually include two larger key position players known as the centre half forward/back and full forward/back (Gray & Jenkins, 2010; Pyne et al., 2006; Young et al., 2005). Nomadic players (midfielders) consist of centre, wing, and ruck players and are responsible for moving/defending the ball up or down the field (Gray & Jenkins, 2010; Pyne et al., 2006; Young et al., 2005).

Game motion analyses indicate AF is an intermittent sport characterised by high-intensity activities (high-speed running, sprinting, acceleration, agility), and low-intensity activities (standing, walking, jogging) (Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004). The game is a contact sport that involves collisions, tackling, blocking, and contested situations when the ball is in dispute during rucks and scrimmages (Boyd, Ball, & Aughey, 2013; Dawson et al., 2004). During an elite level game, AF players involved in a losing team may exhibit higher match activity profiles and lower skill involvements and proficiency (Sullivan et al., 2014). The technical skill of individual players and the team is more advantageous in winning when compared to an individual's physical fitness characteristics or match activity profile (Woods, Joyce, & Robertson, 2013; Sullivan et al., 2014).

### 2.2.2. AFL Participation Pathway

The AFL like many NSO's in the Australian sport system incorporates three key outcomes of sport participation, these being; active lifestyle, sport participation, and sport excellence (Gulbin et al., 2013; Gulbin, Croser, Morley, & Weissensteiner, 2014). The initial levels of the AFL participation pathway focus on providing players with functional movement skills to promote fitness and sporting ability, which results in long-term physical activity and sport participation (AFL, 2018; Bailey et al., 2010; Gulbin et al., 2013). Furthermore, the AFL's AllPlay initiative promotes 'football for all abilities' inclusion programs such as the AFL Auskick program that builds skill and fitness foundations prior to entering the AFL participation pathway (Bailey et al., 2010; AFL, 2018; AFL, 2016; Gulbin et al., 2013). The current AFL participation pathway encompasses the sport excellence program and includes two streams that direct athletes into state and elite senior competitions (Figure 1.1), these being the local participation pathway and the talent pathway (AFL, 2016). Generally, the majority of players transition through the regional-based local participation pathway via school/clubs/community (5-11 years of age), junior schools/clubs (12-14 years), youth schools/clubs (15-18 years), to open age league/associations (>18 years) (AFL, 2016). The talent pathway runs parallel to the local participation pathway (Figure 1.1), and consists of a comparatively smaller number of players selected into talent squads based on objective physical and skill test outcomes, and subjective match performance evaluations conducted by coaches and talent scouts (Burgess et al., 2012). Typically, talent pathway players are between 15 and 18 years of age competing at state or national junior level (Gulbin et al., 2013; Keogh, 1999; Veale, Pearce, Koehn, & Carlson, 2008; Woods, Raynor, Bruce, McDonald, & Collier, 2015b; Young & Pryor, 2007). The talent pathway is a national program consisting of regional development squads where talented players can transition through to U14-U16s state squads from which they may be selected into National U16 and National U18 squads (AFL, 2016).

Players may also be selected for AFL state academies, sporting centres of excellence, and the National AFL Academy if identified as talented from within the state and national squads (Burgess et al., 2012; AFL, 2016; Robertson, Woods, & Gastin, 2015b). While the structure of the AFL participation pathway can provide clear local participation and talent pathways for players, no studies have assessed the differences in physical fitness and match activity profiles between the levels of the AFL participation pathway. It is important to understand and classify the physical differences between AFL participation pathway levels, as this can provide talent development coaches with evidence-based guidelines for player growth and transition into higher levels of AFL competition.

Elite players are defined as those who have represented AF clubs at the professional level, with seasoned elite players having maintained their position in the elite national AF competition for 8 to 10 years (Gulbin et al., 2013). Players are selected into senior state and elite AF competitions from either the local participation or talent pathways, with elite players primarily selected through the annual AFL National Draft (Pyne, Gardner, Sheehan, & Hopkins, 2005). Terminology varies when classifying players, with both Black, Gabbett, Naughton, and McLean (2015) and Veale, Pearce, Buttifant, and Carlson (2010) considering less experienced elite players as those with four or less years' experience at the elite AFL level. Furthermore, Veale et al. (2010) identified rookies as all players within their first two years of participation in professional football, with seniors classified as those with greater than two years of professional experience. Despite the differences in classification nomenclature of players, a trade-off between player experience and age is evident, with age having a negative impact on match performance (Gastin, Fahrner, Meyer, Robinson, & Cook, 2013b). The difference in age and training history between players entering the elite competition and experienced elite players creates a gap in physical fitness and match activity profiles (Black et al., 2015), unfortunately, the magnitude of difference between the players' physical development is unclear. Understanding the physical differences between junior and senior competition can provide guidelines for elite AFL stakeholders on short-term physical preparation and long-term elite development, possibly reducing the risk of early de-selection of players with a greater physical development gap than others.

### 2.2.3. Talent Identification in AFL

The national AFL Draft was introduced in 1986 for the purpose of identifying talented athletes. As such, the AFL Draft has become one of the key list management tools for selection of talented AFL players into professional elite teams, alongside trading periods and free agency (AFL, 2018). The current talent pathway includes junior state and national training/competitions that specifically provide junior AF players with specialist coaching and development in preparation for the AFL Draft (AFL, 2016; AFL, 2017). Furthermore, the AFL has implemented non-traditional football development pathways via talent transfer. This process involves the recruitment of players from other sports that exhibit physical, tactical and technical skills required to be successful in AFL (Burgess & Naughton, 2010; Collins, Collins, MacNamara, & Jones, 2014; Oldenziel, Gagne, & Gulbin, 2004). TID within AFL is a cross-sectional process similar to practices in other professional team sports; however it currently does not systematically take into consideration the longitudinal nature of talent development.

## 2.3. Talent Development

Talent development is the daily variation and progression of skill, physical, and cognitive maturation that is required for improving sport performance (Burgess & Naughton, 2010). Sporting pathways are established by NSO's to provide clear models of athlete participation, progression, and development (Martindale, Collins, & Daubney, 2005; Shilbury, Sotiriadou, & Green, 2008). These pathways may focus on development pathways for elite athlete success, or promote sport participation (Shilbury et al., 2008). Therefore, the development pathway is a critical focus for the AFL in targeting player retention (Baker, Côté, & Abernethy, 2003a; Burgess & Naughton, 2010; Gulbin et al., 2013; Martindale et al., 2005). When considering talent development models, the TID process usually results in exclusion not inclusion of players of differing abilities (Burgess & Naughton, 2010; Vaeyens et al., 2008). Numerous talent development models have been proposed to overcome athlete exclusion, all with varying constructs for developing elite sport performance.

### 2.3.1. Talent Development Models

Talent development models that integrate multiple levels of talent development within sport include; Deliberate Practice model (Baker, 2003; Ericsson, Krampe, & Tesch-Römer, 1993; Wiersma, 2000), the Long Term Athlete Development Model (Balyi & Hamilton, 2004), Development Model of Sport Participation (Côté & Vierimaa, 2014), Differentiated Model of Giftedness and Talent (Gagne, 2006; Gagné, 2004), and the Athletic Talent Development Environment Model (Henriksen, Stambulova, & Roessler, 2010). Furthermore, the Australian Institute of Sport (AIS), in conjunction with the Australian Sports Commission (ASC), developed the Foundations, Talent, Elite, Mastery (FTEM) framework to encapsulate all aspects of athlete development, and consolidated them into one model for a range of sport stakeholders (i.e., clubs, coaches, sport scientists, and NSO's) (Australian Sports Commission [ASC], 2017; Gulbin et al., 2013, 2014). While all models provide valid foci for talent development, they are not without limitations.

The Deliberate Practice model examines the practice of skills in isolation of any other factor of sports performance (i.e., physiology, conditioning, sport diversification) (Bullock et al., 2009; Gulbin et al., 2013; Tucker & Collins, 2012). This model is based on the assumption that development of elite sport expertise involves high levels of training and practice (Baker, Horton, Robertson-Wilson, & Wall, 2003b). The model states that athletes should engage in 10 years or 10,000 hours of deliberate practice with a specific goal of early sport specialisation for improving performance (Baker et al., 2003a; Ericsson et al., 1993). However, in team sports (netball, field hockey, and basketball) between 7 to 20 years of practice is typically needed for athletes to reach national competition (Baker et al., 2003a). The effectiveness of early sport specialisation for optimising elite athlete development is debatable (Baker, 2003; Kaleth & Mikesky, 2010; Mattson & Richards, 2010). Elite team sport athletes (basketball, netball, soccer, and field hockey) that engaged in a greater number of sporting activities outside their chosen sport require less sport-specific practice hours to attain elite status (Baker et al., 2003a; Ward, Hodges, Starkes, & Williams, 2007). The main concern with early specialisation is the risk of burnout, overtraining, and injury in developing athletes (Kaleth & Mikesky, 2010), with overuse injuries and overtraining a common physiological problem in junior athletic populations (Brenner, 2007).

With the intention of avoiding overuse injury concerns and burnout associated with the Deliberate Practice model, the Long-Term Athlete Development Model focuses on providing appropriate levels of training and competition involvement to athletes across six stages of development (Balyi & Hamilton, 2004). The model spans the entire development pathway from fundamental skills through to elite; however it is limited in its focus on chronological age, physiology, and conditioning of athletes (Gulbin et al., 2013). Additionally, the model's focus on sport-specific technical and tactical skill components is restricted during the early stages of development (Ford et al., 2011). Unlike Deliberate Practice and the Long-Term Athlete Development Model, the Development Model of Sport Participation includes sports diversification, deliberate practice, coaching, and socio-cultural factors (i.e., community and family) that influence talent development (Côté, 1999; Gulbin et al., 2013). This model's limitations are the three generic athlete development pathways bound by chronological age, and the exclusion of a definition for elite levels to guide sport practitioners (Côté, 1999; Gulbin et al., 2013).

Conversely, the Differentiated Model of Giftedness and Talent provides a talent development process for athletes that have been identified as "gifted", with the purpose of developing expertise (Gagné, 2004). This process might be beneficial for talented athletes as it is inclusive of psychological, educational, and interpersonal traits required to be successful at elite levels (Gagne, 2006; Gagné, 2004). However, early learning stages of sport development are omitted and therefore it is not ideal for application within sporting development pathways (Gulbin et al., 2013). Like the Differentiated Model of Giftedness and Talent, the Athletic Talent Development Environment Model is more concerned with talent identified athletes and elite level development but it is restricted to sailing and canoeing and has not been applied to team sports (Gulbin et al., 2013). However, this model provides a framework that focuses on the environmental dynamics associated with sport development, including organisational culture, financial necessities, everyday habits for sporting success, and athletic achievement (Henriksen et al., 2010). This model may be ideal for stakeholders and sport practitioners because it includes human, material, and financial requirements, as well as organisational culture for athletic achievement (Henriksen et al., 2010); but it does not take into consideration individual athlete interactions like those outlined in the Deliberate Practice, Long-Term Development Model, and Development Model of Sport Participation models (Gulbin et al., 2013; Henriksen et al., 2010). These development models have been criticised for their limitation to only some areas of athlete development such as skill, physical training, or sport sampling, as opposed to all aspects of development (Gulbin et al., 2013, 2014). Therefore, the FTEM framework has been proposed as an inclusive framework of the critical characteristics identified by other talent development models.

The FTEM framework combines the general and specialised features of sport development identified in other models with active lifestyle, sport participation, and elite sport pathways (Gulbin et al., 2013, 2014). The framework is characterised by four distinct macro-phases of sport participation; foundations, talent, elite and mastery, which are further categorised into 10 micro-phases. The FTEM is commonly used by many NSO's (including the AFL) to establish athlete development pathways, optimise talent development, and improve player retention. The key differences between the AFL and FTEM framework is the emphasis on active lifestyle as a key outcome of sport participation, with the AFL not currently including this outcome in their participation model (Figure 1.1) (ASC, 2017; AFL, 2016; Gulbin et al., 2013, 2014). The provision of specific stages of development might suffice in conceptualising talent development and clear pathways for NSO's and the AFL, however it does not account for the issues associated with the cross-sectional nature of TID in adolescent athletes (MacNamara & Collins, 2014). Further investigation using non-linear analysis (see section 2.9. below) to classify players may identify varying combinations of physical fitness attributes which contribute to a player's likelihood of selection into AFL talent pathways that linear methods may have previously overlooked.

## 2.4. Talent Identification

Talent identification is a cross-sectional process involving the recognition of sport participants that have the potential to reach, and succeed at the highest level of elite sport (Abbott & Collins, 2002; Vaeyens et al., 2008; Williams & Reilly, 2000). Traditionally, TID models focus on selecting junior athletes (under 18 years) based on their current sport performances, physical, and anthropometric characteristics (Abbott & Collins, 2002; Martindale et al., 2005; Vaeyens, Güllich, Warr, & Philippaerts, 2009). This trend towards early TID and sport specialisation of athletes is supported by the Deliberate Practice theory of 10 years or 10,000 hours of deliberate practice for skill specialisation (Baker, 2003; Ericsson et al., 1993; Wiersma, 2000). However, the application of this rule to elite team sports is questionable as elite team sport athletes that engage in multiple sporting activities require less sport-specific practice hours to attain elite status (Baker et al., 2003a; Ward et al., 2007). Additionally, the concern with early TID is the risks of burnout, overtraining, and injury in developing athletes (Kaleth & Mikesky, 2010). The cross-sectional nature of TID is limited because athlete development long-term is multi-factorial and dynamic (Burgess & Naughton, 2010; Martindale et al., 2005; Pankhurst & Collins, 2013; Simonton, 1999; Vaeyens et al., 2008). For expert-level team sport athletes, dedicating less time to sport-specific practice and participation in a diverse range of activities other than sport-specific training allows greater development of physical fitness and decision making skills (Baker, 2003; Baker, Cobley, & Fraser-Thomas, 2009; Baker et al., 2003a; Berry et al., 2008; Burgess & Naughton, 2010). A major role for NSO's is to develop appropriate TID models that ensure future success of their sport (Abbott & Collins, 2002; Martindale et al., 2005; Pankhurst & Collins, 2013). However, organisations and clubs in professional sports continue to invest substantial resources into identifying young athletes and accelerating talent development to guarantee their investments (Abbott & Collins, 2004; Burgess & Naughton, 2010; Malina, 2009; Vaeyens et al., 2008; Williams & Reilly, 2000).

The usefulness of TID models for predictive purposes is problematic because they usually involve player selection for short-term success, not long-term development (Burgess & Naughton, 2010; Davids, Araújo, Vilar, Renshaw, & Pinder, 2013; Falk, Lidor, Lander, & Lang, 2004; Martindale et al., 2005; Vaeyens et al., 2008; Williams & Reilly, 2000). When value is placed on short-term success within junior competition, the natural variability of performance and development of junior athletes as they mature significantly influences their chances of selection/deselection into talent pathways (Martindale et al., 2005). Representative team selection policies that use traditional TID models can be detrimental because they lack the flexibility that is needed for long-term athlete development (Martindale et al., 2005; Vaeyens et al., 2008). Athletes may drop-out if their physical and sport development does not align with selection policies imposed by sporting organisation (Helsen, Starkes, & Hodges, 1998). However, research on the validity of tracking athletes longitudinally to improve TID and development of elite athletes is limited (Elferink-Gemser, Visscher, Lemmink, & Mulder, 2007; Falk et al., 2004; Martindale et al., 2005; Till, Cobley, O'Hara, Chapman, & Cooke, 2013; Till, Cobley, O'Hara, Chapman, & Cooke, 2013; Till et al., 2010; Vaeyens et al., 2008). This shortcoming may be attributed to the lack of patience in long-term athlete development programs as they require the sacrifice of short-term performance outcomes valued by junior players, parents, coaches and clubs (Côté & Hay, 2002; Martindale et al., 2005). Effective TID and development pathways require patience in athlete selection by identifying and overcoming constraints between competition levels of junior and elite athletes, and providing opportunities for all players to progressively train toward their desired goals (Burgess & Naughton, 2010; Davids et al., 2012). As such, it is important to understand how these constraints specifically pertain to the AFL participation pathway.

### 2.5. Constraints Model

Activities in sport utilise whole body actions for posture and locomotion to reach an optimal state of organisation in response to dynamic systems within a game (Davids et al., 2003; Wattie et al., 2015). Constraints are the barriers that may alter a players' movement or hinder their skill development (Newell, 1986, 1991). Constraints models have been applied across multiple sport science disciplines such as; strength and conditioning (Ives & Shelley, 2003), skill acquisition (Araujo & Davids, 2011; Davids et al., 2012), biomechanics (Glazier & Davids, 2009), and motor development (Newell, 1991, 2003) in an attempt to explain sport performance. Additionally, Newell's model of constraints (Newell, 1986) is an underpinning theoretical constructs of the dynamical systems theory, the other being self-organisation (Glazier, 2010; Glazier & Robins, 2013). Therefore this model provides an alternative approach to TID and development because it focuses on the underlying mechanisms and processes that determine a player's ability to be successful in elite competition (Glazier & Robins, 2013). Specifically, Newell's model of constraints proposes that optimal coordination and control of activities is a result of the dynamic interaction between organismic, environment, and task constraints (Figure 1.2) (Newell, 1986). Organismic constraints can be structural or functional in nature (Glazier & Davids, 2009; Newell, 1986). Structural constraints include anthropometrics, genetics, joint range of motion, fast and slow twitch muscle fibre composition, muscle angles and size, and fatigue (Glazier & Davids, 2009). The physical quality of structural constraints remains relatively constant; however, they may fluctuate during biological maturation (Davids et al., 2003; Newell, 1986; Wattie et al., 2015). Functional organismic constraints can be either physical or psychological, varying considerably compared to structural constraints. Examples of functional organismic constraints include; intention, perception, decision-making, and memory (Glazier & Davids, 2009). Environment constraints are external to the athlete and exist in either spatial or temporal arrangements during a game or in training by acting continuously on the neuromuscular system (Glazier & Davids, 2009; Newell, 1986, 2003). Examples of environmental constraints include; light, temperature, playing surfaces, and equipment. Other environmental constraints that can impact on an individual's performance include; opponents and team members, social-cultural influences (i.e., family members, friends, coaches, teachers), and governing policies (Bauer, Young, Fahrner, & Harvey, 2015; Côté, 1999; McKeown, Taylor-McKeown, Woods, & Ball, 2014). Finally, task constraints are those specific to the intended the player wants to achieve, for example; the game rules and boundaries in which a team competes, levels of competition, and the physical size and quality of skill of competition level. The implications of the model of constraints (Figure 1.2) is that players' 'self-organise' neuromuscular responses into distinct combinations of constraints to produce optimal patterns of movement and coordination (Glazier & Davids, 2009; Newell, 1986, 2003). As such, the development of AFL sporting expertise requires the continual adaptation of a player's behaviour in response to constraints with the aim of achieving their intended goal.

### 2.5.1. Organismic Constraints

It is important to contemplate the relevant characteristics of individual players within the AFL participation pathway, especially when considering adolescent athletes. Changes in body dimensions (i.e., anthropometrics and limb sizes) and action capabilities (i.e., physical fitness capabilities) are constantly evolving during puberty (Davids et al., 2013). Organismic constraints such as growth, maturity, and learning stages of individual players all have bearings on the physical fitness of players, and consequent stability of competition within AFL participation pathway (Davids et al., 2012). Specifically, growth spurts in an individual player creates new motor responses and muscle asymmetries, which affects their physical fitness, skill level, and subsequent performance in a game (i.e., environment) (Davids et al., 2012). Furthermore, players with observed asymmetrical movements are more likely to sustain an injury during an AF season (Chalmers et al., 2017). Targeting asymmetry using functional movement training in junior players may reduce injury risk, and improve athletic performance and development potential (Chalmers et al., 2017; Woods, Banyard, McKeown, Fransen, & Robertson, 2016a).

The variability of organismic constraints in players may create inconsistency in the performance environment across the AFL participation pathway, resulting in fluctuations in game structure and players' physical game demands (Vilar, Araújo, Davids, & Button, 2012). For example, differences in physical fitness demands of 13 to 15-year-old soccer players varied over a 5-year longitudinal study, with running speed and technical skills more important for 13 to 14-year-olds, and aerobic endurance more important for 15 to 16-year-old players (Vaeyens et al., 2006). In rugby, high-speed running (HSR) and physical maturity influences performance success of 12-year-old players, but as players mature the impact of size and strength on performance balances out, with decision making and anticipation becoming more important (Abbott & Easson, 2002). With differences in game play, skill level, game policies, and field sizes (Berry et al., 2008; Silva et al., 2014; Tangalos et al., 2015), an investigation into the extent in which organismic constraints such as physical fitness and match activity profiles vary between levels of junior AF competition is warranted.

### 2.5.2. Environmental Constraints

The environmental constraints refer to environmental conditions and social constructs that influence talent development across participation pathways such as; temperature and weather, playing surface and size, rules and policies, the development system, popularity of the sport, and family influences (Wattie et al., 2015). An in-depth investigation into sport popularity and family influences is beyond the scope of this review; however, rule and policy differences are evident between AFL participation pathway levels (Davids et al., 2012; Wattie et al., 2015). For example, Local U12s games are restricted to 15 min quarters, played on smaller grounds, use smaller footballs, with the choice of 15 v 15 or 18 v 18 players at the coaches discretion (AFL, 2018). Furthermore, the AFL match policy provides recommendations on the number of training sessions, session lengths, and training foci for local participation pathway levels, with minimal to no focus on physical fitness (AFL, 2018). Conversely, talent pathway levels are provided with physical fitness training which creates a gap in physical development between the local participation and talent pathways (AFL, 2018; Davids et al., 2012; Wattie et al., 2015). The effect of modified rules and policies on physical fitness and match demands of players across multiple levels of the AFL participation pathway remains unclear (Davids et al., 2012; Wattie et al., 2015). Grouping players based on age does not take into consideration the variability between chronological age and biological maturation in developing players, contributing to the RAE in talent squads (Wattie et al., 2015). The prevalence of the RAE in the talent pathway levels is linked to the biological maturity of players (an organismic constraint), with a bias towards older players selected over younger players (Wattie, Cobley, & Baker, 2008; Wattie et al., 2015). The causation and prevalence of the RAE within the AFL participation pathway will be discussed in further detail below.

### 2.5.3. Task Constraints

The task constraints within the AFL participation pathways include the effect of different game rules in junior levels, the tiers of competition, and the quality of aerobic capacity, jump ability, speed, agility, and movement ability of players' team members and opposition (Wattie et al., 2015). As a result, physical fitness tests have proven useful for tracking career progression, recruiting trends, and players' selection for specific positions into elite AFL competition (Pyne et al., 2005, 2006; Robertson et al., 2015b; Woods et al., 2015b). Substantial physical differences are evident between AFL drafted and state representative players on the following physical fitness tests: vertical jump (VJ), AFL agility test, 20-m sprint, and 20-m MSFT (Pyne et al., 2005; Robertson et al., 2015b). This pattern continues as players are drafted to an elite team with small-to-moderate correlations ($r$ = 0.27-0.31) reported between player progression from the draft and number of senior games played, and their 20-m sprint time, VJ, running VJ, and agility performance (Pyne et al., 2005). Furthermore, higher aerobic capacity (3-km time trial and Yo-Yo Intermittent Recovery (IR) 2) at the elite level has an impact on match performance by increasing direct game involvement and ball disposals (Mooney et al., 2011; Piggott, McGuigan, & Newton, 2015). Several studies have reported differences in physical and anthropometric characteristics between selected junior-elite and non-elite players (Veale et al., 2008; Woods et al., 2015b; Young & Pryor, 2007). When comparing junior-elite and non-elite players, junior-elite had better values for VJ (Veale et al., 2008; Young & Pryor, 2007), 20-m sprint time (Young & Pryor, 2007), upper-body strength (Keogh, 1999), and 20-m MSFT performance (Woods et al., 2015b). The current AFL Draft Combine test battery has been used to differentiate players on physical fitness (Pyne et al., 2005; Robertson et al., 2015b; Woods et al., 2015b). Unfortunately, few studies have documented the physical fitness and match activity profiles of local participation pathway players, with the exception of a single study showing running endurance in 10 to 15-year-old AF players contributed to more player disposals during games (Tangalos et al., 2015). Players may perform well on physical fitness tests, but how well these tests represent match activity demands of games at different levels across AFL participation pathway is yet to be established.

## 2.6. Relative Age Effects

The RAE is a demographic characteristic where a bias exists towards selecting athletes born earlier in a defined age group year comparative to those born later (Andronikos, Elumaro, Westbury, & Martindale, 2016; Coutts, Kempton, & Vaeyens, 2014; Simmons & Paull, 2001). The prevalence of the RAE has been described in several team sports (i.e., ice hockey, baseball, soccer, and basketball), and is more commonly reported in male competitions (Cobley et al., 2009; Coutts et al., 2014; Finnegan, Richardson, Littlewood, & McArdle, 2017; Mann & van Ginneken, 2017; Simmons & Paull, 2001; van den Honert, 2012; Woods, Robertson, & Gastin, 2015c). The presence of the phenomenon has been partially attributed to the organismic constraint of biological maturation in developing players, where more physically mature players of the same age gain a performance advantage (Cobley et al., 2009; Simmons & Paull, 2001; van den Honert, 2012). A selection bias in birth distributions of AFL drafted adolescent players has been reported, with more players born in the first half of the selection year (Coutts et al., 2014). There are conflicting reports on the point in which the RAE originates within the talent pathway. Previous work noted that the RAE was present in AFL national draftee playing groups under 20 years of age, however, the reverse existed in mature aged AFL draftees (those drafted over the age of 20) (Coutts et al., 2014). Furthermore, in high performance levels of soccer and rugby the difference between late and early maturating players at the elite level has no impact on selection (Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004; Sherar, Baxter-Jones, Faulkner, & Russell, 2007; Till et al., 2010; Till et al., 2014). Therefore, early maturing athletes may not be able to maintain their physical advantages into adult competitions (Ackland & Bloomfield, 1996). This discrepancy between junior and senior levels of competition supports further analyses to identify the point RAE emerges when evaluating the AFL talent identification and development models.

Chronological age appears to have little influence on the selection of talented junior AF players; however selected players typically, but not always, possess greater physical and anthropometric qualities than non-selected players within the same age competition (Keogh, 1999; Veale et al., 2010; Veale et al., 2008; Woods et al., 2015b; Young & Pryor, 2007). The biological maturity of players partially explains differences in anthropometric measures, running fitness, and match running performance in AF players aged between 11 to 19 years (Gastin & Bennett, 2014; Gastin, Bennett, & Cook, 2013a). Strong relationships between biological maturity and running endurance (20-m MSFT score) ($r = 0.65$) and 20-m sprint time ($r = -0.77$) have been reported (Gastin et al., 2013a). Players born earlier in the year may mature earlier than those born later in the same year, creating this performance gap (Cobley et al., 2009). Furthermore, players that mature earlier gain a performance advantage over their late developing peers, and are therefore more likely to be identified for representative AF squads (Gastin & Bennett, 2014; Gastin et al., 2013a). However, other components of physical fitness or match activity profiles have not been assessed in AFL players under 15 years. As such, the RAE in developing AF players needs to be considered when developing TID and development models.

## 2.7. Physical Fitness Profiles of Australian Rules Football

Small-to-moderate positive relationships between physical fitness testing and career progressions have been reported in elite AF players (Pyne et al., 2005). Common physical assessments for AF include, but are not limited to; 20-m sprint, VJ variations, AFL agility run, and 20-m MSFT's (Pyne et al., 2005, 2006; Robertson et al., 2015b; Woods et al., 2015b). Furthermore, the Technical Error of Measurement (TEM) for these assessments was previously reported by Pyne et al. (2005), with these measures outlined in Table 2.1. Additionally, movement screenings are used regularly to assess functional skills of players (Kiesel, Plisky, & Voight, 2007; Lockie et al., 2015; McKeown et al., 2014). Physical fitness research across the AFL participation pathway is extensive, and a comprehensive systematic review of relevant studies was conducted for Study I (Chapter 3) of this dissertation. Therefore, readers are referred to Chapter 3.

**Table 2.1.** Technical Error of Measurement (TEM) of common physical fitness tests used in the AFL Draft Combine test battery reported by Pyne et al. (2005).

| Physical Fitness Test | Technical Error Measurement |
|---|---|
| 20-m sprint (sec) | 0.04 s |
| Vertical jump (cm) | 1.4 cm |
| Running vertical jump (cm) | 1.4 cm |
| AFL agility run (sec) | 0.13 s |
| 20-m MSFT (estimated ml.kg.min$^{-1}$) | 1.4 ml.kg.min$^{-1}$ |

## 2.8. Movement Ability

The interaction of organismic, environmental, and task constraints may attribute to variability in functional movement ability across the AFL participation pathway. Specifically, the standardised AFL Draft Combine tests do not account for differences between players' capacity to perform athletic movement patterns. For example, muscular strength, power and speed form the basis of athletic training in AF (Hori et al., 2007; Nibali, Chapman, Robergs, & Drinkwater, 2013), with physical qualities requiring basic competency in athletic movement patterns (i.e., squatting, lunging, hip hinging, pushing, and pulling) to perform movements safely and effectively (Garrett, McKeown, Burgess, Woods, & Eston, 2018; McKeown et al., 2014). Within the local participation pathways, players exposure to specialist movement training is restricted which can impede athletic movement patterns required for specialised training programs within talent squads and elite teams. As such, younger players transitioning into talent pathway levels may demonstrate a reduced ability to coordinate limbs to achieve body control (Seifert, Button, & Davids, 2013). Additionally, movement ability assessments have become a common tool used by sport practitioners to quantifying movement competency for injury prevention (McCunn, aus der Fünten, Fullagar, McKeown, & Meyer, 2016). The application of movement screenings for injury prevention is beyond the scope of this review, however their usefulness as a TID and development assessment has been investigated in talent and elite levels of AF.

Two movement screening protocols have been reported within AF literature, the Functional Movement Screen (FMS) (Chalmers et al., 2017) and the Athlete Ability Assessment (AAA) (Gaudion, Doma, Sinclair, Banyard, & Woods, 2017; Woods, Banyard, McKeown, Fransen, & Robertson, 2016c; Woods, McKeown, Haff, & Robertson, 2015d; Woods, McKeown, Keogh, & Robertson, 2017). The FMS is the most prevalent test in general populations and sport literature compared to other movement screens (McCunn et al., 2016), however it is suggested that the fundamental movement skills required for sport performance is more demanding than movements assessed in the FMS (McKeown & Ball, 2013). Consequently, the AAA was proposed as an alternative movement screen that specifically targets athletic populations because it allows increases in load for the athlete as they progress through sporting pathways (McKeown et al., 2014), as such the AAA may be more appropriate as talent development and TID assessment in AF. Subsequently, the AAA has reported moderate discriminant validity between selected and non-selected State U18 players, and starters and non-starters in elite AFL players. Of the AAA movements, overhead squat, lunge, and single-leg Romanian deadlift (left) have shown significant moderate-to-very large effects (ES: 0.56-1.19) between selected and on-selected players (Woods et al., 2016c; Woods et al., 2015d). Furthermore, differences in movement ability between elite and talent pathway players in previous studies highlight the importance of developing movement ability for long-term success (Gaudion, Kenji, Wade, Harry, & Carl, 2017; Woods et al., 2016a; Woods, McKeown, Haff, & Robertson, 2015a). However, the movement ability of local participation pathways has not been investigated, or the magnitude of difference between AFL participation pathway levels movement ability.

### 2.9. Match Activity Profiles

Global positioning system (GPS) technology is commonly used in team sports to measure athlete positions, movement patterns, and velocities during both matches and training sessions, thus allowing for a greater understanding of the physical demands of the sport (Cummins, Orr, O'Connor, & West, 2013). More recent versions of GPS units include tri-axial accelerometer technology that provides information on players contact and collision intensity, and impacts (i.e., player-to-player collisions, change of directions, foot strikes and falls) through the measurement of vector magnitude through three axes (X, Y, and Z planes of movement) (Boyd, Ball, & Aughey, 2011; Cummins et al., 2013; Waldron, Twist, Highton, Worsfold, & Daniels, 2011). The vector magnitude accumulated from the three axes is referred to as player load, and had been found to be highly reliable (CV% <2%) at measuring external load in AF (Boyd et al., 2011). The validity and reliability of GPS units for measuring movement in various football codes, field hockey, and cricket has been established (Aughey, 2011; Cummins et al., 2013; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010). With improvements in sampling rates of GPS from 1-Hz to 5-Hz, and subsequently 10-Hz, the standard error has decreased to 11% over a 15-m sprint (Aughey, 2011), as opposed to 32% (1-Hz) and 31% (5-Hz) over a 10-m sprint (Jennings et al., 2010). Furthermore, higher sampling rates for GPS (10-Hz) has yielded more accurate measurement of accelerations and decelerations that were not possible at 5-Hz (Varley, Fairweather, & Aughey1, 2012), enhancing the monitoring movement patterns in team sport athletes (Cummins et al., 2013; Jennings et al., 2010; Wundersitz, Gastin, Richter, Robertson, & Netto, 2015). Specifically, higher sampling rates have permitted improvements in the reliability and validity of measuring AF game metrics, therefore becoming a popular tool to measure, monitor and analyse player movements (Bauer et al., 2015; Boyd et al., 2011; Jennings et al., 2010). Furthermore, the addition of accelerometers has allowed the quantification of AF players' external loads through measurement of the frequency and magnitude of movements (Boyd et al., 2013; Wundersitz et al., 2015). The field testing reliability of accelerometers during AF matches (measured at 100-Hz) indicates acceptable between-device reliability (coefficient of variation (CV); 1.9%, smallest worthwhile difference; 5.9%) (Boyd et al., 2011). However, the validity of accelerometers is lower as the magnitude of acceleration increases, for example during high running speeds (Gray, Jenkins, Andrews, Taaffe, & Glover, 2010; Wundersitz et al., 2015). This shortcoming is partly accounted for by the positioning of trunk-worn accelerometers which have reported an error range of 12-24% compared to ground reaction forces obtained via a force plate (Wundersitz, Netto, Aisbett, & Gastin, 2013). As such, despite adequate inter- and intra-unit reliability of accelerometers and their ability to measure players collisions and impacts (i.e., tackles and bumps) (Gastin, McLean, Breed, & Spittle, 2014), the sensitivity of trunk-worn accelerometers to accurately measure ground reaction force is unclear. Considering the task constraints of variations in ground size and game rules between AFL participation pathway levels, GPS-derived metrics may be more suitable for measuring match activity profiles for TID as opposed to accelerometers.

Match activity profiles of AFL players are commonly collected via GPS during competition in both junior talent squads and senior elite competition (Bauer et al., 2015; Boyd et al., 2011, 2013; Brewer, Dawson, Heasman, Stewart, & Cormack, 2010; Burgess et al., 2012; Colby, Dawson, Heasman, Rogalski, & Gabbett, 2014; Coutts et al., 2010; Gastin et al., 2013a; Wisbey, Montgomery, Pyne, & Rattray, 2010). Typical GPS variables reported include; total metreage, total game time, time/distance within speed zones (e.g. standing, walking, jogging, sprinting), relative speed, high intensity efforts, HSR, and maximal velocity (Bauer et al., 2015; Brewer et al., 2010; Burgess et al., 2012; Coutts et al., 2010; Gastin et al., 2013a; Wisbey et al., 2010). Generally, elite players cover greater distances (11,100-13,400 m) per game compared to local and talent participation pathway players (Aughey, 2010; Kempton, Sullivan, Bilsborough, Cordy, & Coutts, 2015). Elite AFL players also exhibit higher relative speeds and relative high intensity efforts than senior state level players (relative speed: +10 $m.min^{-1}$, high intensity efforts: +0.6 $efforts.min^{-1}$) and talent pathway levels (relative speed: +8-16 $m.min^{-1}$, high intensity efforts: +0.1 $efforts.min^{-1}$) (Brewer et al., 2010; Burgess et al., 2012). Within the local participation pathway levels (Local U11 to U19), incremental improvements in relative speed and HSR during a game is evident as players progress through competition levels, with early maturing players producing higher relative HSR (>10 $m.min^{-1}$) than late maturing players (Gastin et al., 2013a). However, an understanding of the relationship between physical fitness and match activity profiles across the AFL participation pathways levels is also required.

The relationships between match activity profiles and game performance has previously been analysed in elite level players (Bauer et al., 2015; Black et al., 2015; Gastin et al., 2013b; Mooney et al., 2011). Specifically, GPS measures that best predicted Champion Data© player rankings for nomadic players (on-ballers, half-forwards, half-backs, and centre-line) was walking distance ($R^2 = -0.24$) and walking frequency ($R^2 = -0.22$), with higher ranked players spending less time and distance walking during a game (Bauer et al., 2015). However, HSR and sprinting (game time and number of entries; $R^2 = 0.30$) variables were positively related with Champion Data© player rankings for fixed players (full-forwards and full backs) (Bauer et al., 2015). Furthermore, playing experience has a positive impact on physical match activity profiles, as HSR affects a player's involvement in a game and subsequent total number of disposals (Black et al., 2015; Gastin et al., 2013b; Mooney et al., 2011). A players competition experience (>50 games) significantly affects the relationship between HSR and total disposals during a game, compared to players with less than 50 games experience (Mooney et al., 2011). Still, the influence of physical fitness characteristics on match activity profiles of AF players under 15 years has not been reported. Furthermore, a comparison of match activity profiles has not been undertaken for each level of the AFL participation pathway. The collection of GPS/accelerometer data in junior levels is limited by the cost and specialist skills for performance analysis. However, this information is critical for informing the development of more effective training programs in junior and senior AF players, and would highlight the physical fitness attributes most suited for TID and development programs.

### 2.10. Non-linear Statistical Modelling

The dynamic nature of AFL development requires players to physically adapt to continual changes in constraints across the participation pathways. Linear statistical approaches may have shortcomings in identifying the multifactorial patterns that classify players into appropriate participation pathway levels (Dutt-Mazumder, Button, Robins, & Bartlett, 2011; Robertson, Back, & Bartlett, 2015a). Machine learning provides non-linear statistical methodology that includes classification and prediction, accounting for multiple patterns in data without being constrained by a single linear function (Bunker & Thabtah, 2017; Dutt-Mazumder et al., 2011; Robertson et al., 2015a). Non-linear modelling techniques have been used in AFL to explain match outcomes (Robertson et al., 2015a), player positions (McIntosh, Kovalchik, & Robertson, 2018; Woods, Veale, Collier, & Robertson, 2017), representativeness of training drills (Corbett et al., 2017), and player selection into elite competitions based on physical fitness attributes (Robertson et al., 2015b). In addition, non-linear statistical methods have been proven to outperform linear analyses decision making abilities relating to TID in professional basketball (Maymin, 2017), as well as reducing the risk of overlooking talented gymnasts (Pion, Hohmann, Liu, Lenoir, & Segers, 2017). Therefore, non-linear models can identify the key physical fitness and movement attributes that are specific to a given AFL participation pathway (Morgan, Williams, & Barnes, 2013; Robertson et al., 2015b). This approach allows coaches and talent selectors to make more informed decisions regarding player selection into higher levels of competition, as they provide a more in-depth explanation of the relationships between tests and match performance (Morgan et al., 2013; Robertson et al., 2015b). While these methods have been used for player selection into elite levels of AF competition, their application across the entire AFL participation pathway have yet to be investigated.

### 2.11. Aims of Thesis

This doctoral investigation forms part of a larger AFL collaborative project creating an athlete development matrix inclusive of technical (skill) and tactical (decision making), sociocultural, and psychological influences on player development. The primary aim of this thesis is to model physical fitness of players at each stage of the AF participation pathway, while systematically accounting for the Relative Age Effect. The secondary aim is to evaluate the validity of current physical fitness tests for explaining player match activity at each level of the AF participation pathway. The final aim is to use non-linear analyses to determine the extent to which physical fitness tests can accurately classify players into specific AFL participation pathway levels.

## 2.12. Significance of Thesis

A body of experimental research has investigated the physical fitness characteristics and match activity profiles of AF players; however no studies have conducted a large scale cross-sectional analysis comparing these factors across the AFL participation pathway. Some measurement studies of reliability and validity have assessed the ability of GPS to quantify match activity profiles in AF, but detailed observational studies and comparisons across levels of the AFL participation pathway are lacking. The associations between physical fitness measures and match activity profiles will also be compared across the pathway. This data will provide a systematic and comprehensive set of reference standards that indicate the relationship between physical fitness and match activity profiles in junior AF. In addition, a retrospective cross-sectional analysis of the effect that age-policy changes have on reducing the prevalence of the RAE within the talent pathway will also be conducted. This research will use non-linear data analyses to quantify and evaluate physical fitness and movement ability TID and development profiles of AF players for each level of the AFL participation pathway. The multi-factorial modelling of each level of the AF participation pathway will provide evidence to develop more appropriate AFL TID and player development policies. Finally, this research will provide practical TID and player development guidelines for coaches, talent selectors, and physical preparation staff that can be used to systematically shape talent development priorities of individual players at critical stages within the AF participation pathway.

## 2.13. References


Abbott, A., & Collins, D. (2002). A theoretical and empirical analysis of a 'state of the art' talent identification model. High Ability Studies, 13(2), 156-178. doi:10.1080/1359813022000048798

Abbott, A., & Collins, D. (2004). Eliminating the dichotomy between theory and practice in talent identification and development: considering the role of psychology. Journal of Sports Sciences, 22(5), 395-408. doi:10.1080/02640410410001675324

Abbott, A., & Easson, B. (2002). The mental profile. In B. D. Hale & D. Collins (Eds.), Rugby Tough (pp. 17-33). Champaign, IL: Human Kinetics.

Ackland, T. R., & Bloomfield, J. (1996). Stability of human proportions through adolescent growth. Australian Journal of Science and Medicine in Sport, 28(2), 57-60.

AFL Community. (2018). Australian football match policy. Retrieved from http://www.aflcommunityclub.com.au/index.php?id=32

AFL Development. (2016). Participation and talent pathways. Retrieved from http://www.aflcommunityclub.com.au/index.php?id=559

Andronikos, G., Elumaro, A. I., Westbury, T., & Martindale, R. J. J. (2016). Relative age effect: implications for effective practice. Journal of Sports Sciences, 34(12), 1124-1131. doi:10.1080/02640414.2015.1093647

Araujo, D., & Davids, K. (2011). Embodied cognition and emergent decision-making in dynamical movement systems. Junctures: The Journal for Thematic Dialogue (2), 45-57.

Aughey, R. J. (2010). Australian football player work rate: Evidence of fatigue and pacing? International Journal of Sports Physiology and Performance, 5(3), 394-405. doi:10.1123/ijspp.5.3.394

Aughey, R. J. (2011). Applications of GPS technologies to field sports. International Journal of Sports Physiology and Performance, 6(3), 295-310. doi:10.1123/ijspp.6.3.295

Australian Football League. (2017). Australian Football League annual report 2017. Retrieved from https://adobeindd.com/view/publications/3dab2f7a-5539-4c78-a88e-76d91cea5788/1/publication-web-resources/pdf/AFL_Annual_Report_2017.pdf

Australian Football League. (2018). NAB Draft Hub - draft history. Retrieved from http://www.afl.com.au/draft/draft-history/

Australian Sports Commission. (2017). FTEM. Retrieved from https://www.ausport.gov.au/ais/athlete_pathways_and_development/pathways

Bailey, R., Collins, D., Ford, P., MacNamara, Á., Toms, M., & Pearce, G. (2010). Participant development in sport: an academic review. Sports Coach UK, 4, 1-134.

Baker, J. (2003). Early specialization in youth sport: a requirement for adult expertise? High Ability Studies, 14(1), 85-94. doi:10.1080/13032000093526

Baker, J., Cobley, S., & Fraser-Thomas, J. (2009). What do we know about early sport specialization? not much! High Ability Studies, 20(1), 77-89. doi:10.1080/13598130902860507

Baker, J., Côté, J., & Abernethy, B. (2003a). Sport-specific practice and the development of expert decision-making in team ball sports. Journal of Applied Sport Psychology, 15(1), 12-25. doi:10.1080/10413200305400

Baker, J., Horton, S., Robertson-Wilson, J., & Wall, M. (2003b). Nurturing sport expertise: factors influencing the development of elite athlete. Journal of Sports Science and Medicine, 2(1), 1-9.

Balyi, I., & Hamilton, A. (2004). Long-term athlete development: trainability in childhood and adolescence. Olympic Coach, 16(1), 4-9.

Balyi, I., & Hamilton, A. (2004). Long-term athlete development: trainability in childhood and adolescence. Olympic Coach, 16(1), 4-9.

Bauer, A. M., Young, W., Fahrner, B., & Harvey, J. (2015). GPS variables most related to match performance in an elite Australian football team. International Journal of Performance Analysis in Sport, 15(1), 187-202. doi:10.1080/24748668.2015.11868786

Baxter-Jones, A. D. (1995). Growth and development of young athletes. Sports Medicine, 20(2), 59-64.

Berry, J., Abernethy, B., & Cote, J. (2008). The contribution of structured activity and deliberate play to the development of expert perceptual and decision-making skill. Journal of Sport and Exercise Psychology, 30(6), 685-708. doi:10.1123/jsep.30.6.685

Black, G. M., Gabbett, T. J., Naughton, G. A., & McLean, B. D. (2015). The effect of intense exercise periods on physical and technical performance during elite Australian Football match-play: A comparison of experienced and less experienced players. Journal of Science and Medicine in Sport, 19(7), 596-602. doi:10.1016/j.jsams.2015.07.007

Boyd, L. J., Ball, K., & Aughey, R. J. (2011). The reliability of minimaxx accelerometers for measuring physical activity in Australian football. International Journal of Sports Physiology and Performance, 6(3), 311-321. doi:10.1123/ijspp.6.3.311

Boyd, L. J., Ball, K., & Aughey, R. J. (2013). Quantifying external load in australian football matches and training using accelerometers. International Journal of Sports Physiology and Performance, 8(1), 44-51. doi:10.1123/ijspp.8.1.44

Brenner, J. S. (2007). Overuse injuries, overtraining, and burnout in child and adolescent athletes. Pediatrics, 119(6), 1242-1245. doi:10.1542/peds.2007-0887

Brewer, C., Dawson, B., Heasman, J., Stewart, G., & Cormack, S. (2010). Movement pattern comparisons in elite (AFL) and sub-elite (WAFL) Australian football games using GPS. Journal of Science and Medicine in Sport, 13(6), 618-623. doi:10.1016/j.jsams.2010.01.005

Bullock, N., Gulbin, J. P., Martin, D. T., Ross, A., Holland, T., & Marino, F. (2009). Talent identification and deliberate programming in skeleton: Ice novice to Winter Olympian in 14 months. Journal of Sports Sciences, 27(4), 397-404. doi:10.1080/02640410802549751

Bunker, R. P., & Thabtah, F. (2017). A machine learning framework for sport result prediction. Applied Computing and Informatics, In Press. doi:10.1016/j.aci.2017.09.005

Burgess, D., & Naughton, G. (2010). Talent development in adolescent team sports: a review. International journal of Sports Physiology and Performance, 5(1), 103-116. doi:10.1123/ijspp.5.1.103

Burgess, D., Naughton, G., & Norton, K. (2012). Quantifying the gap between under 18 and senior AFL football: 2003 and 2009. International journal of Sports Physiology and Performance, 7(1), 53-58. doi:10.1123/ijspp.7.1.53

Chalmers, S., Fuller, J. T., Debenedictis, T. A., Townsley, S., Lynagh, M., Gleeson, C., Zacharia, A., Thomson, S., & Magarey, M. (2017). Asymmetry during preseason Functional Movement Screen testing is associated with injury during a junior Australian football season. Journal of Science and Medicine in Sport, 20(7), 653-657. doi:10.1016/j.jsams.2016.12.076

Cobley, S., Baker, J., Wattie, N., & McKenna, J. (2009). Annual age-grouping and athlete development. Sports Medicine, 39(3), 235-256. doi:10.2165/00007256-200939030-00005

Colby, M. J., Dawson, B., Heasman, J., Rogalski, B., & Gabbett, T. J. (2014). Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. Journal of Strength and Conditioning Research, 28(8), 2244-2252. doi:10.1519/JSC.0000000000000362

Collins, R., Collins, D., MacNamara, Á., & Jones, M. I. (2014). Change of plans: an evaluation of the effectiveness and underlying mechanisms of successful talent transfer. Journal of Sports Sciences, 32(17), 1621-1630. doi:10.1080/02640414.2014.908324

Corbett, D. M., Bartlett, J. D., O'connor, F., Back, N., Torres-Ronda, L., & Robertson, S. (2017). Development of physical and skill training drill prescription systems for elite Australian Rules football. Science and Medicine in Football, 2(1), 1-7. doi:10.1080/24733938.2017.1381344

Côté, J. (1999). The influence of the family in the development of talent in sport. Sport Psychologist, 13(4), 395. doi:10.1123/tsp.13.4.395

Côté, J., & Hay, J. (2002). Children's involvement in sport: A developmental perspective. In M. A. Bacon (Ed.), Psychological Foundations of Sport. (pp. 484-502). Boston.

Côté, J., & Vierimaa, M. (2014). The developmental model of sport participation: 15 years after its first conceptualization. Science and Sports, 29, S63-S69. doi:10.1016/j.scispo.2014.08.133

Coutts, A. J., Kempton, T., & Vaeyens, R. (2014). Relative age effects in Australian Football League national draftees. Journal of Sports Sciences, 32(7), 623-628. doi:10.1080/02640414.2013.847277

Coutts, A. J., Quinn, J., Hocking, J., Castagna, C., & Rampinini, E. (2010). Match running performance in elite Australian Rules football. Journal of Science and Medicine in Sport, 13(5), 543-548. doi:10.1016/j.jsams.2009.09.004

Cummins, C., Orr, R., O'Connor, H., & West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: A systematic review. Sports Medicine, 43(10), 1025-1042. doi:10.1007/s40279-013-0069-2

Davids, K., Araújo, D., Hristovski, R., Passos, P., & Chow, J. Y. (2012). Ecological dynamics and motor learning design in sport. In N. J. Hodges & A. M. Williams (Eds.), Skill Acquisition in Sport: Research, Theory and Practice (2nd ed., pp. 112-130). New York: Routledge.

Davids, K., Araújo, D., Vilar, L., Renshaw, I., & Pinder, R. (2013). An ecological dynamics approach to skill acquisition: implications for development of talent in sport. Talent Development and Excellence, 5(1), 21-34.

Davids, K., Glazier, P., Araújo, D., & Bartlett, R. (2003). Movement systems as dynamical systems. Sports Medicine, 33(4), 245-260. doi:10.2165/00007256-200333040-00001

Dawson, B., Hopkinson, R., Appleby, B., Stewart, G., & Roberts, C. (2004). Player movement patterns and game activities in the Australian Football League. Journal of Science and Medicine in Sport, 7(3), 278-291. doi:10.1016/S1440-2440(04)80023-9

Dutt-Mazumder, A., Button, C., Robins, A., & Bartlett, R. (2011). Neural network modelling and dynamical system theory: are they relevant to study the governing dynamics of association football players? Sports Medicine, 41(12), 1003-1017. doi:10.2165/11593950-000000000-00000

Elferink-Gemser, M. T., Visscher, C., Lemmink, K. A., & Mulder, T. (2007). Multidimensional performance characteristics and standard of performance in talented youth field hockey players: a longitudinal study. Journal of Sport Sciences, 25(4), 481-489. doi:10.1080/02640410600719945

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. Psychological Review, 100(3), 363-406. doi:10.1037/0033-295X.100.3.363

Falk, B., Lidor, R., Lander, Y., & Lang, B. (2004). Talent identification and early development of elite water-polo players: a 2-year follow-up study. Journal of Sports Sciences, 22(4), 347-355. doi:10.1080/02640410310001641566

Finnegan, L., Richardson, D., Littlewood, M., & McArdle, J. (2017). The influence of date and place of birth on youth player selection to a National Football Association elite development programme. Science and Medicine in Football, 1(1), 30-39. doi:10.1080/02640414.2016.1254807

Ford, P., De Ste Croix, M., Lloyd, R., Meyers, R., Moosavi, M., Oliver, J., . . . Williams, C. (2011). The long-term athlete development model: Physiological evidence and application. Journal of Sports Sciences, 29(4), 389-402. doi:10.1080/02640414.2010.536849

Gagne, F. (2006). Understanding the complete choreography of talent development through DMGT-analysis. International Handbook of Giftednees and Talent, Oxford: Elsvier Science, 1-21.

Gagné, F. (2004). Transforming gifts into talents: The DMGT as a developmental theory. High Ability Studies, 15(2), 119-147. doi:10.1080/1359813042000314682

Gastin, P. B., & Bennett, G. (2014). Late maturers at a performance disadvantage to their more mature peers in junior Australian football. Journal of Sport Sciences, 32(6), 563-571. doi:10.1080/02640414.2013.843016

Gastin, P. B., Bennett, G., & Cook, J. (2013a). Biological maturity influences running performance in junior Australian football. Journal of Science and Medicine in Sport, 16(2), 140-145. doi:10.1016/j.jsams.2012.05.005

Gastin, P. B., Fahrner, B., Meyer, D., Robinson, D., & Cook, J. L. (2013b). Influence of physical fitness, age, experience, and weekly training load on match performance in elite Australian football. Journal of Strength and Conditioning Research, 27(5), 1272-1279. doi:10.1519/JSC.0b013e318267925f

Gastin, P. B., McLean, O. C., Breed, R. V. P., & Spittle, M. (2014). Tackle and impact detection in elite Australian football using wearable microsensor technology. Journal of Sports Sciences, 32(10), 947-953. doi:10.1080/02640414.2013.868920

Gaudion, S. L., Doma, K., Sinclair, W., Banyard, H. G., & Woods, C. T. (2017). Identifying the physical fitness, anthropometric and athletic movement qualities discriminant of developmental level in elite junior Australian football: Implications for the development of talent. Journal of Strength and Conditioning Research, 31(7), 1830-1839. doi:10.1519/jsc.0000000000001682

Glazier, P. S. (2010). Game, set and match? Substantive issues and future directions in performance analysis. Sports Medicine, 40(8), 625-634. doi:10.2165/11534970-000000000-00000

Glazier, P. S., & Davids, K. (2009). Constraints on the complete optimization of human motion. Sports Medicine, 39(1), 15-28. doi:10.2165/00007256-200939010-00002

Glazier, P. S., & Robins, M. T. (2013). Self-organisation and constraints in sports performance. In T. McGarry, P. O'Donoghue, & J. Sampaio (Eds.), Routledge Handbook of Sports Performance Analysis (pp. 42-51). New York: Routledge.

Gray, A. J., Jenkins, D., Andrews, M. H., Taaffe, D. R., & Glover, M. L. (2010). Validity and reliability of GPS for measuring distance travelled in field-based team sports. Journal of Sports Sciences, 28(12), 1319-1325. doi:10.1080/02640414.2010.504783

Gray, A. J., & Jenkins, D. G. (2010). Match analysis and the physiological demands of Australian football. Sports Medicine, 40(4), 347-360. doi:10.2165/11531400-000000000-00000

Gulbin, J. P., Croser, M. J., Morley, E. J., & Weissensteiner, J. R. (2013). An integrated framework for the optimisation of sport and athlete development: A practitioner approach. Journal of Sports Sciences, 31(12), 1319-1331. doi:10.1080/02640414.2013.781661

Gulbin, J. P., Croser, M. J., Morley, E. J., & Weissensteiner, J. R. (2014). A closer look at the FTEM framework. Response to "More of the same? Comment on 'An integrated framework for the optimisation of sport and athlete development: A practitioner approach'". Journal of Sports Sciences, 32(8), 796-800. doi:10.1080/02640414.2013.855806

Helsen, W., Starkes, J., & Hodges, N. (1998). Team sports and the theory of deliberate practice. Journal of Sport and Exercise Psychology, 20, 12-34. doi:10.1123/jsep.20.1.12

Henriksen, K., Stambulova, N., & Roessler, K. K. (2010). Holistic approach to athletic talent development environments: A successful sailing milieu. Psychology of Sport and Exercise, 11(3), 212-222. doi:10.1016/j.psychsport.2009.10.005

Hori, N., Newton, R. U., Andrews, W. A., Kawamori, N., McGuigan, M. R., & Nosaka, K. (2007). Comparison of four different methods to measure power output during the hang power clean and the weighted jump squat. Journal of Strength and Conditioning Research, 21(2), 314-320. doi:10.1519/R-22896.1

Ives, J. C., & Shelley, G. A. (2003). Psychophysics in functional strength and power training: Review and implementation framework. Journal of Strength and Conditioning Research, 17(1), 177-186.

Jennings, D., Cormack, S., Coutts, A. J., Boyd, L., & Aughey, R. J. (2010). The validity and reliability of GPS units for measuring distance in team sport specific running patterns. International Journal of Sports Physiology and Performance, 5(3), 328-341. doi:10.1123/ijspp.5.3.328

Kaleth, A. S., & Mikesky, A. E. (2010). Impact of early sport specialization: A physiological perspective. Journal of Physical Education, Recreation and Dance, 81(8), 29-37. doi:10.1080/07303084.2010.10598524

Kempton, T., Sullivan, C., Bilsborough, J. C., Cordy, J., & Coutts, A. J. (2015). Match-to-match variation in physical activity and technical skill measures in professional Australian Football. Journal of Science and Medicine in Sport, 18(1), 109-113. doi:10.1016/j.jsams.2013.12.006

Keogh, J. (1999). The use of physical fitness scores and anthropometric data to predict selection in an elite under 18 Australian rules football team. Journal of Science and Medicine in Sport, 2(2), 125-133. doi:10.1016/S1440-2440(99)80192-3

Kiesel, K., Plisky, P. J., & Voight, M. L. (2007). Can serious injury in professional football be predicted by a preseason functional movement screen? North American Journal of Sports Physical Therapy, 2(3), 147-158.

Lockie, R. G., Schultz, A. B., Jordan, C. A., Callaghan, S. J., Jeffriess, M. D., & Luczo, T. M. (2015). Can selected functional movement screen assessments be used to identify movement deficiencies that could affect multidirectional speed and jump performance? Journal of Strength and Conditioning Research, 29(1), 195-205. doi:10.1519/JSC.0000000000000613

MacNamara, A., & Collins, D. (2014). More of the same? Comment on "An integrated framework for the optimisation of sport and athlete development: A practitioner approach". Journal of Sports Sciences, 32(8), 793-795. doi:10.1080/02640414.2013.855805

Malina, R. M. (2009). Children and Adolescents in the Sport Culture: The Overwhelming Majority to the Select Few. Journal of Exercise Science and Fitness, 7(2), S1-S10. doi:10.1016/s1728-869x(09)60017-4

Malina, R. M., Eisenmann, J. C., Cumming, S. P., Ribeiro, B., & Aroso, J. (2004). Maturity-associated variation in the growth and functional capacities of youth football (soccer) players 13-15 years. European Journal of Applied Physiology, 91(5-6), 555-562. doi:10.1007/s00421-003-0995-z

Mann, D. L., & van Ginneken, P. J. M. A. (2017). Age-ordered shirt numbering reduces the selection bias associated with the relative age effect. Journal of Sports Sciences, 35(8), 784-790. doi:10.1080/02640414.2016.1189588

Martindale, R. J. J., Collins, D., & Daubney, J. (2005). Talent development: A guide for practice and research within sport. Quest, 57(4), 353-375. doi:10.1080/00336297.2005.10491862

Mattson, J. M., & Richards, J. (2010). Early specialization in youth sport: A biomechanical perspective. Journal of Physical Education, Recreation and Dance, 81(8), 26-28. doi:10.1080/07303084.2010.10598523

Maymin, P. Z. (2017). The automated general manager: can an algorithmic system for drafts, trades, and free agency outperform human front offices? Journal of Global Sport Management, 2(4), 234-249. doi:10.1080/24704067.2017.1389248

McCunn, R., aus der Fünten, K., Fullagar, H. H., McKeown, I., & Meyer, T. (2016). Reliability and association with injury of movement screens: a critical review. Sports Medicine, 46(6), 763-781. doi: 10.1007/s40279-015-0453-1

McIntosh, S., Kovalchik, S., & Robertson, S. (2018). Examination of player role in the Australian Football League using match performance data. International Journal of Performance Analysis in Sport, 18(3), 1-12. doi:10.1080/24748668.2018.1486116

McKeown, I., Taylor-McKeown, K., Woods, C., & Ball, N. (2014). Athletic Ability Assessment: A movement assessment protocol for athletes. International journal of Sports Physical Therapy, 9(7), 862-873.

Mooney, M., O'Brien, B., Cormack, S., Coutts, A., Berry, J., & Young, W. (2011). The relationship between physical capacity and match performance in elite Australian football: A mediation approach. Journal of Science and Medicine in Sport, 14(5), 447-452. doi:10.1016/j.jsams.2011.03.010

Morgan, S., Williams, M. D., & Barnes, C. (2013). Applying decision tree induction for identification of important attributes in one-versus-one player interactions: A hockey exemplar. Journal of Sports Sciences, 31(10), 1031-1037. doi:10.1080/02640414.2013.770906

Newell, K. M. (1986). Constraints on the development of coordination. In M. Wade (Ed.), Motor Development in Children: Aspects of Coordination and Control (pp. 341-361). Amsterdam: Martin Nijhoff.

Newell, K. M. (1991). Motor skill acquisition. Annual Review of Pychology, 42(1), 213-237. doi:10.1146/annurev.ps.42.020191.001241

Newell, K. M. (2003). Change in motor learning: A coordination and control perspective. Motriz, Rio Claro, 9(1), 1-6.

Nibali, M. L., Chapman, D. W., Robergs, R. A., & Drinkwater, E. J. (2013). A rationale for assessing the lower-body power profile in team sport athletes. Journal of Strength and Conditioning Research, 27(2), 388-397. doi:10.1519/JSC.0b013e3182576feb

Norton, K. I., Craig, N. P., & Olds, T. S. (1999). The evolution of Australian football. Journal of Science and Medicine in Sport, 2(4), 389-404. doi:10.1016/S1440-2440(99)80011-5

Oldenziel, K., Gagne, F., & Gulbin, J. (2004). Factors affecting the rate of athlete development from novice to senior elite: How applicable is the 10-year rule. Paper presented at the Athens Pre-Olympic Congress. Retrieved from http://cev.org.br/biblioteca/factors-affecting-the-rate-of-athlete-development-from-novice-to-senior-elite-how-applicable-is-the-10-year-rule/

Pankhurst, A., & Collins, D. (2013). Talent identification and development: The need for coherence between research, system, and process. Quest, 65(1), 83-97. doi:10.1080/00336297.2012.727374

Piggott, B. G., McGuigan, M. R., & Newton, M. J. (2015). Relationship between physical capacity and match performance in semiprofessional Australian rules football. Journal of Strength and Conditioning Research, 29(2), 478-482. doi:10.1519/jsc.0000000000000765

Pion, J., Hohmann, A., Liu, T., Lenoir, M., & Segers, V. (2017). Predictive models reduce talent development costs in female gymnastics. Journal of Sports Sciences, 35(8), 806-811. doi:10.1080/02640414.2016.1192669

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2005). Fitness testing and career progression in AFL football. Journal of Science and Medicine in Sport, 8(3), 321-332. doi:10.1016/S1440-2440(05)80043-X

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2006). Positional differences in fitness and anthropometric characteristics in Australian football. Journal of Science and Medicine in Sport, 9(1), 143-150. doi:10.1016/j.jsams.2005.10.001

Robertson, S., Back, N., & Bartlett, J. D. (2015a). Explaining match outcome in elite Australian Rules football using team performance indicators. Journal of Sports Sciences, 34(7), 637-644. doi:10.1080/02640414.2015.1066026

Robertson, S., Woods, C., & Gastin, P. (2015b). Predicting higher selection in elite junior Australian Rules football: The influence of physical performance and anthropometric attributes. Journal of Science and Medicine in Sport, 18(5), 601-606. doi:10.1016/j.jsams.2014.07.019

Seifert, L., Button, C., & Davids, K. (2013). Key properties of expert movement systems in sport. Sports Medicine, 43(3), 167-178. doi: https://doi.org/10.1007/s40279-012-0011-z

Sherar, L. B., Baxter-Jones, A. D., Faulkner, R. A., & Russell, K. W. (2007). Do physical maturity and birth date predict talent in male youth ice hockey players? Journal of Sports Sciences, 25(8), 879-886. doi:10.1080/02640410600908001

Shilbury, D., Sotiriadou, K. P., & Green, B. C. (2008). Sport development. systems, policies and pathways: An introduction to the special issue. Sport Management Review, 11(3), 217-223. doi:10.1016/S1441-3523(08)70110-4

Silva, P., Aguiar, P., Duarte, R., Davids, K., Araújo, D., & Garganta, J. (2014). Effects of pitch size and skill level on tactical behaviours of association football players during small-sided and conditioned games. International Journal of Sports Science and Coaching, 9(5), 993-1006.

Simmons, C., & Paull, G. C. (2001). Season-of-birth bias in association football. Journal of Sports Sciences, 19(9), 677-686. doi:10.1080/02640410152475801

Simonton, D. K. (1999). Talent and its development: An emergenic and epigenetic model. Psychological Review, 106(3), 435-457. doi:10.1037/0033-295X.106.3.435

Sullivan, C., Bilsborough, J. C., Cianciosi, M., Hocking, J., Cordy, J., & Coutts, A. J. (2014). Match score affects activity profile and skill performance in professional Australian Football players. Journal of Science and Medicine in Sport, 17(3), 326-331. doi:10.1016/j.jsams.2013.05.001

Tangalos, C., Robertson, S., Spittle, M., & Gastin, P. B. (2015). Predictors of individual player match performance in junior Australian football. International Journal of Sports Physiology and Performance, 10(7), 853-859. doi:10.1123/ijspp.2014-0428

Till, K., Cobley, S., O'Hara, J., Chapman, C., & Cooke, C. (2013a). An individualized longitudinal approach to monitoring the dynamics of growth and fitness development in adolescent athletes. Journal of Strength and Conditioning Research, 27(5), 1313-1321. doi:10.1519/JSC.0b013e31828a1ea7

Till, K., Cobley, S., O'Hara, J., Chapman, C., & Cooke, C. (2013b). A longitudinal evaluation of anthropometric and fitness characteristics in junior rugby league players considering playing position and selection level. Journal of Science and Medicine in Sport, 16(5), 438-443. doi:10.1016/j.jsams.2012.09.002

Till, K., Cobley, S., Wattie, N., O'Hara, J., Cooke, C., & Chapman, C. (2010). The prevalence, influential factors and mechanisms of relative age effects in UK Rugby League. Scandinavian Journal of Medicine and Science in Sports, 20(2), 320-329. doi:10.1111/j.1600-0838.2009.00884.x

Till, K., Tester, E., Jones, B., Emmonds, S., Fahey, J., & Cooke, C. (2014). Anthropometric and physical characteristics of English academy rugby league players. Journal of Strength and Conditioning Research, 28(2), 319-327. doi:10.1519/JSC.0b013e3182a73c0e

Tucker, R., & Collins, M. (2012). What makes champions? A review of the relative contribution of genes and training to sporting success. British Journal of Sports Medicine, 46(8), 555-561. doi:10.1136/bjsports-2011-090548

Vaeyens, R., Güllich, A., Warr, C. R., & Philippaerts, R. (2009). Talent identification and promotion programmes of Olympic athletes. Journal of Sports Sciences, 27(13), 1367-1380. doi:10.1080/02640410903110974

Vaeyens, R., Lenoir, M., Williams, A. M., & Philippaerts, R. M. (2008). Talent identification and development programmes in sport. Sports Medicine, 38(9), 703-714.

Vaeyens, R., Malina, R. M., Janssens, M., Van Renterghem, B., Bourgois, J., Vrijens, J., & Philippaerts, R. M. (2006). A multidisciplinary selection model for youth soccer: the Ghent Youth Soccer Project. British Journal of Sports Medicine, 40(11), 928-934. doi:10.1136/bjsm.2006.029652 van den Honert, R. (2012). Evidence of the relative age effect in football in Australia. Journal of Sports Sciences, 30(13), 1365-1374. doi:10.1080/02640414.2012.707329

Varley, M. C., Fairweather, I. H., & Aughey1, Robert J. (2012). Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. Journal of Sports Sciences, 30(2), 121-127. doi:10.1080/02640414.2011.627941

Veale, J., Pearce, A. J., Buttifant, D., & Carlson, J. S. (2010). Anthropometric profiling of elite junior and senior Australian football players. International Journal of Sports Physiology and Performance, 5(4), 509-520. doi:10.1123/ijspp.5.4.509

Veale, J., Pearce, A. J., Koehn, S., & Carlson, J. S. (2008). Performance and anthropometric characteristics of prospective elite junior Australian footballers: A case study in one junior team. Journal of Science and Medicine in Sport, 11(2), 227-230. doi:10.1016/j.jsams.2006.12.119

Vilar, L., Araújo, D., Davids, K., & Button, C. (2012). The role of ecological dynamics in analysing performance in team sports. Sports Medicine, 42(1), 1-10. doi:10.2165/11596520-000000000-00000

Waldron, M., Twist, C., Highton, J., Worsfold, P., & Daniels, M. (2011). Movement and physiological match demands of elite rugby league using portable global positioning systems. Journal of Sport Sciences, 29(11), 1223-1230. doi:10.1080/02640414.2011.587445

Ward, P., Hodges, N. J., Starkes, J. L., & Williams, M. A. (2007). The road to excellence: deliberate practice and the development of expertise. High Ability Studies, 18(2), 119-153. doi:10.1080/13598130701709715

Wattie, N., Cobley, S., & Baker, J. (2008). Towards a unified understanding of relative age effects. Journal of Sports Sciences, 26(13), 1403-1409. doi:10.1080/02640410802233034

Wattie, N., Schorer, J., & Baker, J. (2015). The relative age effect in sport: A developmental systems model. Sports Medicine, 45(1), 83-94. doi:10.1007/s40279-014-0248-9

Wiersma, L. D. (2000). Risks and benefits of youth sport specialization: Perspectives and recommendations. Pediatric Exercise Science, 12(1), 13-22. doi:10.1123/pes.12.1.13

Williams, A. M., & Reilly, T. (2000). Talent identification and development in soccer. Journal of Sports Sciences, 18(9), 657-667. doi:10.1080/02640410050120041

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

Woods, C., Banyard, H. G., McKeown, I., Fransen, J., & Robertson, S. (2016a). Discriminating talent identified junior Australian footballers using a fundamental gross athletic movement assessment. Journal of Sports Science and Medicine, 15(3), 548-553.

Woods, C., Raynor, A. J., Bruce, L., McDonald, Z., & Collier, N. (2015a). Predicting playing status in junior Australian football using physical and anthropometric parameters. Journal of Science and Medicine in Sport, 18(2), 225-229. doi:10.1016/j.jsams.2014.02.006

Woods, C., Robertson, S. J., & Gastin, P. B. (2015b). Does relative age distribution influence the physical and anthropometric profiles of drafted under 18 Australian footballers? An investigation between the 2010 and 2013 seasons. Talent Development and Excellence, 7(1), 83-90.

Woods, C., Veale, J. P., Collier, N., & Robertson, S. (2017). The use of player physical and technical skill match activity profiles to predict position in the Australian Football League draft. Journal of Sports Sciences, 35(4), 325-330. doi:10.1080/02640414.2016.1164334

Woods, C. T., Banyard, H. G., McKeown, I., Fransen, J., & Robertson, S. (2016c). Discriminating talent identified junior Australian footballers using a fundamental gross athletic movement assessment. Journal of Sports Science and Medicine, 15(3), 548-553.

Woods, C. T., McKeown, I., Haff, G. G., & Robertson, S. (2015d). Comparison of athletic movement between elite junior and senior Australian football players. Journal of Sports Sciences, 34(13), 1260-1265. doi:10.1080/02640414.2015.1107185

Woods, C. T., McKeown, I., Keogh, J., & Robertson, S. (2017). The association between fundamental athletic movements and physical fitness in elite junior Australian footballers. Journal of Sports Sciences, 36(4), 455-450. doi:10.1080/02640414.2017.1313996

Wundersitz, D. W. T., Gastin, P. B., Richter, C., Robertson, S. J., & Netto, K. J. (2015). Validity of a trunk-mounted accelerometer to assess peak accelerations during walking, jogging and running. European Journal of Sport Science, 15(5), 382-390. doi:10.1080/17461391.2014.955131

Wundersitz, D. W. T., Netto, K. J., Aisbett, B., & Gastin, P. B. (2013). Validity of an upper-body-mounted accelerometer to measure peak vertical and resultant force during running and change-of-direction tasks. Sports Biomechanics, 12(4), 403-412. doi: 10.1080/14763141.2013.811284

Young, W. B., Newton, R. U., Doyle, T. L. A., Chapman, D., Cormack, S., Stewart, C., & Dawson, B. (2005). Physiological and anthropometric characteristics of starters and non-starters and playing positions in elite Australian Rules football: A case study. Journal of Science and Medicine in Sport, 8(3), 333-345. doi:10.1016/S1440-2440(05)80044-1

Young, W. B., & Pryor, L. (2007). Relationship between pre-season anthropometric and fitness measures and indicators of playing performance in elite junior Australian Rules football. Journal of Science and Medicine in Sport, 10(2), 110-118. doi:10.1016/j.jsams.2006.06.003

# CHAPTER 3 – Study I

## 'Physical characteristics of players within the Australian Football League participation pathways: A systematic review'

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

Haycraft, J., Kovalchik, S., Pyne, D. B., & Robertson, S. (2017). Physical characteristics of players within the Australian Football League participation pathways: a systematic review. *Sports Medicine Open*, 3(1), 46-62. doi:10.1186/s40798-017-0109-9

### 3.1. Abstract

Australian Football (AF) players require endurance, strength, speed and agility to be successful. Tests assessing physical characteristics are commonly used for talent identification; however, their ability to differentiate between players across the Australian Football League's (AFL) participation pathway remains unclear. The objective of this systematic review was to quantify the physical characteristics of male AF players across the AFL participation pathway.

A search of databases was undertaken. Studies examining tests of physical performance were included, with 27 meeting the inclusion/exclusion criteria. Study appraisal was conducted using a checklist of selection criteria. The 20-m sprint time was the most reported test, followed by vertical jump (VJ), AFL planned agility, and 20-m multi-stage fitness test (MSFT). The fastest times for 20-m sprint were for Elite AFL players (range 2.94 – 3.13 s), with local level players the slowest (3.22 – 4.06 s). State Junior Under (U) 18s (58 – 66 cm) had higher jumps than senior players; with the lowest jumps reported for Local U10s (mean 31 cm). No elite-level data were reported for the AFL planned agility or 20-m MSFT. AFL planned agility times were only reported for talent pathway levels, with large performance variability evident across all levels (8.17 – 9.12 s). Only mean 20-m MSFT scores were reported from Local U10s to National Draft Camp (6.10 – 13.50 shuttles).

Talent pathway players exhibit similar mean test scores irrespective of the physical test, with the exception of 20-m sprint and VJ. Physical tests can discriminate between local participation level players, but are less useful within the AFL talent pathway.

## 3.2. Introduction

Australian Football (AF) is a popular team sport in Australia, with selection of players across the participation pathway partially based on physical characteristics and subjective evaluation of playing ability (Burgess, Naughton, & Hopkins, 2012a). Game motion analyses indicate that AF is an intermittent team sport characterised by both high-intensity (high-speed running, sprinting, acceleration, agility), and low-intensity activities (standing, walking, jogging) (Boyd, Ball, & Aughey, 2013; Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004; Gray & Jenkins, 2010; Hiscock, Dawson, Heasman, & Peeling, 2012; Veale, Pearce, & Carlson, 2007; Wisbey, Montgomery, Pyne, & Rattray, 2010). A player's ability to progress through to, and perform at the elite level requires high levels of aerobic endurance, speed, strength, power and agility (Gray & Jenkins, 2010).

The physical performance and anthropometric characteristics of AF players have been well documented, with common physical assessments including sprinting, vertical jumps, agility, and multi-stage fitness tests (MSFT) (Pyne, Gardner, Sheehan, & Hopkins, 2005; Robertson, Woods, & Gastin, 2015; Woods, Raynor, Bruce, McDonald, & Collier, 2015b; Woods, Raynor, Bruce, McDonald, & Robertson, 2016c; Young & Rogers, 2014). These tests also form part of the annual Australian Football League (AFL) National Draft Combine, where players are evaluated prior to the National Draft. Small-to-moderate ($r$ = 0.27-0.31) positive relationships between physical fitness and career progression have been reported in various AF player cohorts (Pyne et al., 2005). These physical assessments have been primarily conducted to inform the selection of players for professional contracts and specific positions, but also to elucidate longitudinal recruiting trends (Pyne, Gardner, Sheehan, & Hopkins, 2006).

A review of AF physical performance studies identified a variety of physical test outcomes for players from senior elite, national junior and state junior levels of AF competition (Gray & Jenkins, 2010). However, to date the magnitude of differences in physical performance characteristics along the AFL participation pathway (Figure 3.1) has not been reported. Given the prevalence of test use for talent identification and player physical development within the AFL pathway, a review of the relevant literature would help inform recruitment practices (Gray & Jenkins, 2010). Furthermore, a variety of speed (Gastin & Bennett, 2014; Gastin, Fahrner, Meyer, Robinson, & Cook, 2013b; Gastin, Meyer, Huntsman, & Cook, 2015; Gastin, Tangalos, Torres, & Robertson, 2017; Gaudion, Kenji, Wade, Harry, & Carl, 2017; Young, Cormack, &

Crichton, 2011a; Young et al., 2008; Young et al., 2005), agility (Chalmers et al., 2013; Young, Farrow, Pyne, McGregor, & Handke, 2011b; Young & Rogers, 2014), power (Bilsborough et al., 2015; Buchheit et al., 2013; Caia, Doyle, & Benson, 2013; Cormack, Newton, McGulgan, & Doyle, 2008; Crow, Buttifant, Kearny, & Hrysomallis, 2012; Dawson, Gow, Modra, Bishop, & Stewart, 2005; Woods, Cripps, Hopper, & Joyce, 2016b), strength (Bilsborough et al., 2015; Hart, Nimphius, Spiteri, & Newton, 2014; Hori et al., 2008; Keogh, 1999; Woods, Watsford, Cavanagh, & Pruyn, 2015d), movement quality (Chalmers et al., 2017; Gaudion et al., 2017; Woods, Banyard, McKeown, Fransen, & Robertson, 2016a; Woods, McKeown, Haff, & Robertson, 2015a), and aerobic (Aughey, 2013; Bellenger et al., 2015; Gastin et al., 2013b; Inness, Billaut, & Aughey, 2016) tests have been analysed using AF player samples, however these tests are not administered using the standardised AFL National Combine protocols. With a large number of studies reporting physical performance measures of AF players across the AFL participation pathway, a review of relevant studies is needed to provide an overview of players' physical characteristics. Furthermore, a detailed analysis of physical performance measures would provide team coaches and support staff (i.e. strength and conditioning coaches, and sport science advisors) benchmarks to inform the physical preparation of players at each level of the AFL participation pathway.

The current AFL participation pathway (Figure 3.1) involves two streams that funnel athletes into state and elite senior competitions; the *local participation* pathway and the *talent* pathway (Australian Football League [AFL], 2016). Generally, the majority of players transition through the state-based local participation pathway via the following teams: school/clubs/community (5-11 years of age), junior schools/clubs (12-14 years), youth schools/clubs (15-18 years), to open age league/associations (>18 years) (AFL, 2016). The talent pathway runs parallel to the local participation pathway, with a smaller cohort of more elite junior players selected for talent pathway squads based on their objective test outcomes, and subjective match performance assessments conducted by coaches and talent scouts (Burgess, Naughton, & Norton, 2012b). The talent pathway is a national program consisting of regional development squads where talented players can transition through to Under (U) 14-16s state championship teams and national U16s and U18s championship teams (AFL, 2016). Furthermore, talented AF players may be selected for AFL state academies, sporting centres of excellence, and the National AFL academy (Burgess et al., 2012b; AFL, 2016; Robertson et al., 2015). Players are selected into senior state AF competitions from either the local participation or talent pathways, with elite players primarily selected through the annual AFL

National Draft (Pyne et al., 2005). While the structure of the AFL participation pathway may provide clear local participation and talent pathways for players, no studies have assessed the physical differences between the levels within both pathways using standardised testing methods.

The aim of this article was to conduct a systematic review of the physical test performance of AF players, and establish a comprehensive model of differences in physical performance along the AFL local and talent pathways that informs talent selection, recruitment, and fitness program design.

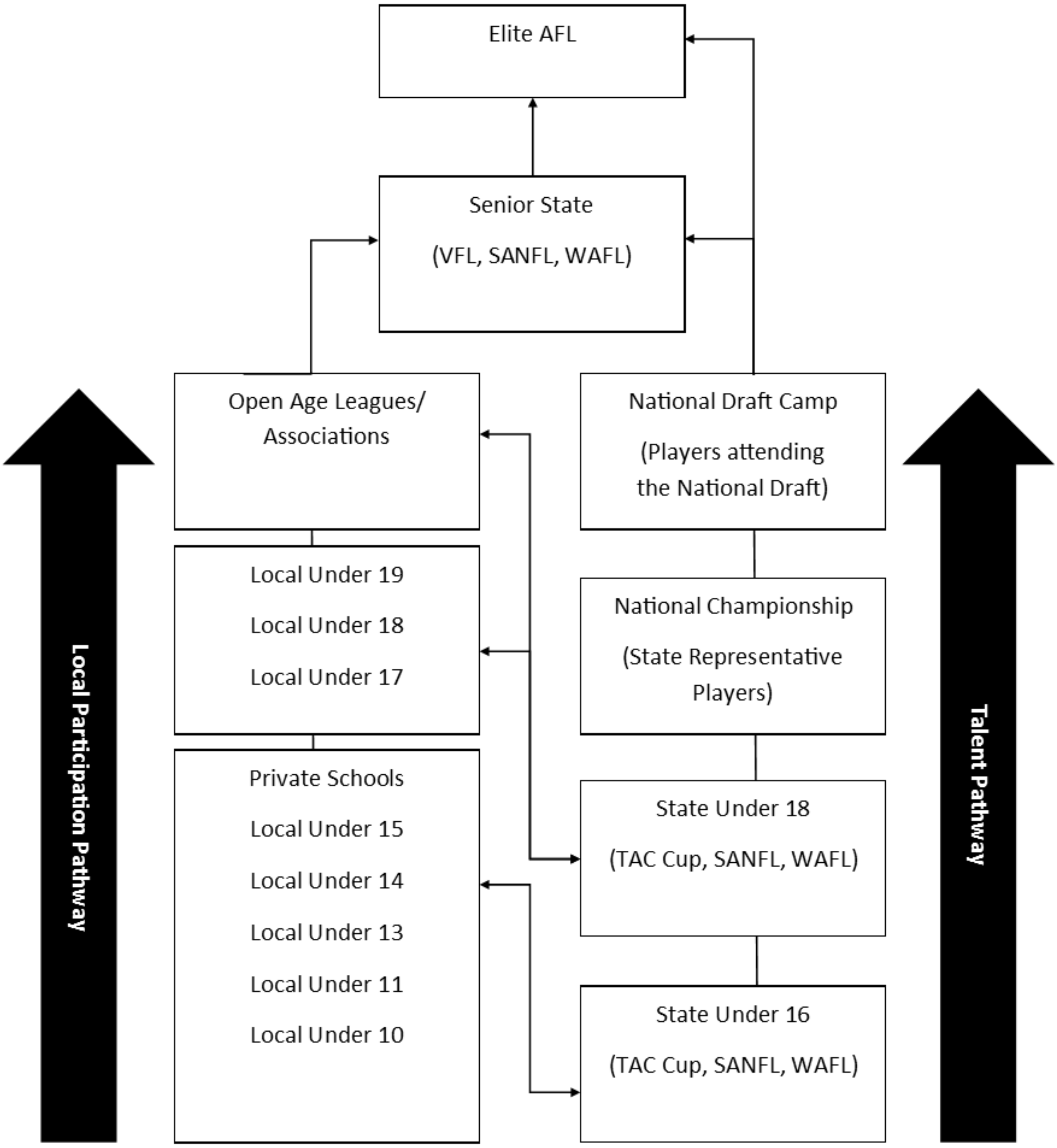


**Figure 3.1.** The AFL participation pathway adapted from AFL Development (AFL, 2016). AFL: Australian Football League; TAC: Transport Accident Commission (Victorian State Junior Football League); VFL: Victorian Football League; SANFL: South Australian National Football League; WAFL: Western Australian Football League.

## 3.3. Methods

### 3.3.1. Design

The PRISMA (Preferred Items for Systematic reviews and Meta-analyses) statement was used for this systematic review. The PRISMA allows for improved quality of reporting and evaluation of literature for systematic reviews (Moher, Liberati, Tetzlaff, Altman, & Group, 2010). Studies investigating physical performance tests for speed, change of direction (COD), power, strength, aerobic, and anaerobic capacity of male AF players were assessed for potential inclusion. A detailed outline of the search strategy, and criteria used for inclusion/exclusion of studies for review is shown in Figure 3.2.

### 3.3.2. Search strategy

A literature search was conducted between August 2015 and March 2017 using SPORTDiscus, PubMed, and Scopus. Key search terms utilised in the search were multiple combinations of AND/OR phrases that included 'Australian', 'football', 'physical', 'performance' and 'talent'. Studies were also identified by examination of citations listed in the collected publications (Moher et al., 2010).

### 3.3.3. Inclusion criteria

The initial search revealed multiple studies as far back as 1970 that investigated physical performance measures of football players. However, no studies prior to 1999 met the inclusion criteria (below) for this review. The final search process specified articles published between 1999 and March 2017. Inclusion criteria for physical performance tests of AF players were as follows: i) each study had been peer reviewed and written in English; ii) abstracts of articles were available; iii) articles that reported multiple test results were included where results could be extracted and reported in isolation of other tests; and iv) the testing methods used to collect physical performance data were outlined in detail by the authors.

### 3.3.4. Exclusion Criteria

Studies were excluded from this review when i) no physical performance measures for AF players were reported; ii) AF-specific data were not clearly identifiable; iii) the article was a review study or author commentary/reply; iv) the article was an AF coaching-specific study; or v) the authors tested AF players who had competed in the local participation pathway open age leagues/associations.

3.3.5. Data Extraction

The author list and publication date were recorded for each study identified during the database search. All articles identified in the search were coded as "Yes" or "No" to identify those meeting, or possibly meeting, the inclusion/exclusion criteria. Specifically, sample size, participant characteristics (age, height and body mass), reported player level within the AFL participation pathway, whether the inclusion/exclusion criteria were reported, and the methodology of physical tests, were assessed. Articles were further excluded from this review based on the characteristics detailed in the PRISMA statement (Figure 3.2).

3.3.6. Analysis

Mean and standard deviation of the physical performance test measures were extracted for each AFL level using a customised Microsoft Excel™ (Microsoft Corporation, Santa Rosa, California, USA) spreadsheet. All data from each study were extracted by the lead author (JH). The magnitude of differences in testing values between each of the participation levels was summarised and displayed using forest plots. These plots were developed for each physical test and player group reported by studies across the multiple AFL participation pathway levels. Each point in the forest plot displays the mean and lines denote 95% confidence interval (CI) about the mean for a specific player group report for each study. Any group whose mean score was not contained within the range of the CIs for any other group within the same AFL level was deemed an outlier. Plots were produced using the RStudio® statistical computing software version 1.0.136 (RStudio, Boston, Massachusetts, USA). A formal meta-analysis was explored but not presented in the report because exploratory analysis showed substantial between-study heterogeneity for the majority of physical measures.

## 3.4. Results

3.4.1. Overview of Studies

The initial search process yielded 2507 articles, 1237 were screened and 321 underwent a detailed review for eligibility. Data was extracted from 27 studies that met the inclusion/exclusion criteria (Figure 3.2). This data included all reported performance measures for the following physical tests; anaerobic power, aerobic power, speed, strength, power, and change of direction (COD). Extracted physical data was further classified into AFL participation pathway levels based on the team levels reported in each study. Player data was obtained from the following AFL participation pathway levels; "Elite AFL", "Senior State", "National Draft Camp", "National Championship", "State Junior U18", "Private School", and local "U19", "U18", "U17", "U15", "U13", "U11" and "U10".

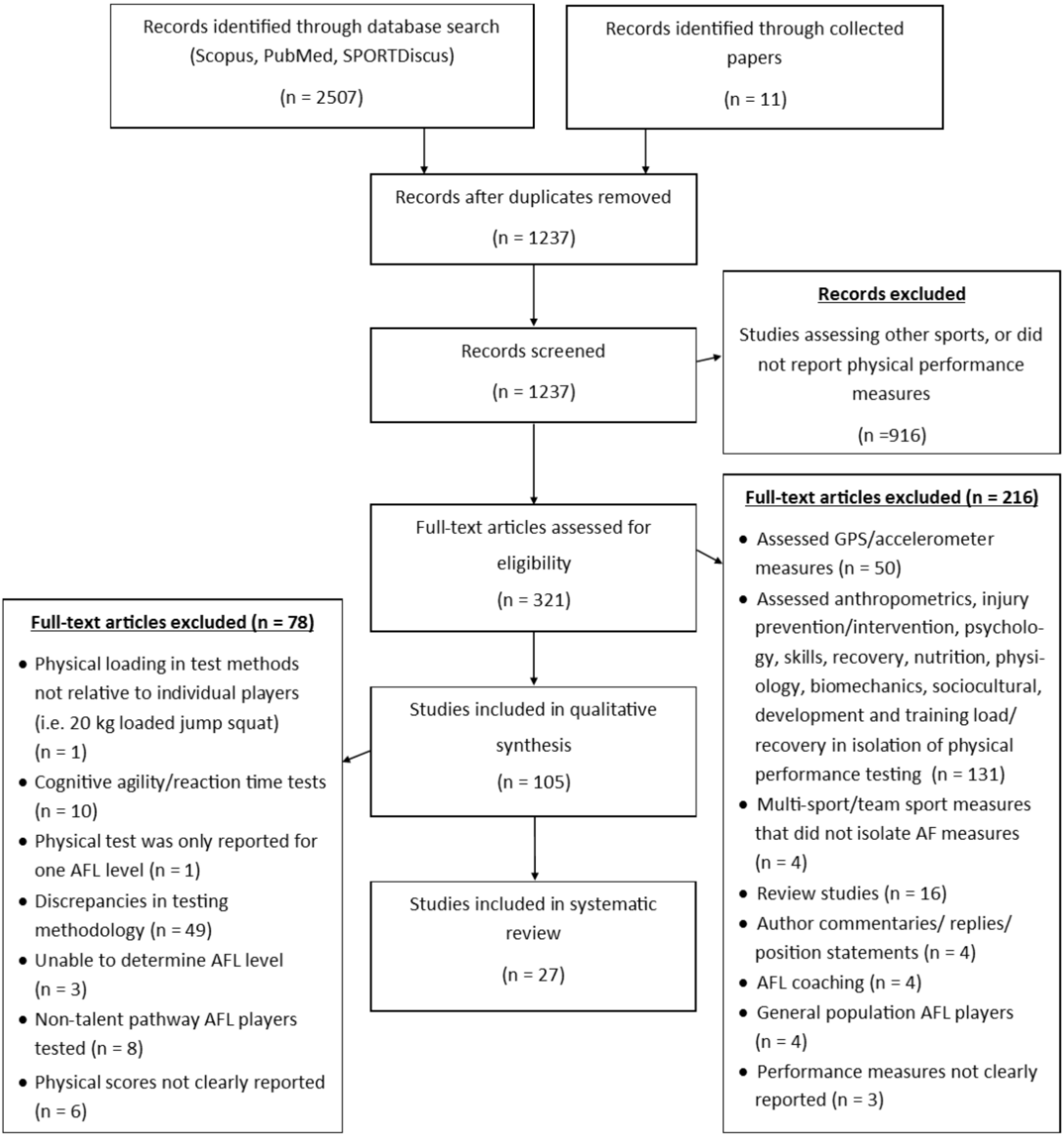


**Figure 3.2.** PRISMA flow diagram of study search strategy for systematic review of AFL development pathway. AF: Australian Football; AFL: Australian Football League; GPS: Global Positioning System.

### 3.4.2. Speed

Of the 27 articles reviewed, 20 reported 20-m sprint time across all levels of the AFL participation pathway, with the exception of Private School players. The mean 20-m sprint times across the local participation were observed for the following levels; Local U10 (4.00 s), Local U11 (range 3.90 – 4.06 s), Local U12 (3.70 s), Local U13 (range 3.70 – 3.82 s), Local U14 (3.40 s), Local U15 (range 3.30 – 3.57 s), Local U17 (3.33 s), and Local U19 (3.20 s). Observed mean times were not only slower among the local participation groups, when compared with talent pathway groups, but also more variable (Figure 3.3). For example, the difference in the range between means for U15 players was nearly 0.30 s and more than 0.10 s for U13, suggesting greater (variation) inconsistency in sprint performance at the lowest levels of the AFL participation pathway. The slowest observed mean sprint time was reported for the Local U11 group. All mean times from the Local U18 level and below were 3.30 seconds or slower.

A substantially faster 20-m sprint time is evident as players' transition through the AFL participation pathway from Local U10s to Elite AFL competition. The mean range of elite AFL players' 20-m sprint times was 2.94 – 3.13 s (Figure 3). However, one group reported by Young et al. (2008) was deemed an outlier within this level, and after removal the mean range for Elite AFL players was 2.94 – 3.01 s. The most similar AFL levels in reported 20-m sprint time means and CIs were the State Senior (range 3.11 – 3.22 s), National Draft Camp (range 3.04 – 3.05 s), National Championship (mean 3.09 s), State Junior U18s (range 2.99 – 3.16 s), and State Junior U16s (range 3.04 – 3.20 s). Multiple studies in these AFL levels had similar 20-m sprint results.

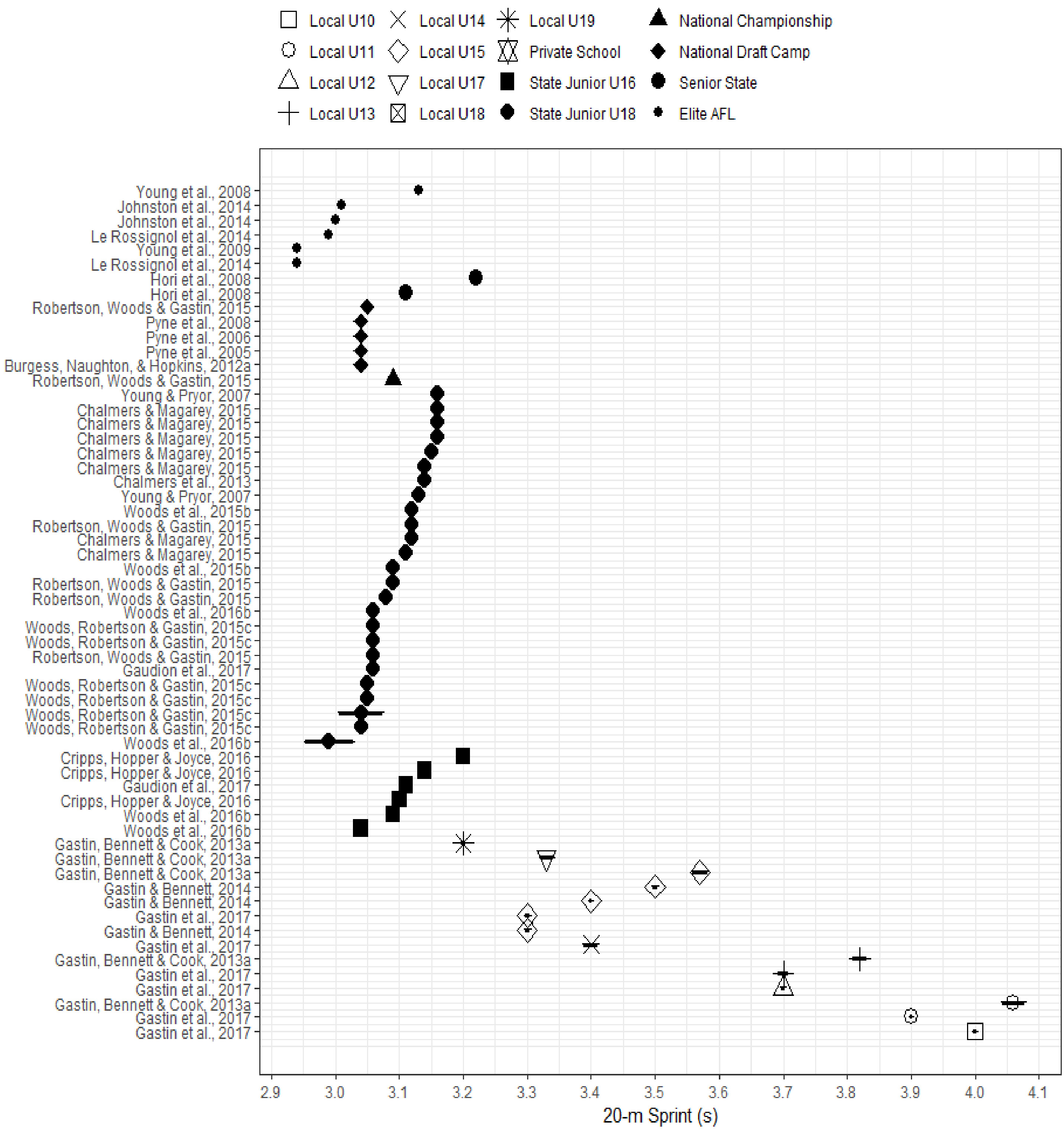


**Figure 3.3.** Mean and CIs of reported 20-m sprint times across the AFL participation pathway levels. Values are ordered by position in AFL participation pathway, then by sample size reported for each group. All players' levels are shown in the legend for consistency though not all levels may have data on the charted performance measure. AFL: Australian Football League; U: Under.

### 3.4.3. Change of Direction

The AFL planned agility time was stated in thirteen (48%) of the 27 studies. Only one study reported local participation pathway levels (Private School), with all others reporting talent pathway levels. The Private School players' mean AFL planned agility time was 8.86 s. Within the talent pathway, no study reported mean AFL planned agility times for Elite AF players, one group reported State Senior players (range 8.17 – 8.99 s), four for National Draft Camp (range 8.57 – 8.63 s), three for National Championship (range 8.61 – 9.08 s), six reported State Junior U18 (range 8.37 – 9.12 s), and one reported State Junior U16 (8.58 s). The fastest reported AFL planned agility time was recorded for State Senior level players (Figure 3.4), however the range for mean agility time within the four groups was split, with two groups having a mean time range of 8.17 – 8.27 s, and another two ranged between 8.90 – 8.99 s. The slowest reported mean AFL planned agility time was observed for State Junior U18 players (9.12 s) (see Figure 3.4). There was a high-degree of variability in the State Junior U18 mean times, with three group times for State Junior U18s (Chalmers and Magarey (2015), and two by Young and Pryor (2007) above 8.80 s. All other groups reported mean agility times between 8.37 – 8.74 s. The most consistent mean agility times were observed for the National Draft Camp (range 8.57 – 8.63 s). The National Championship level reported mean agility times (total range 8.61 – 9.08 s) were consistent across three of the four reported groups (range 8.61 – 8.67 s), with one outlier observed reported by Young et al. (2011b). All groups mean agility time and CIs for AFL talent and local participation pathway levels overlapped; as such AFL planned agility performance is similar across these levels.

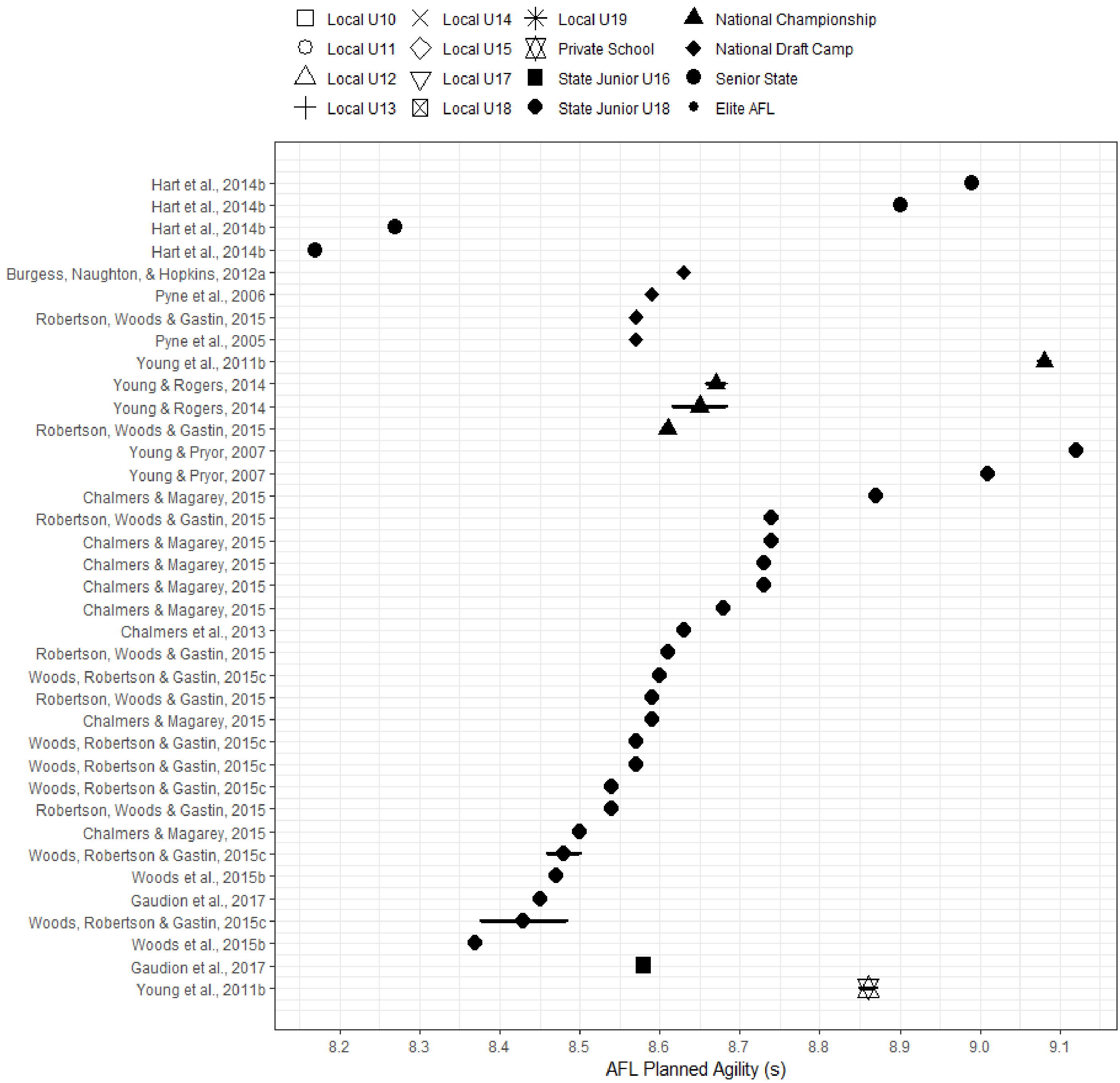


**Figure 3.4.** Mean and CIs of reported AFL planned agility times across AFL participation pathway levels. Values are ordered by position in AFL participation pathway, then by sample size reported for each group. All players' levels are shown in the legend for consistency though not all levels may have data on the charted performance measure. AFL: Australian Football League; U: Under.

### 3.4.4. Jump Tests

Vertical jump performance of AF players was reported in 15 of the 27 reviewed studies (56%), with a number of studies excluded due to variation in testing methods. Only one study reported jump means for Elite and State Senior AF players respectively, with three studies reporting National Draft level, two studies for National Championship, eight for State Junior U18s, three for State Junior U16s levels, and one for Local U15, U14, U13, U12, U11, and U10s (see Figure 3.5).

The lowest reported VJ means were within the local participation pathway, with a gradual increase in jump height observed with every age competition level increase. The reported jump means within the local participation pathway were as follows; Local U10 (31 cm), Local U11 (33 cm), Local U12 (36 cm), Local U13 (39 cm), Local U14 (47 cm) and Local U15 (52 cm). Overlap in jump means and CIs between each level within the local participation pathway was observed, therefore similarities in jump performance are assumed between these players.

The highest mean jump height was observed for the State Junior U18 level (range 58 – 66 cm). The most overlap observed in reported means and CIs was noted in the State Junior U16 (range 48 – 60 cm), National Championship (range 57 – 62 cm), National Draft Camp (range 60 – 63 cm), Senior State (range 52 – 54 cm) and Elite AFL (range 59 – 63 cm). Both the National Draft Camp and State Junior U16 groups appeared to have one outlying study Robertson et al. (2015), and Cripps, Hopper, and Joyce (2016). When these outliers were removed, the jump mean was 60 cm for National Draft Camp and range 48 – 52 cm for State Junior U16s. Multiple studies across the AFL talent pathway levels had overlapping CIs, with jump performance observed to be similar among these levels.

No overlap in reported means and CIs was evident for jump height performance between the Local U10s, U11s, and U12s, when compared with all other levels along the AFL participation pathway. High variability in mean jump heights was noted within the Elite AFL, State Senior, State Junior U16s, and local U10 to U15s as these levels were observed to exhibit the largest CIs.

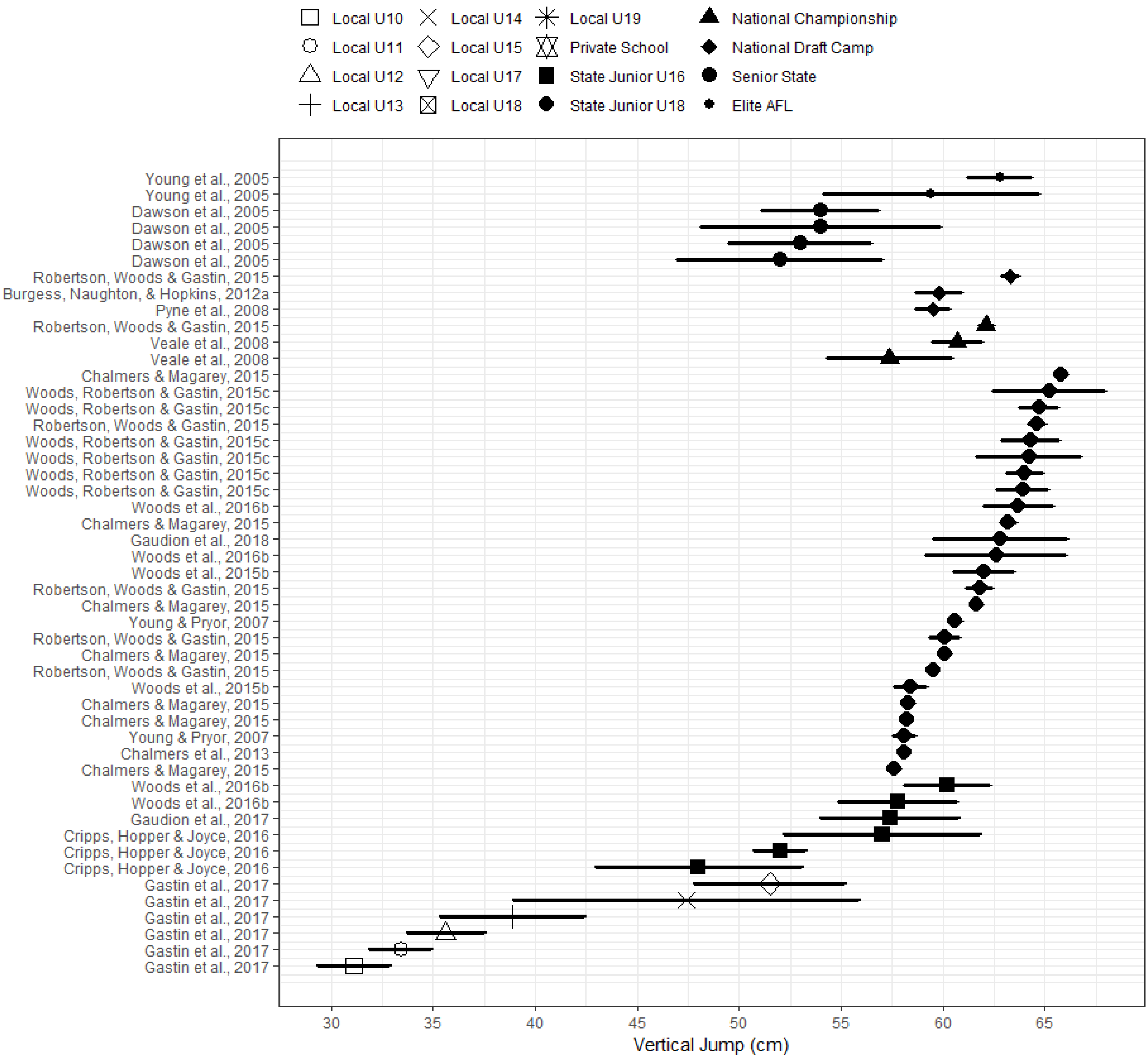


**Figure 3.5.** Mean and CIs of reported countermovement jump height across the AFL participation pathway levels. Values are ordered by position in AFL participation pathway, then by sample size reported for each group. All players' levels are shown in the legend for consistency though not all levels may have data on the charted performance measure. AFL: Australian Football League; U: Under.

Another reported measure was the running vertical jump (RVJ) off the left and right foot, with 5 of the 27 studies reporting running jump performance (see Table 3.1). Of these, one reported running RVJ scores for State Junior U16s, five for State Junior U18s, one for National Draft Camp, and one for National Championship level players. No running RVJ measures were reported for Elite and Senior State players. As such, no comparison across the entire AFL participation pathway was conducted. The highest running jump score for the right foot was State Junior U18s (mean range 66 – 75 cm), and for the left (mean range 70 – 79 cm). The lowest mean scores were recorded for State Junior U16s (right foot: 66 cm, left foot: 71 cm), with National Draft Camp (right foot: 72 cm, left foot: 78 cm) and National Championship (right foot: 71 cm, left foot: 76 cm) players not differing from State Junior U18s. When comparing jump scores for left and right legs; left leg jumps were higher than the right leg for all levels. This trend was found across the State Junior U16s (+ 6 cm), State Junior U18s (+ 4 cm), National Championship (+ 4 cm), and National Draft Camp (+ 6 cm) levels (see Table 3.1).

**Table 3.1**. Jump performance measures reported for level of AFL participation pathway. Measures represented as mean ± standard deviation.

| Study | AFL Pathway Level | Sample (n) | Running Vertical Jump Right (cm) | Running Vertical Jump Left (cm) |
|---|---|---|---|---|
| Robertson et al. (2015) | National Draft Camp | 229 | 72 ± 9 | 78 ± 9 |
| Robertson et al. (2015) | National Championship | 219 | 71 ± 9 | 76 ± 8 |
| Chalmers and Magarey (2015) | State Junior U18 | 247 | 67 ± 8 | 71 ± 8 |
| | | 219 | 67 ± 8 | 70 ± 8 |
| | | 240 | 66 ± 9 | 10 ± 8 |
| | | 240 | 69 ± 8 | 72 ± 8 |
| | | 220 | 69 ± 8 | 73 ± 8 |
| | | 248 | 71 ± 8 | 75 ± 8 |
| | | 300 | 74 ± 8 | 78 ± 8 |
| Chalmers et al. (2013) | State Junior U18 | 382 | 66 ± 8 | 71 ± 8 |
| Woods et al. (2015c) | State Junior U18 | 212 | 72 ± 10 | 79 ± 11 |
| | | | 73 ± 8 | 78 ± 8 |
| | | | 75 ± 9 | 79 ± 9 |
| | | | 71 ± 10 | 77 ± 9 |
| | | | 73 ± 9 | 78 ± 9 |
| | | | 73 ± 9 | 78 ± 9 |
| Robertson et al. (2015) | State Junior U18 | 3708 | 67 ± 9 | 72 ± 9 |
| | State Junior U18 | 115 | 70 ± 8 | 74 ± 8 |
| | State Junior U18 | 219 | 73 ± 9 | 79 ± 9 |
| | State Junior U18 | 115 | 71 ± 8 | 75 ± 8 |
| Gaudion et al. (2017) | State Junior U18 | 37 | 73 ± 9 | 75 ± 8 |
| Gaudion et al. (2017) | State Junior U16 | 40 | 66 ± 6 | 71 ± 6 |

AFL: Australian Football League; U: Under.

### 3.4.5. Aerobic

Only 11 articles reviewed reported measures of aerobic fitness using the 20-m MSFT shuttles, with none reporting 20-m MSFT shuttles for Elite and Senior State levels. Mean 20-m MSFT performance was only published for AF players involved in local participation and talent pathway levels (see Figure 3.6). Two groups reported the mean number of shuttles achieved for National Draft Camp (range 13.20 – 13.50 shuttles) and National Championship (12.90 shuttles), seven groups reported for State Junior U18 (range 11.90 – 13.30 shuttles), two reported State Junior U16 (range 11.08 – 12.60 shuttles), and four reporting local participation levels (Local U10 to U19) player scores (range 6.10 – 12.02 shuttles).

A linear trend was observed (Figure 3.6) for 20-m MSFT shuttles in local participation levels, with performance increasing approximately 1 shuttle per age group from U11s (mean range 6.10 – 6.40 shuttles) to U17s (mean 11.40 shuttles). This trend plateaued as players entered the AFL talent pathway levels. The U10 level (mean 6.40 shuttles) performed slightly better in the 20-MSFT when compared to U11s, despite being a level lower in the local participation pathway. The highest mean 20-m MSFT shuttle reached was observed for the National Draft Camp group (range 13.20 – 13.50 shuttles). The State Junior U16 (range 11.08 – 12.60 shuttles), State Junior U18 (range 11.90 – 13.30 shuttles), National Championship (12.90 shuttles), and National Draft Camp remained consistent in 20-m MSFT test scores range when comparing between these talent pathway levels. Overlap in reported means and CIs for these levels was evident, however only 8 out of 17 (47%) of the State Junior U18 groups exhibited overlapping CIs with the National level groups. As such, the 20-m MSFT scores between these talent levels were considered to be most similar. No overlap in reported means and CIs were found between the National Championship and National Draft Camp levels, and all other levels reported within the local participation pathway (mean shuttle range 6.10 – 12.02 shuttles), with the exception of Local U19s (mean 10.70 shuttles). The greatest variability in 20-m MSFT scores was observed within the Local U15 group (range 8.70 – 11.30 shuttles) and State Junior U16s when compared to all levels across the both the entire local participation and talent pathways.

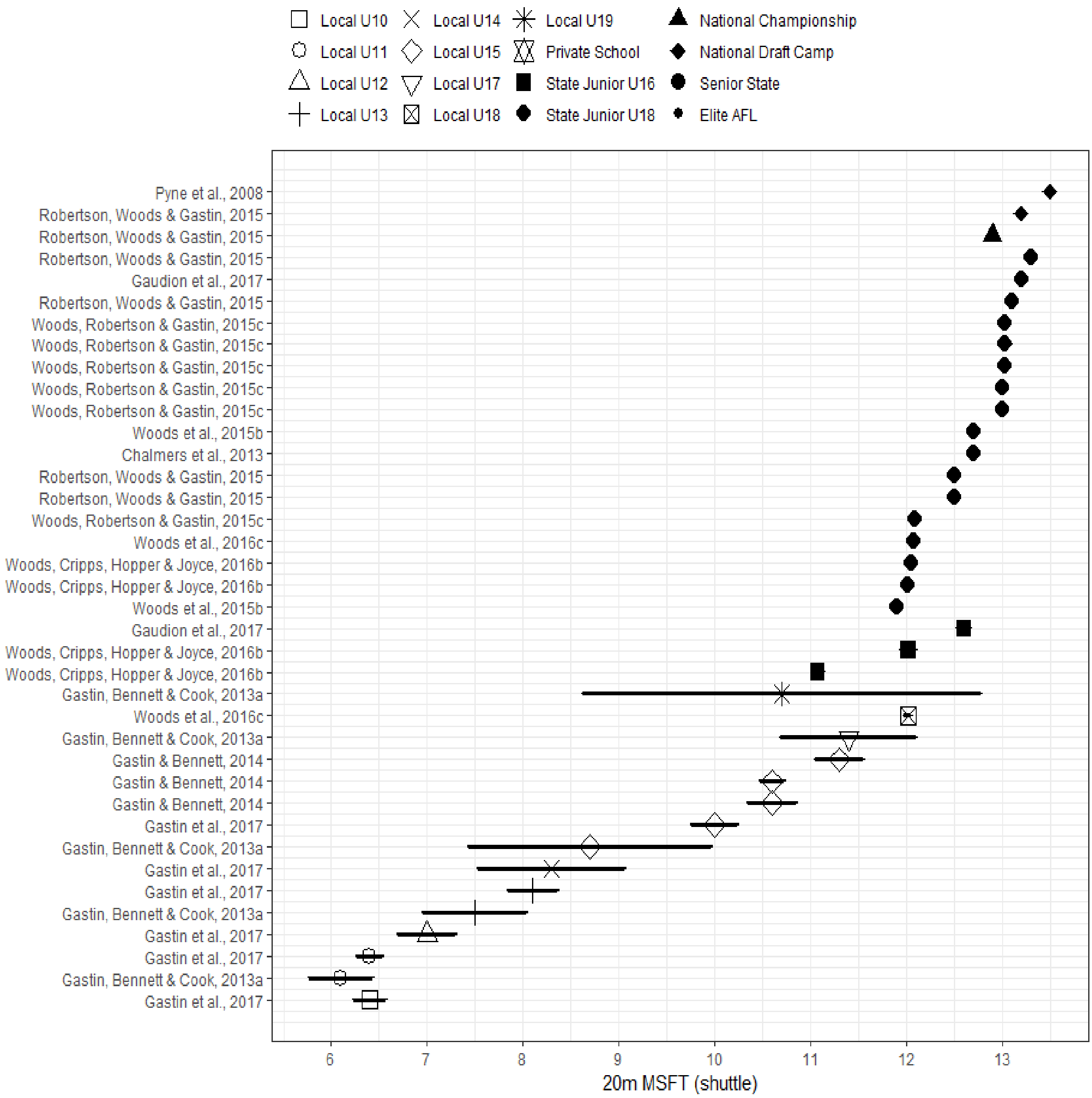


**Figure 3.6.** Mean and CIs of 20-m MSFT shuttles reached by levels across the local participation and talent pathways. Values are ordered by position in AFL participation pathway, then by sample size reported for each group. All players' levels are shown in the legend for consistency though not all levels may have data on the charted performance measure. AFL: Australian Football League; MSFT: Multi-stage fitness test; U: Under.

### 3.4.6. Strength

Compared to other physical performance measures, reported strength measures across the AFL participation levels were limited. Bench press was the most reported measure, followed by bench pull and back squat (see Table 3.2). One group reported mean bench pull 1RM measures for Elite AFL (mean 99 kg), one for Senior State (86 kg), and one for State Junior U18s (78 kg). The differences between mean pull strength for Elite and State Junior U18s 1RM was 21 kg with a 13 kg difference between Elite and Senior State players. Mean bench pull 1RM was 8 kg heavier for Senior State than State Junior U18s. Bench press 1RM was reported for State Junior U18s (mean 88 kg) and Senior State (mean 97 kg) by one group, with two groups reporting Elite AFL 1RM (mean range 103 – 114 kg). State Junior U18's bench pressed 9 kg less than State Senior, and a further 21 kg less than Elite AFL players, with State Senior pressing 12 kg less than Elite. A comparison of lower body strength across AFL participation pathway levels was not possible as only two groups reported back squat 1RM for Elite players, with no performance measures reported for Senior State or levels within the local participation and talent pathways.

**Table 3.2.** Reported strength performance measures reported for level of AFL participation pathway. Measures represented as mean ± standard deviation.

| Study | AFL Pathway Level | Sample (n) | Bench Press (kg) | Bench Pull (kg) |
|---|---|---|---|---|
| Bilsborough et al. (2015) | Elite AFL | 19<br>27 | 109 ± 13.3<br>114 ± 7.2 | 98.6 ± 5.2<br>98.5 ± 10.3 |
| Hrysomallis and Buttifant (2012) | Elite AFL | 20 | 108.3 ± 13.3<br>102.8 ± 14.0<br>113.8 ± 10.5 | |
| Bilsborough et al. (2015) | Senior State | 22 | 96.5 ± 16.6 | 85.8 ± 9.2 |
| Bilsborough et al. (2015) | State Junior U18 | 21 | 87.9 ± 12.7 | 77.8 ± 9.6 |

AFL: Australian Football League; U: Under.

### 3.4.7. Repeat Sprint Ability

Studies assessing repeat sprint ability were limited, with only 2 articles of the 27 reporting repeated sprint times in AF players (see Table 3.3). The only tests reported across the AFL participation pathway were the 6 x 20 m sprint on 30 s (2 studies), the 6 x 30 m sprint on 20 s (3 studies), and the 6 x 40 m sprint on 15 s test protocols (2 studies). Reported 6 x 20 m sprint times were not different between Elite AFL and Senior State groups, with no studies reporting times for talent or local participation levels. Two groups reported mean total sprint time (s) for 6 x 20m sprints on 30 s for Elite and Senior State players (range 17.99 - 19.08 s), with no substantial difference observed. Repeat sprint times were reported for Elite and National Draft Camp level players for the 6 x 30 m sprints on 20 s, with National Draft Camp players' mean total sprint time approximately 0.50 s slower than elite players. Two groups reported measures for Elite and Senior State players using the 6 x 40 m sprints on 15 s, with total sprint time similar between these levels (mean range 32.40 - 37.00 s).

**Table 3.3.** Repeat sprint performance measures reported for level of AFL participation pathway. Measures represented as mean ± standard deviation.

| Study | AFL Pathway Level | Sample (n) | Repeat Sprint Ability (s) |
|---|---|---|---|
| Aughey (2013) | Elite AFL | 35 | 6 x 20m sprint on 30 s |
| | | | 18.25 ± 0.26 |
| Elias et al. (2012) | Elite AFL | 14 | 6 x 20m sprint on 30 s |
| | | | 18.53 ± 0.38 |
| | | | 18.62 ± 0.46 |
| | | | 18.63 ± 0.45 |
| Gastin et al. (2013) | Elite AFL | 25 | 6 x 40 m on 15 s |
| | | | 35.56 ± 0.91 |
| Gastin et al. (2015) | Elite AFL | 69 | 6 x 40 m on 15 s |
| | | | 35.6 ± 1.4 |
| Le Rossignol et al. (2014) | Elite AFL | 20 | 6 x 30m |
| | | | 25.26 ± 0.55 |
| | | | 25.92 ± 0.80 |
| Aughey (2013) | Senior State | 35 | 6 x 20m sprint on 30 s |
| | | | 18.27 ± 0.27 |
| Gastin et al. (2015) | Senior State | 69 | 6 x 40 m on 15 s |
| | | | 35.6 ± 1.4 |
| Pyne et al. (2008) | National Draft Camp | 60 | 6 x 30m on 20 s |
| | | | 25.83 ± 0.6 |
| Gaudion et al. (2017) | State Junior U18 | 37 | 6 x 30m on 20 s |
| | | | 26.89 ± 0.98 |
| Gaudion et al. (2017) | State Junior U16 | 40 | 6 x 30m on 20 s |
| | | | 27.64 ± 0.81 |

AFL: Australian Football League; U: Under.

### 3.4.8. Movement Quality

Movement quality was measured using three different assessments: the Athletic Abilities Assessment (AAA) (1 study), a modified AAA (2 studies), and the Functional Movement Screen (FMS) (1 study) (Table 3.4). Four groups reported movement ability across the AFL participation pathway, with one group reporting for Elite AFL, three for State Junior U18, one for State Junior U16, and one for Local U18 levels, with no other levels reported. The AAA and modified AAA tests use the same movement assessment criteria, with the exception of the chin-up and total AAA score. The scores for the overhead squat, double lunge, single-leg Romanian deadlift, and push-up were compared across multiple AFL participation pathway levels. Elite AFL players performed better on all AAA and modified AAA exercises (mean score ranges; overhead squat: 6 – 9, double lunge: 7 – 9, single-leg Romanian deadlift: 6 – 9, and push up: 8 – 9). No substantial differences were noted between State Junior U18s, State Junior U16s, and Local U18s for all exercises in the modified AAA (mean score ranges; overhead squat: 3 – 9, double lunge: 3 – 7, single-leg Romanian deadlift: 3 – 7, and push up: 4 - 9). State Junior U16 and Local U18 scored approximately 1-2 points lower on all modified AAA exercises than Elite AFL players. The AAA was only reported for Elite AFL and State Junior U18 players, with Elite AFL reported to score slightly higher for the chin up (6 – 9 points) and total AAA score (45 – 63 points) than State U18s (chin up: 4 – 6; total AAA score: 37 – 47). Comparisons of the AAA performance across the AFL participation pathway were not possible as no other AFL levels reported. Only one group reported the FMS, with State Junior U18s the only level reported. The mean range for the FMS score was 10.9 – 15.5 out of a possible 21, with no comparison between AFL levels conducted.

**Table 3.4.** Movement ability measures reported for level of AFL participation pathway. Measures represented as mean ± standard deviation.

| **Study** | **AFL Pathway Level** | **Sample (*n*)** | **Overhead Squat (score/9)** | **Double Lunge (score/9)** | **Single-Leg Romanian Deadlift (score/9)** | **Push Up (score/9)** | **Chin Up (score/9)** | **Total AAA (score/63)** | **FMS (score/21)** |
|---|---|---|---|---|---|---|---|---|---|
| Woods et al. (2015) | Elite AFL | *n* = 20 | 7.5 ± 1.3 | Left: 7.8 ± 0.9<br>Right: 7.7 ± 1.0 | Left: 7.5 ± 1.5<br>Right: 7.3 ± 1.4 | 9.0 ± 0.0 | 7.8 ± 1.6 | 53.2 ± 8.5 | |
| Woods et al. (2015) | Elite AFL | *n* = 14 | 7.5 ± 1.6 | Left: 8.0 ± 1.2<br>Right: 8.1 ± 1.1 | Left: 7.8 ± 1.02<br>Right: 7.8 ± 1.2 | 8.7 ± 0.8 | 8.9 ± 0.2 | 55.7 ± 7.4 | |
| Woods et al. (2015) | State Junior U18 | *n* = 13 | 7.0 ± 1.5 | Left: 5.8 ± 1.2<br>Right: 5.9 ± 1.1 | Left: 5.3 ± 1.9<br>Right: 5.0 ± 1.2 | 7.6 ± 0.9 | 4.7 ± 1.0 | 41.6 ± 5.1 | |
| Woods et al. (2016) | State Junior U18 | *n* = 25 | 5.2 ± 1.7 | Left: 5.5 ± 1.0<br>Right: 5.7 ± 0.9 | Left: 4.8 ± 1.1<br>Right: 4.8 ± 1.1 | 6.3 ± 0.9 | | | |
| Gaudion et al. (2017) | State Junior U18 | *n* = 37 | 5.1 ± 1.2 | Left: 5.8 ± 1.0<br>Right: 5.7 ± 0.9 | Left: 4.1 ± 1.4<br>Right: 4.2 ± 1.4 | 5.5 ± 1.1 | | | |
| Chalmers et al. (2017) | State Junior U18 | *n* = 237 | | | | | | | 13.2 ± 2.3 |
| Gaudion et al. (2017) | State Junior U16 | *n* = 40 | 5.4 ± 1.1 | Left: 5.6 ± 1.0<br>Right: 5.7 ± 0.9 | Left: 3.8 ± 1.3<br>Right: 3.8 ± 1.1 | 4.9 ± 1.2 | | | |
| Woods et al. (2016) | Local U18 | *n* = 25 | 4.0 ± 0.5 | Left: 4.4 ± 1.4<br>Right: 4.6 ± 1.1 | Left: 4.1 ± 1.2<br>Right: 4.2 ± 1.1 | 6.1 ± 0.8 | | | |

AAA: Athletic Ability Assessment; AFL: Australian Football League; FMS: Functional Movement Screen; U: Under.

### 3.5. Discussion

The overarching aim of this review was to i) conduct a systematic review of physical test performances measures reported for AF players, and ii) establish differences in physical performance across the AFL participation pathway to inform talent selection, recruitment, and fitness program design. The literature search yielded a relatively small number of articles assessing physical performance measures that used consistent testing methods across multiple studies. Moreover, a large number of articles reporting physical tests in AF players were excluded as testing protocols were not consistent across multiple levels of the AFL local participation and talent pathways. Physical testing of AF players is of particular interest in the identification of talented AF players, however inconsistency in test protocols is a challenge for researchers and the football community in understanding what is required physically of players as they transition from local to elite competition.

As expected, the fastest reported 20-m sprint time in this review was by Elite AF players (Johnston, Watsford, Pine, & Spurrs, 2014; Le Rossignol, Gabbett, Comerford, & Stanton, 2014; Young et al., 2008), however the differences in sprint time between Elite and National Junior players were minimal (Burgess et al., 2012a; Pyne et al., 2005, 2006; Pyne, Saunders, Montgomery, Hewitt, & Sheehan, 2008; Robertson et al., 2015; Woods et al., 2015b). Junior Local level players were consistently slower than Junior National and Elite AFL respectively (Chalmers & Magarey, 2015; Chalmers et al., 2013; Gastin et al., 2017; Robertson et al., 2015; Woods et al., 2015b; Woods, Robertson, & Gastin, 2015c; Young & Pryor, 2007). This finding is supported by those of Papaiakovou et al. (2009) and Dupler, Amonette, Coleman, Hoffman, and Wenzel (2010), where more physically mature players between the ages of 14 and 18 years were faster than less mature athletes. Previous studies have reported that 20-m sprint time is purportedly a discriminating factor between drafted and non-drafted players when combined with their 20-m MSFT score (Pyne et al., 2005). Additionally, 20-m sprint performance is associated with match outcomes across junior state level competitions, and players' subsequent selection into higher AF competitions (Pyne et al., 2005; Woods et al., 2016b; Young & Pryor, 2007). However, only one group in this review reported 20-m sprint time for Senior State, with their sprint times slower than junior National and State level players, despite the higher competition ranking within the AFL participation pathway (Hori et al., 2008). Furthermore, few differences in 20-m sprint performance across the State junior and National levels of the AFL talent pathway were observed in this review. This outcome is supported by previous work showing that sprint time did not contribute to predicting whether a State junior player may be selected for a junior National team (Woods et al., 2015b). It appears that the 20-m sprint time may not be a discriminating physical characteristic between junior talent levels; however, it may contribute to player selection from local participation in the talent pathway, or junior talent levels into elite AF competition.

The AFL planned agility run course is 21.8 m in length including one 180˚ and four 90˚ turns for assessing a player's ability to change direction at AFL talent identification camps (Burgess et al., 2012a; Hart, Spiteri, Lockie, Nimphius, & Newton, 2014; Pyne et al., 2005; Young & Rogers, 2014). Junior and adult AF players' agility scores were similar across the AFL participation pathway. This is comparable to previous literature, as the AFL planned agility test did not discriminate between drafted and non-drafted AF players, unless players also performed better in the 20-m MSFT and 20-m sprint (Pyne et al., 2005). Moreover, it has not been shown to be related with career success of players as a stand-alone measure (Burgess et al., 2012a). AFL planned agility time across the 1999-2004 AFL drafts was largely unchanged, despite increases in AF match speeds, and improvements in other combine tests (height and 20-m sprint) (Pyne et al., 2006). However, small and medium sized players were slightly faster (effect size (ES) = 0.64 – 1.11) than taller players, or ruckmen. The ability of the AFL planned agility test to identify talented AF players within a positional group is questionable, but it should be useful in discriminating between different positional groups. Shoe surface friction may have influenced the variability in the AFL planned agility tests, with less friction possibly causing a player to slip during a COD test, decreasing their performance (Damm et al., 2014). Of the studies reported in this review, only seven (Chalmers & Magarey, 2015; Gaudion et al., 2017; Robertson et al., 2015; Woods et al., 2015b; Woods et al., 2015c; Young & Rogers, 2014; Young & Pryor, 2007) of the thirteen disclosed the surface used to assess player COD, with all using indoor, wooden surfaces. However, when conducting large-scale fitness testing, it is not feasible to supply footwear to players to control for surface friction (Dos' Santos, Thomas, Jones, & Comfort, 2017). As such, surface friction and footwear is a consideration when analysing any COD testing.

The VJ was the second most commonly assessed physical measure reported. However, visually there was greater spread in VJ results within the Elite and Senior State levels when compared across the AFL participation pathway. Studies by Pyne et al. (2005) and Burgess et al. (2012a) reported that VJ performance did not impact on a player's success within elite AFL competition. Relative VJ scores can be counterintuitive, as lower jump scores were reported for players that were drafted to an AFL team, debuted in the elite competition, played more elite level games, and had greater career potential and value (Pyne et al., 2005). This data may support the variation in VJ performance in the Senior State group, as the training and development of adult AF players may be focused on other physical and skill attributes, and not their jumping ability.

Inconsistency in VJ performance was also evident across the junior talent pathway, with the greatest disparity in VJ scores in National Draft Camp players (Veale, Pearce, Koehn, & Carlson, 2008), and for State U16s players (Gaudion et al., 2017; Woods et al., 2015c). This variability in results may be caused by differences in the physical maturity levels of the players tested, with ages ranging between 16-18 years. Players may be at different pubertal stages, with Gastin, Bennett, and Cook (2013a) reporting AF players within this age group spanned across the $4^{th}$ and $5^{th}$ pubertal stages of development (outlined by Duke, Litt, and Gross (1980)). Similar differences in VJ performance were also noted by Jones, Hitchen, and Stratton (2000), who reported that jump performance increased with biological maturity in males ($r$ = 0.56). While VJ performance may not contribute directly to a player's success in the elite AFL completion, it may enhance the success of a player's selection and transition across the AFL talent pathway. Several groups reported that VJ performance was higher in elite junior AF players (State and National level) than non-selected players (Keogh, 1999; Woods et al., 2016b; Woods et al., 2015b; Woods et al., 2016c; Young & Pryor, 2007). However, other groups reported that VJ does not significantly contribute to the success of players' progression through the AFL talent pathway (Pyne et al., 2005; Robertson et al., 2015). The similarity between the VJ scores in this review supports the mixed findings indicating that the VJ is not a highly reliable tool for talent identification of AF players.

This review only reported running endurance performance measures of aerobic capacity, with the 20-m MSFT considered a proxy test for measuring aerobic capacity of individuals (Aandstad, Holme, Berntsen, & Anderssen, 2011; Wagner, 1996). As expected, a gradual increase in 20-m MSFT scores occurred as players' progressed along the AFL participation pathway. This increase in aerobic performance was also reported by two groups (Gastin & Bennett, 2014; Gastin et al., 2013a), who found a significant increase in 20-m MSFT with player maturity. Furthermore, large positive correlations ($r$ = 0.65) were observed between the biological maturity of junior AF players and 20-m MSFT score (Gastin et al., 2013a). This trend is not restricted to AF players, with similar increases reported across general population males of the same ages (Beets & Pitelli, 2004; Jones et al., 2000). Substantial differences in 20-m MSFT scores were not observed between National Championship, State Junior U18s, State Junior U16s, and Senior State players. This outcome contradicts previous observations showing 20-m MSFT scores contributed significantly to differences between junior national and junior state level players (Woods et al., 2015b), and subsequent draft success of players (Robertson et al., 2015). While no studies reported shuttle levels achieved for Elite AFL players, predicted maximal oxygen uptake ($VO_2max$) ($58.0 \pm 3.2$ $mL.kg^{-1}.min^{-1}$) from the 20-m MSFT had small associations with career progression of Elite AFL players (Pyne et al., 2005). Furthermore, Elite AFL player's $VO_2max$ range between 51 – 68 $mL.kg^{-1}.min^{-1}$ (Aughey, 2013; Lorenzen, D.Williams, Turk, Meehan, & Clclonl Kolsky, 2009) when measured using a laboratory-based $VO_2max$ treadmill test, with these measures providing a guideline as to the estimated $VO_2max$ capacity of Elite AFL players. When comparing local participation level players to players within the talent pathway, there was larger variability in 20-m MSFT shuttle scores for local U15 players (Gastin et al., 2013a). The standard deviation of tests scores was 3 shuttles for U15, which is almost two-fold higher than other groups across the talent pathway levels. This observation is explained partly by variations in biological maturity (Gastin et al., 2013a) and pubertal stages (Duke et al., 1980) of players competing in this age group.

Lower body strength is an underlying physical characteristic that affects force generation, thus influencing both injury prevention, and power production in team sport athletes' (Hori et al., 2008; Nibali, Chapman, Robergs, & Drinkwater, 2013; Orchard, Marsden, Lord, & Garlick, 1997; Scase, Cook, Makdissi, Gabbe, & Shuck, 2006; Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004). Unfortunately, only one group (Nibali et al., 2013) reported Elite AFL 1RM back squat, and one (Hori et al., 2008) reported Senior State 1RM front squat as measures of lower body strength. No 1RM strength measures in any lower body exercise were reported for junior and developing AF players. The absence of strength testing literature may relate to concerns regarding the safety and reliability of 1RM testing in inexperienced athletes; however the 1RM back squat is a reliable measure provided players have had 6-12 months of familiarisation with the exercise (Comfort & McMahon, 2015; Kraemer, Fry, Ratamess, & French, 1995). Tackling and fending off opponents during AF game play requires upper body strength (Bilsborough et al., 2015; Hrysomallis & Buttifant, 2012), however the upper body strength literature was also limited. A gradual increase in bench press and bench pull measures was noted as players' progress through the AFL participation pathway. This trend is likely a result of long-term adaptations to specific resistance training (Baker, 2013; Bilsborough et al., 2015), in combination with physical maturation of players (Lloyd, Oliver, Faigenbaum, Myer, & De Ste

Croix, 2014; Matthys, Vaeyens, Coelho-e-Silva, Lenoir, & Philippaerts, 2012; Philippaerts et al., 2006). Clearly strength development is important in AF players, however further research is required to profile lower and upper body strength of AF players across the entire local and junior talent pathways.

Repeat sprint ability is considered to be one of the more critical aspects in AFL performance, as the game requires players to repeatedly chase defensively, and sprint to create space offensively (Gastin et al., 2013b; Gray & Jenkins, 2010; Le Rossignol et al., 2014). Unfortunately, comparisons of repeat sprint ability between AFL participation pathway levels are not possible given inconsistencies across test protocols. One group found repeat sprint ability using the 6 x 30 m sprints on 20 sec protocol was a discriminating performance measure between selected and non-selected elite AF player (Le Rossignol et al., 2014). This protocol is currently used as a test in the annual AFL Draft Combine (Pyne et al., 2008), yet no other studies have determined the relationship between performance in this test, and a players' likelihood of being drafted.

Another two repeat sprint protocols, the 6 x 20 m sprint on 30 s, and the 6 x 40 m sprint on 15 s, have been used in the literature (Aughey, 2013; Elias et al., 2012; Gastin et al., 2013b; Gastin et al., 2015). Of these, Aughey (2013) and Elias et al. (2012) only reported 6 x 20 m sprint results as a profiling tool for Elite and Senior State level players, with no analysis conducted on repeat sprint testing as a talent discriminating factor. Similarly, the 6 x 40 m sprint protocol reported by Gastin et al. (2013b) and Gastin et al. (2015) was assessed in relation to its influence on injury risks of Elite AFL players, and predicting match performance. Neither study evaluated this repeat sprint test as a tool for talent identification. Furthermore, Gastin et al. (2013b) noted that 6 x 40 m sprint protocol was not significantly associated with match performance in elite AF players. It appears the repeat sprint test may not be a reliable tool for assessing whether a player will become a successful AF player. Future research should focus on reporting repeated sprint measures using uniform protocols across the AFL participation pathway levels to allow for meaningful comparisons between groups. This is essential as repeated sprint testing is currently included in the annual AFL National Draft Combine physical testing battery to identify elite AF players.

Movement quality is an underpinning quality of sporting performance, with AF players requiring strong foundation movements such as squats, lunges, pushing, pulling and bracing to be successful in competition (Cook, Burton, Hoogenboom, & Voight, 2014; McKeown, Taylor-McKeown, Woods, & Ball, 2014; Woods et al., 2015a). Movement quality is measured using an objectively assessed criterion to determine if dysfunctional patterns are present (Cook et al., 2014; McKeown et al., 2014). Three movement assessments (AAA, modified AAA, and FMS) were reported for AFL players within the Elite AFL, State Junior U18, State Junior U16, and Local U18 levels (Chalmers et al., 2017; Gaudion et al., 2017; Woods et al., 2016a; Woods et al., 2015a). The AAA and modified AAA allowed movement comparisons across abovementioned levels for the following exercises: overhead squat, double lunge, single-leg Romanian deadlift, and push up. Furthermore, the AAA or modified AAA has been used as a talent identification tool across Elite AFL, State Junior U18, State Junior U16, and Local U18 levels, with junior talent players (State Junior U18 and State Junior U16) exhibiting lesser movement ability than Elite AFL (Gaudion et al., 2017; Woods et al., 2016a; Woods et al., 2015a). Woods et al. (2016a) did find significant differences in AAA scores between State Junior U18 and Local U18 players for the overhead squat, double lunge (both legs), and single-leg Romanian deadlift (right leg). Additionally, a significant effect between State Junior U18 and State Junior U16 levels for the single-leg Romanian deadlift (left leg) ($ES = 0.24$, $p < 0.05$) and push up ($ES = 0.52$, $p < 0.05$) was noted (Gaudion et al., 2017). However, no substantial differences were observed between levels in the junior talent pathway when scores were pooled in this review. The FMS is another movement screening reported by Chalmers et al. (2017), however this group only examined the association between the FMS and injury risk in State Junior U18 level. Players with observed asymmetrical movements were more likely to sustain an injury during an AF season (Chalmers et al., 2017). Targeting asymmetry in junior players may reduce injury risk, and improve athletic performance and development potential as players' transition through the AFL participation pathways (Chalmers et al., 2017; Woods et al., 2016a). Whilst movement ability was found to be similar within the AFL talent pathway, the differences observed between Elite AFL and talent pathway players highlights the importance of developing junior players' movement ability.

The 20-m sprint (Johnston et al., 2014; Le Rossignol et al., 2014; Young et al., 2008), VJ (Young et al., 2005), and 6 x 30 m repeated sprint tests (Le Rossignol et al., 2014) were the only AFL Draft Combine tests reported for Elite AFL players. No elite level data were noted for the AFL planned agility, RVJ, or 20-m MSFT, in spite of these physical performance measures forming the physical component of talent identification (Pyne et al., 2005, 2006; Robertson et al., 2015; Woods et al., 2015b; Woods et al., 2016c; Young & Rogers, 2014). The limited number of studies reporting Elite AFL players may suggest that elite clubs place less value on physical performance measures as talent identification tools, or they do not release results of these tests to preserve any competitive advantage. Other studies reported that jump performance (Burgess et al., 2012a; Pyne et al., 2005) , 20-m MSFT (Pyne et al., 2005), and AFL planned agility time (Burgess et al., 2012a; Pyne et al., 2006) had small to trivial associations with career progression of Elite AFL players unless combined with performances in other physical tests. Furthermore, repeat sprint (Aughey, 2013; Elias et al., 2012; Gastin et al., 2013b; Gastin et al., 2015) and strength (Bilsborough et al., 2015; Hrysomallis & Buttifant, 2012) tests were reported mainly for Elite AFL players, indicating that elite clubs place more value on developing these physical characteristics in players than on other qualities assessed through the AFL Draft Combine test battery. Physical performance tests were not consistent across the entire AFL participation pathway; as such, a testing battery that can provide valuable insight into physical differences across the AFL participation pathway is required.

### 3.6. Conclusion

The physical tests reported in this review are currently used to assess physical characteristics of players, and their subsequent progress through the AFL participation pathway. Elite AFL data was only reported for the 20-m sprint and VJ, with no other physical tests results available. Elite AFL players had the fastest reported means for 20-m sprint time, with Local level players the slowest. All other sprint performances were similar across the talent levels (State U16s – Elite AFL), as mean and CIs in sprint time overlapped with each other. For VJ performance, the State U18s had, counterintuitively, greater jump heights than senior level players. The lowest jumps were reported for Local U10s, however reported means and CIs for VJ heights overlapped across the AFL talent pathway and thus VJ performances were largely similar. AFL planned agility times were only available in the talent pathway, with mean performance times similar across all groups. The 20-m MSFT mean scores were only reported from Local U10s to National Draft Camp, with similarities in performance between the AFL levels. Furthermore, a linear improvement was evident within the local participation pathway for 20-m MSFT performance (1 shuttle per level) as players progressed through the levels. This trend was plateaued when players entered the talent pathway. Finally, players forming the talent pathway performed better in all physical tests than local participation players. However, when assessing levels within the talent pathway, players across different levels tended to exhibit similar mean test scores for each physical test. Physical tests will more effectively discriminate levels of competition between local participation AFL players but are less useful within the AFL talent pathway.

### 3.7. References


Aandstad, A., Holme, I., Berntsen, S., & Anderssen, S. A. (2011). Validity and reliability of the 20 meter shuttle run test in military personnel. Military Medicine, 176(5), 513-518. doi:10.7205/MILMED-D-10-00373

AFL Development. (2016). Participation and talent pathways. Retrieved from http://www.aflcommunityclub.com.au/index.php?id=559

Aughey, R. J. (2013). Widening margin in activity profile between elite and sub-elite Australian football: a case study. Journal of Science and Medicine in Sport, 16(4), 382-386. doi:10.1016/j.jsams.2012.10.003

Baker, D. G. (2013). 10-year changes in upper body strength and power in elite professional rugby league players -the effect of training age, stage, and content. Journal of Strength and Conditioning Research, 27(2), 285-292. doi:10.1519/JSC.0b013e318270fc6b

Beets, M. W., & Pitelli, K. H. (2004). A comparison of shuttle-run performance between midwestern youth and their national and international counterparts. Pediatric Exercise Science, 16(2), 94-112. doi:10.1123/pes.16.2.94

Bellenger, C. R., Fuller, J. T., Nelson, M. J., Hartland, M., Buckley, J. D., & Debenedictis, T. A. (2015). Predicting maximal aerobic speed through set distance time-trials. European Journal of Applied Physiology, 115(12), 2593-2598. doi:10.1007/s00421-015-3233-6

Bilsborough, J. C., Greenway, K. G., Opar, D. A., Livingstone, S. G., Cordy, J. T., Bird, S. R., & Coutts, A. J. (2015). Comparison of anthropometry, upper-body strength, and lower-body power characteristics in different levels of Australian football players. Journal of Strength and Conditioning Research, 29(3), 826-834. doi:10.1519/JSC.0000000000000682

Boyd, L. J., Ball, K., & Aughey, R. J. (2013). Quantifying external load in australian football matches and training using accelerometers. International Journal of Sports Physiology and Performance, 8(1), 44-51. doi:10.1123/ijspp.8.1.44

Buchheit, M., Racinais, S., Bilsborough, J., Hocking, J., Mendez-Villanueva, A., Bourdon, P. C., Voss, S., Livingston, S., Christian, R., Périard, J., Cordy, J., & Coutts, A. J. (2013). Adding heat to the live-high train-low altitude model: A practical insight from professional football. British Journal of Sports Medicine, 47(SUPPL. 1), i59-i69. doi:10.1136/bjsports-2013-092559

Burgess, D., Naughton, G., & Hopkins, W. (2012a). Draft-camp predictors of subsequent career success in the Australian Football League. Journal of Science and medicine in Sport, 15(6), 561-567. doi:10.1016/j.jsams.2012.01.006

Burgess, D., Naughton, G., & Norton, K. (2012b). Quantifying the gap between under 18 and senior AFL football: 2003 and 2009. International journal of Sports Physiology and Performance, 7(1), 53-58. doi:10.1123/ijspp.7.1.53

Caia, J., Doyle, T. L. A., & Benson, A. C. (2013). A cross-sectional lower-body power profile of elite and subelite australian football players. Journal of Strength and Conditioning Research, 27(10), 2836-2841. doi:10.1519/JSC.0b013e3182815743

Chalmers, S., Fuller, J. T., Debenedictis, T. A., Townsley, S., Lynagh, M., Gleeson, C., Zacharia, A., Thomson, S., & Magarey, M. (2017). Asymmetry during preseason Functional Movement Screen testing is associated with injury during a junior Australian football season. Journal of Science and Medicine in Sport, 20(7), 653-657. doi:10.1016/j.jsams.2016.12.076

Chalmers, S., & Magarey, M. (2015). Annual improvement in fitness test performance for elite junior Australian football cohorts. Journal of Science and Medicine in Sport, 19(10), 843-847. doi:10.1016/j.jsams.2015.12.008

Chalmers, S., Magarey, M. E., Esterman, A., Speechley, M., Scase, E., & Heynen, M. (2013). The relationship between pre-season fitness testing and injury in elite junior Australian football players. Journal of Science and Medicine in Sport, 16(4), 307-311. doi:10.1016/j.jsams.2012.09.005

Comfort, P., & McMahon, J. J. (2015). Reliability of maximal back squat and power clean performances in inexperienced athletes. Journal of Strength and Conditioning Research, 29(11), 3089-3096. doi:10.1519/JSC.0000000000000815

Cook, G., Burton, L., Hoogenboom, B. J., & Voight, M. (2014). Functional movement screening: the use of fundamental movements as an assessment of function - part 1. International Journal of Sports Physical Therapy, 9(3), 396-409.

Cormack, S. J., Newton, R. U., McGulgan, M. R., & Doyle, T. L. A. (2008). Reliability of measures obtained during single and repeated countermovement jumps. International Journal of Sports Physiology and Performance, 3(2), 131-144. doi:10.1123/ijspp.3.2.131

Coutts, A. J., Quinn, J., Hocking, J., Castagna, C., & Rampinini, E. (2010). Match running performance in elite Australian Rules football. Journal of Science and Medicine in Sport, 13(5), 543-548. doi:10.1016/j.jsams.2009.09.004

Cripps, A. J., Hopper, L., & Joyce, C. (2016). Maturity, physical ability, technical skill and coaches' perception of semi-elite adolescent australian footballers. Pediatric Exercise Science, 28(4), 535-541. doi:10.1123/pes.2015-0238

Crow, J. F., Buttifant, D., Kearny, S. G., & Hrysomallis, C. (2012). Low load exercises targeting the gluteal muscle group acutely enhance explosive power output in elite athletes. Journal of Strength and Conditioning Research, 26(2), 438-442. doi:10.1519/JSC.0b013e318220dfab

Damm, L., Starbuck, C., Stocker, N., Clarke, J., Carré, M., & Dixon, S. (2014). Shoe-surface friction in tennis: influence on plantar pressure and implications for injury. Footwear Science, 6(3), 155-164. doi:10.1080/19424280.2014.891659

Dawson, B., Gow, S., Modra, S., Bishop, D., & Stewart, G. (2005). Effects of immediate post-game recovery procedures on muscle soreness, power and flexiblity levels over the next 48 hours. Journal of Science and Medicine in Sport, 8(2), 210-221. doi:10.1016/S1440-2440(05)80012-X

Dawson, B., Hopkinson, R., Appleby, B., Stewart, G., & Roberts, C. (2004). Player movement patterns and game activities in the Australian Football League. Journal of Science and Medicine in Sport, 7(3), 278-291. doi:10.1016/S1440-2440(04)80023-9

Dos' Santos, T., Thomas, C., Jones, P. A., & Comfort, P. (2017). Mechanical determinants of faster change of direction speed performance in male athletes. Journal of Strength and Conditioning Research, 31(3), 696-705. doi:10.1519/JSC.0000000000001535

Duke, P. M., Litt, I. F., & Gross, R. T. (1980). Adolescents' self-assessment of sexual maturation. Pediatrics, 66(6), 918-920.

Dupler, T. L., Amonette, W. E., Coleman, A. E., Hoffman, J. R., & Wenzel, T. (2010). Anthropometric and performance differences among high-school football players. Journal of Strength and Conditioning Research, 24(8), 1975-1982. doi:10.1519/JSC.0b013e3181e4f9ec

Elias, G. P., Varley, M. C., Wyckelsma, V. L., McKenna, M. J., Minahan, C. L., & Aughey, R. J. (2012). Effects of water immersion on posttraining recovery in Australian footballers. International Journal of Sports Physiology and Performance, 7(4), 357-366. doi:10.1123/ijspp.7.4.357

Gastin, P. B., & Bennett, G. (2014). Late maturers at a performance disadvantage to their more mature peers in junior Australian football. Journal of Sport Sciences, 32(6), 563-571. doi:10.1080/02640414.2013.843016

Gastin, P. B., Bennett, G., & Cook, J. (2013a). Biological maturity influences running performance in junior Australian football. Journal of Science and Medicine in Sport, 16(2), 140-145. doi:10.1016/j.jsams.2012.05.005

Gastin, P. B., Fahrner, B., Meyer, D., Robinson, D., & Cook, J. L. (2013b). Influence of physical fitness, age, experience, and weekly training load on match performance in elite Australian football. Journal of Strength and Conditioning Research, 27(5), 1272-1279. doi:10.1519/JSC.0b013e318267925f

Gastin, P. B., Meyer, D., Huntsman, E., & Cook, J. (2015). Increase in injury risk with low body mass and aerobic-running fitness in elite Australian football. International Journal of Sports Physiology and Performance, 10(4), 458-463. doi:10.1123/ijspp.2014-0257

Gastin, P. B., Tangalos, C., Torres, L., & Robertson, S. (2017). Match running performance and skill execution improves with age but not the number of disposals in young Australian footballers. Journal of Sport Sciences, 35(24), 1-8. doi:10.1080/02640414.2016.1271137

Gaudion, S. L., Kenji, D., Wade, S., Harry, B. G., & Carl, W. T. (2017). Identifying the physical fitness, anthropometric and athletic movement qualities discriminant of developmental level in elite junior Australian football: Implications for the development of talent. Journal of Strength and Conditioning Research, 31(7), 1830-1839. doi:10.1519/jsc.0000000000001682

Gray, A. J., & Jenkins, D. G. (2010). Match analysis and the physiological demands of Australian football. Sports Medicine, 40(4), 347-360. doi:10.2165/11531400-000000000-00000

Hart, N. H., Nimphius, S., Spiteri, T., & Newton, R. U. (2014a). Leg strength and lean mass symmetry influences kicking performance in Australian football. Journal of Sport Science and Medicine, 13(1), 157-165.

Hart, N. H., Spiteri, T., Lockie, R. G., Nimphius, S., & Newton, R. U. (2014b). Detecting deficits in change of direction performance using the preplanned multidirectional Australian football league agility test. Journal of Strength and Conditioning Research, 28(12), 3552-3556. doi:10.1519/jsc.0000000000000587

Hiscock, D., Dawson, B., Heasman, J., & Peeling, P. (2012). Game movements and player performance in the australian football league. International Journal of Performance Analysis in Sport, 12(3), 531-545. doi:10.1080/24748668.2012.11868617

Hori, N., Newton, R. U., Andrews, W. A., Kawamori, N., McGuigan, M. R., & Nosaka, K. (2008). Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? Journal of Strength and Conditioning Research, 22(2), 412-418. doi:10.1519/JSC.0b013e318166052b

Hrysomallis, C., & Buttifant, D. (2012). Influence of training years on upper-body strength and power changes during the competitive season for professional Australian rules football players. Journal of Science and Medicine in Sport, 15(4), 374-378. doi:10.1016/j.jsams.2012.01.001

Inness, M. W. H., Billaut, F., & Aughey, R. J. (2016). Team-sport athletes' improvement of performance on the Yo-Yo Intermittent Recovery Test Level 2, but not of time-trial performance, with intermittent hypoxic training. International Journal of Sports Physiology and Performance, 11(1), 15-21. doi:10.1123/ijspp.2014-0246

Johnston, R., Watsford, M., Pine, M., & Spurrs, R. (2014). Standardisation of acceleration zones in professional field sport athletes. International Journal of Sports Science and Coaching, 9(5), 1161-1168. doi:10.1260/1747-9541.9.5.1161

Jones, M. A., Hitchen, P. J., & Stratton, G. (2000). The importance of considering biological maturity when assessing physical fitness measures in girls and boys aged 10 to 16 years. Annals of Human Biology, 27(1), 57-65. doi:10.1080/030144600282389

Keogh, J. (1999). The use of physical fitness scores and anthropometric data to predict selection in an elite under 18 Australian rules football team. Journal of Science and Medicine in Sport, 2(2), 125-133. doi:10.1016/S1440-2440(99)80192-3

Kraemer, W., Fry, A., Ratamess, N., & French, D. (1995). Strength testing: development and evaluation of methodology. In P. Maud & C. Foster (Eds.), Physiological Assessment of Human Fitness (Vol. 2, pp. 115-138). Champaign, IL: Human Kinetics.

Le Rossignol, P., Gabbett, T. J., Comerford, D., & Stanton, W. R. (2014). Repeated-sprint ability and team selection in Australian Football League players. International Journal of Sports Physiology and Performance, 9(1), 161-165. doi:10.1123/IJSPP.2013-0005

Lloyd, R. S., Oliver, J. L., Faigenbaum, A. D., Myer, G. D., & De Ste Croix, M. B. (2014). Chronological age vs. biological maturation: implications for exercise programming in youth. Journal of Strength and Conditioning Research, 28(5), 1454-1464. doi:10.1519/JSC.0000000000000391

Lorenzen, C., D.Williams, M., Turk, P. S., Meehan, D. L., & Clclonl Kolsky, D. J. (2009). Relationship between velocity reached at VO2maxand time-trial performances in elite Australian rules footballers. International Journal of Sports Physiology and Performance, 4(3), 408-411. doi:10.1123/ijspp.4.3.408

Matthys, S., Vaeyens, R., Coelho-e-Silva, M., Lenoir, M., & Philippaerts, R. (2012). The contribution of growth and maturation in the functional capacity and skill performance of male adolescent handball players. International Journal of Sports Medicine, 33(07), 543-549. doi:10.1055/s-0031-1298000

McKeown, I., Taylor-McKeown, K., Woods, C., & Ball, N. (2014). Athletic Ability Assessment: A movement assessment protocol for athletes. International Journal of Sports Physical Therapy, 9(7), 862-873.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Group, P. (2010). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. International Journal of Surgery, 8(5), 336-341. doi:10.1016/j.ijsu.2010.02.007

Nibali, M. L., Chapman, D. W., Robergs, R. A., & Drinkwater, E. J. (2013). A rationale for assessing the lower-body power profile in team sport athletes. Journal of Strength and Conditioning Research, 27(2), 388-397. doi:10.1519/JSC.0b013e3182576feb

Orchard, J., Marsden, J., Lord, S., & Garlick, D. (1997). Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. The American Journal of Sports Medicine, 25(1), 81-85. doi:10.1177/036354659702500116

Papaiakovou, G., Giannakos, A., Michailidis, C., Patikas, D., Bassa, E., Kalopisis, V., . . . Kotzamanidis, C. (2009). The effect of chronological age and gender on the development of sprint performance during childhood and puberty. Journal of Strength and Conditioning Research, 23(9), 2568-2573. doi:10.1519/JSC.0b013e3181c0d8ec

Philippaerts, R. M., Vaeyens, R., Janssens, M., Van Renterghem, B., Matthys, D., Craen, R., . . . Malina, R. M. (2006). The relationship between peak height velocity and physical performance in youth soccer players. Journal of Sport Sciences, 24(3), 221-230. doi:10.1080/02640410500189371

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2005). Fitness testing and career progression in AFL football. Journal of Science and Medicine in Sport, 8(3), 321-332. doi:10.1016/S1440-2440(05)80043-X

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2006). Positional differences in fitness and anthropometric characteristics in Australian football. Journal of Science and Medicine in Sport, 9(1), 143-150. doi:10.1016/j.jsams.2005.10.001

Pyne, D. B., Saunders, P. U., Montgomery, P. G., Hewitt, A. J., & Sheehan, K. (2008). Relationships between repeated sprint testing, speed, and endurance. Journal of Strength and Conditioning Research, 22(5), 1633-1637. doi:10.1519/JSC.0b013e318181fe7a

Robertson, S., Woods, C., & Gastin, P. (2015). Predicting higher selection in elite junior Australian Rules football: The influence of physical performance and anthropometric attributes. Journal of Science and Medicine in Sport, 18(5), 601-606. doi:10.1016/j.jsams.2014.07.019

Scase, E., Cook, J., Makdissi, M., Gabbe, B., & Shuck, L. (2006). Teaching landing skills in elite junior Australian football: Evaluation of an injury prevention strategy. British Journal of Sports Medicine, 40(10), 834-838. doi:10.1136/bjsm.2006.025692

Veale, J., Pearce, A. J., & Carlson, J. S. (2007). Player movement patterns in an elite junior Australian Rules Football Team: An exploratory study. Journal of Sport Science and Medicine, 6(2), 254-260.

Veale, J., Pearce, A. J., Koehn, S., & Carlson, J. S. (2008). Performance and anthropometric characteristics of prospective elite junior Australian footballers: A case study in one junior team. Journal of Science and Medicine in Sport, 11(2), 227-230. doi:10.1016/j.jsams.2006.12.119

Wagner, P. D. (1996). Determinants of maximal oxygen transport and utilization. Annual Review of Physiology, 58(1), 21-50. doi:10.1146/annurev.ph.58.030196.000321

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

Wisløff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. British Journal of Sports Medicine, 38(3), 285-288. doi:10.1136/bjsm.2002.002071

Woods, C., Banyard, H. G., McKeown, I., Fransen, J., & Robertson, S. (2016a). Discriminating talent identified junior Australian footballers using a fundamental gross athletic movement assessment. Journal of Sports Science and Medicine, 15(3), 548-553.

Woods, C., Cripps, A., Hopper, L., & Joyce, C. (2016b). A comparison of the physical and anthropometric qualities explanatory of talent in the elite junior Australian football development pathway. Journal of Science and Medicine in Sport, 20(7), 684-688. doi:10.1016/j.jsams.2016.11.002

Woods, C., McKeown, I., Haff, G. G., & Robertson, S. (2015a). Comparison of athletic movement between elite junior and senior Australian football players. Journal of Sports Sciences, 34(1260-1265), 1-6. doi:10.1080/02640414.2015.1107185

Woods, C., Raynor, A. J., Bruce, L., McDonald, Z., & Collier, N. (2015b). Predicting playing status in junior Australian football using physical and anthropometric parameters. Journal of Science and Medicine in Sport, 18(2), 225-229. doi:10.1016/j.jsams.2014.02.006

Woods, C., Robertson, S. J., & Gastin, P. B. (2015c). Does relative age distribution influence the physical and anthropometric profiles of drafted under 18 Australian footballers? An investigation between the 2010 and 2013 seasons. Talent Development and Excellence, 7(1), 83-90.

Woods, C. T., Raynor, A. J., Bruce, L., McDonald, Z., & Robertson, S. (2016c). The application of a multi-dimensional assessment approach to talent identification in Australian football. Journal of Sports Science, 1-6. doi:10.1080/02640414.2016.1142668

Woods, M. A., Watsford, M. L., Cavanagh, B. P., & Pruyn, E. C. (2015d). Factors affecting jump performance in professional Australian rules footballers. Journal of Sports Medicine and Physical Fitness, 55(10), 1114-1121.

Young, W., Cormack, S., & Crichton, M. (2011a). Which jump variables should be used to assess explosive leg muscle function? International Journal of Sports Physiology and Performance, 6(1), 51-57. doi:10.1123/ijspp.6.1.51

Young, W., Farrow, D., Pyne, D., McGregor, W., & Handke, T. (2011b). Validity and reliability of agility tests in junior Australian football players. Journal of Strength and Conditioning Research, 25(12), 3399-3403. doi:10.1519/JSC.0b013e318215fa1c

Young, W., & Rogers, N. (2014). Effects of small-sided game and change-of-direction training on reactive agility and change-of-direction speed. Journal of Sport Sciences, 32(4), 307-314. doi:10.1080/02640414.2013.823230

Young, W., Russell, A., Burge, P., Clarke, A., Cormack, S., & Stewart, G. (2008). The use of sprint tests for assessment of speed qualities of elite Australian Rules footballers. International Journal of Sports Physiology and Performance, 3(2), 199-206. doi:10.1123/ijspp.3.2.199

Young, W. B., Newton, R. U., Doyle, T. L. A., Chapman, D., Cormack, S., Stewart, C., & Dawson, B. (2005). Physiological and anthropometric characteristics of starters and non-starters and playing positions in elite Australian Rules football: A case study. Journal of Science and Medicine in Sport, 8(3), 333-345. doi:10.1016/S1440-2440(05)80044-1

Young, W. B., & Pryor, L. (2007). Relationship between pre-season anthropometric and fitness measures and indicators of playing performance in elite junior Australian Rules football. Journal of Science and Medicine in Sport, 10(2), 110-118. doi:10.1016/j.jsams.2006.06.003

# CHAPTER 4 – Study II

**‘The influence of age-policy changes on the relative age effect across the Australian Rules football talent pathway’**

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

Haycraft, J., Kovalchik, S., Pyne, D. B., Larkin, P., & Robertson, S. (2018). The influence of age-policy changes on the relative age effect across the Australian Rules football talent pathway. *Journal of Science and Medicine in Sport*, 21(10), 1106-1111. doi: https://doi.org/10.1016/j.jsams.2018.03.008

## 4.1. Abstract

The objective of this study was to identify the influence of age-policy changes on the relative age effect (RAE) across the Australian Football League (AFL) talent pathway. The study design was a retrospective cross-sectional analysis of junior AFL players attending the National Draft (National), State, and State Under 16s (U16) combines between 1999-2016.

Birth-date data was obtained for players attending the AFL State U16 ($n$ = 663, age: 15.9 ± 0.4 years), State ($n$ = 803, age: 19.1 ± 1.7 years), National ($n$ = 1111, age: 18.3 ± 0.8 years) combines. Corresponding aged-matched Australian general population birth rate data was also collected. A chi-squared analysis comparing birth month distributions found all Combine groups differed significantly from the general population (Under 16s: $\chi^2$ = 62.61, State: $\chi^2$ =38.83, National: $\chi^2$ = 129.13, $p < 0.001$). Specifically, Under 16s had greater birth frequencies for months January to March (≥2%, $p < 0.05$), with more State players born in January (4.9%, $p<0.05$). Age-policy changes at the National level reduced birth distribution bias for some months, however the RAE remained for March, June and July (3.9%, 6.1%, 4.3%, $p < 0.05$). State U16s and National players had 2-9% lower birth frequencies for November - December births compared general population.

Selection bias exists towards older players is present at the AFL’s State U16, and is maintained at State and National level combines. Age-policy changes are only partially successful at addressing the RAE at the National level, with alternative strategies also recommended in order to address the RAE across the AFL talent pathways.

## 4.2. Introduction

The relative age effect (RAE) is a demographic characteristic where a bias exists towards selecting athletes born earlier in a defined age group year comparative to those born later (Andronikos, Elumaro, Westbury, & Martindale, 2016; Coutts, Kempton, & Vaeyens, 2014; Simmons & Paull, 2001). The prevalence of the RAE has been described in several team sports (i.e., ice hockey, baseball, soccer, and basketball) (Cobley, Baker, Wattie, & McKenna, 2009; Finnegan, Richardson, Littlewood, & McArdle, 2017; van den Honert, 2012). A common environmental constraint in junior sport is the placement of children into annual age-grouped teams to balance competition between players of similar skill and maturity (Mann & van Ginneken, 2017; Wattie, Schorer, & Baker, 2015). As such, RAE usually occurs in more physically demanding sports, with up to a year of developmental variation in skill and maturity levels arising amongst players within a single age group (Baxter-Jones, 1995; Cobley et al., 2009; Mann & van Ginneken, 2017). This developmental variation between chronological age and biological maturation is considered an individual constraint amongst players (Simmons & Paull, 2001; van den Honert, 2012; Wattie et al., 2015). The task constraints within the game, player position, and competition level in Australian football (AF) place value on skill, physical strength, speed, and aerobic capacity. As such AF is susceptible to the RAE within talent development pathways, as there is an increased pressure to identify and select talented players into highly competitive junior state and national competitions (Coutts et al., 2014; Till et al., 2010; Wattie et al., 2015). The consequence of the RAE is that talented late-developers may be overlooked at talent selection points, as early developers exhibit the physical and skill characteristics valued by coaches and talent scouts (Coutts et al., 2014; Gastin, Bennett, & Cook, 2013; Woods, Raynor, Bruce, McDonald, & Collier, 2015a).

The Australian Football League (AFL) participation pathway is comprised of the local participation pathway and the talent pathway, with many elite level players progressing through the latter (Australian Football League [AFL], 2016). The first major AFL talent selection point is the State U16, with players recruited from the local participation pathway into a representative team consisting of the most talented players from each Australian State. Talented local level players overlooked at the State U16 level may be invited by the AFL to attend the State and National level combines, with subsequent selection into these development squads (AFL, 2016). Elite AF players are usually selected through the annual AFL National Draft, with most players nominated from National junior teams (Pyne, Gardner, Sheehan, & Hopkins, 2005).

Specific to this investigation, a selection bias in birth distributions of National junior players drafted into the AFL has been reported, with more players born in the first half of the selection year (60% vs. 40%) (Coutts et al., 2014). Furthermore, 56% of State junior Under 18 (U18) AFL draftees were born in the first half of the year compared to the second half (44%) (Woods, Robertson, & Gastin, 2015c). Contrary to this, a reverse RAE exists for mature aged AF draftees (those drafted over the age of 20), with 63% born in the first half and 37% in the second half (Coutts et al., 2014). The bias in birth distribution within junior talent levels of the AFL pathway may be attributed to the differences observed in biological maturation between talent selected and non-selected AF players' of similar age (Coutts et al., 2014; Gastin et al., 2013; Keogh, 1999). These differences have also been observed in local level players aged between 11 and 19 years, with biological maturation having strong positive correlations with 20-m sprint time, aerobic capacity, and high-intensity game running (Gastin & Bennett, 2014; Gastin et al., 2013). As such, the RAE is linked to athlete dropout rates, with players born later in the selection year having a performance disadvantage compared to older players, thus contributing to them being overlooked for representative AF squads (Andronikos et al., 2016; Cobley et al., 2009; Gastin & Bennett, 2014). However, to date no research has assessed the prevalence of the RAE in the AFL's State U16 level, with further analysis required to determine whether RAE exists within this AFL talent pathway level.

Numerous policy changes have been suggested to eliminate or reduce the RAE in individual and team sports, with many involving the modification of age-groupings for competition (Hurley, 2009; Mann & van Ginneken, 2017; Musch & Grondin, 2001). Further policy change recommendations include; grouping players based on their biological maturity (Musch & Grondin, 2001; Musch & Hay, 1999), shifting selection dates for talent and elite teams (Hurley, 2009; Mann & van Ginneken, 2017; Wattie et al., 2015), and allocating uniform numbers based on the relative age of players (Mann & van Ginneken, 2017). Policy modifications specifically targeting the RAE require sporting organisation's to make dramatic changes to their competition structures, with organisation seeking more simple methods to reduce the RAE (Mann & van Ginneken, 2017). As such, it is difficult to implement and test these policy changes within a sporting organisation's talent identification structure, leading to limited research regarding the impact of policy change on reducing the RAE (Mann & van Ginneken, 2017). Some studies have found changing selection dates only shifted the bias to the first month of the new selection year (Musch & Hay, 1999; Till et al., 2010). However, selection bias in junior soccer was reduced when numbering players shirts according to their relative age within the team, allowing talent scouts to clearly identify early and late developing players (Mann & van Ginneken, 2017).

The AFL has implemented two changes (in 2003 and 2008, see Table 4.1) to talent selection policies between 1999 and 2016. These policy changes were specifically aimed at minimising the impact of the RAE on players transitioning through the development pathway. The policies imposed restrictions on the age in which players were invited to attend National Draft camps, and elite club's ability to select players through the AFL's National Draft. However, to date there is no empirical evidence concerning the impact these policy changes had on reducing the RAE.

While there is evidence of the RAE in AF, no studies have analysed the RAE in the modern era (past 17 years) of the AFL's National, State, and State U16 testing combines. The annual combines are physical and skill testing days for talent identification of elite (National) and sub-elite (State) junior players, as well as being the entry point into the AFL's talent pathway (U16s) (Pyne et al., 2005; Woods, Cripps, Hopper, & Joyce, 2016; Woods, Raynor, Bruce, & McDonald, 2015b). The point at which the RAE originates within the AFL talent pathway should be identified to allow more targeted selection interventions that address the RAE. It is unknown whether the distribution of players selected to participate from each year quartile differs between those at the National, State, and U16 combines. Furthermore, it is unclear whether the age-policy changes regarding players invited to the AFL National Draft has affected the RAE at this level. The aim of this study was to i) determine the prevalence of the RAE across the AFL talent pathway between 1999 and 2016, and ii) analyse the influence that age-policy changes of National Draft invitees have had on the RAE at the National level.

## 4.3. Methods

This study used a retrospective cross-sectional analysis to assess the RAE and impact of the AFL's age-policy changes within the junior National, State, and State U16s Combines held between 1999 and 2016. Date of birth (DOB) data was obtained for players attending the AFL National Combine ($n$ = 1111, age: 18.3 ± 0.8 years), State Combine ($n$ = 803, age: 19.1 ± 1.7 years), and State U16 Combine ($n$ = 663, age: 15.9 ± 0.4 years). National player data was available for all years between 1999-2016, with State and State U16 player data only available between 2004-2016 and 2008-2016 respectively. Players were classified by the Combine level they attended (National, State, State U16), then further classified into birth month (1 to 12; starting with January as ‘1’), and quartile (Q1: January – March, Q2: April – June, Q3: July – September, Q4: October – December) categories.

The frequency of male births by month in the general population was obtained from statistics on monthly live births between 1981 and 2000 reported by the Australian Bureau of Statistics (Australian Bureau of Statistics [ABS], 2017). Birth statistics were calculated for three different periods to match (as close as possible) the birth cohorts for the three combine groups: the AFL National Combine (birth years 1981-1998), the State Combine (birth years 1985-1997), and State U16 Combine (birth years 1992-2000). Ethics approval for this research was obtained by the Victoria University Human Research Ethics Committee.

Changes in age eligibility policies that effect a players’ invitation to an AFL National Draft Combine between 1999 and 2016 were accounted for within the analysis. The policy changes imposed by the AFL regarding age of eligible Draft attendees are presented in Table 4.1. To account for age-related policies imposed on player attendance at the Draft for a given year, three periods were identified between 1999 and 2016. Pre-2003 was considered as between 1999-2003, where players were required to turn 17 years by June 30. The second policy period was determined as the years between 2004-2008, where player eligibility based on birth month was shifted from June to April and players were required to turn 17 years by April 30. Post-2009 was established as the years between 2009-2016, with all eligible players required to turn 18 by December 31$^{st}$ in the year of the draft. Within each period, National Combine players were further divided into 17 and 18-year-old sub-groups for analysis, as eligibility policies differed by birth year. For example, with the pre-2003 only those 17-year-olds born before July could be observed. Since 100% of the 17-year-olds were to fall between January-July, the general population proportions in Q1 and Q2 are normalized to sum to 100% in the pre-2003 comparison. All 17-year-olds were excluded from analysis in Post-2009 as, during these years, the acquisition of 17-year-olds became limited to trades for a select number of teams and were eliminated from 2013 on.

**Table 4.1.** AFL National Draft Combine birth month codes based on player invitee age rules and policy changes between 1999 to 2016.

| Draft Years | Analysis sub-section | Draft Selection Rule |
|---|---|---|
| 1999-2003 | Pre-2003 | Players required to turn 17 years by June 30 |
| 2004-2008 | 2004-2008 | Players required to turn 17 years by April 30 |
| 2009 | Post-2009 | New AFL team introduced (Gold Coast Suns, GC)– able to select 12 players turning 17 years by 1st January.<br><br>All other players required to turn 18 years in draft year |
| 2010 | Post-2009 | New AFL team introduced (Greater Western Sydney, GWS) – able to select 12 players turning 17 years by 1st January.<br><br>All other players required to turn 18 years in draft year |
| 2011 | Post-2009 | GC trade rights to 2 players aged 17 years by 1st January.<br><br>All other players required to turn 18 years in draft year. |
| 2012 | Post-2009 | GWS trade rights to 2 players aged 17 years by 1st January.<br><br>All other players required to turn 18 years in draft year. |
| 2013-Current | Post-2009 | All players turn 18 years in draft year |

### 4.3.1. Data Analysis

All statistical analyses and figures were conducted and produced using RStudio® statistical computing software version 1.0.136 (RStudio, Boston, Massachusetts). Differences in the Combine and age-matched general population birth month and quartile frequencies were assessed with chi-squared ($\chi^2$) analyses. Comparisons were conducted separately for National (18-year-old players only), State, and State U16 groups. A p-value of $< 0.05$ was the criteria for a significant difference in distributions (global difference). To understand the time-periods contributing to global differences, individual proportion tests were undertaken for each birth month and quartile against its general population estimate (Newcombe, 1998). When global differences were found in birth distributions, these further analyses were used to interpret where and in what direction the largest differences occurred. Odds ratios (OR) were used as the effect size for the relative age effect and were calculated as the player sample odds against the Australian general population odds for each AFL player level.

For the National Combine group, further chi-squared analysis was conducted to account for the varying eligibility rules for 17 and 18-year-olds (Table 4.1). In these analyses, separate groups were created for 17 and 18-year-olds for Pre-2003 (18y: $n$ = 211, 17y: $n$ = 104), 2004-2008 (18y: $n$ = 195, 17y: $n$ = 58) and Post-2009 (18y: $n$ = 435, 17y: $n$ = 46) based on the associated age-policy changes for 17 and 18-year-olds in the National Combine sub-group. For the Pre-2003 and 2004-2008 periods, 17 and 18-year-olds in the National Combine sub-group were separated. The birth month of this sub-group was contrasted against the general population, adjusting for any non-eligible months in the 17-year-old group (Pre-2003: July – December; 2004-2008: May – December). Strict cut-off dates with respect to birth month only affected 17-year-olds; as such global redefinition of the month/quartile categories was not undertaken for all birth-year groups. Instead, the general population birth month proportions were adjusted to reflect the truncation due to eligibility rules for all comparisons against the 17-year-old birth-year group. The 18-year-old players were compared against all months in the general population, with no age restrictions placed on this group. This allowed for normalising of the year proportions for the 17-year-olds for all years prior to 2008.

In addition to assessing the players separately by birth-year group, a combined analysis was also performed with the 17 and 18-year-olds for the National players. In these analyses, the combined proportion of players in a given birth month (quartile) and rule period were compared against an adjusted general population comparison, which was equal to the weighted average of the general population comparisons used in the birth-year specific comparisons, with weight equal to the proportion of each birth-year of the player sample and period. A Chi-squared test was performed to determine the overall agreement between the combined player birth month (quartile) distributions against the general population for each period.

### 4.4. Results

4.4.1. Under 16s

The birth month distribution for the Under 16s player group differed significantly from the distribution in the age-matched general population ($\chi^2$ = 62.61, $p < 0.001$, Figure 4.1). The month-by-month comparisons of State U16s birth distributions showed higher representation in the first months of the year and a lower representation in the later months of the when compared with the general population. Also, more players (>2%) were born in January (*n* = 81, OR: 1.53), February (*n* = 67, OR: 1.32) and March (*n* = 75, OR: 1.33) compared to those born in the general population (Figure 4.1). Similarly, the months of November (*n* = 32, OR: 0.59) and December (n = 19, OR: 0.34) had birth month frequencies 3% or less ($p < 0.05$) than the general population (Figure 4.1).

Year-quartile distributions differed significantly between the Under 16s and the age-matched general population (Figure 4.1; $\chi^2$ =50.80, $p < 0.001$). Higher frequencies in birth rates were observed for Q1 (8.7%, *n* = 223, OR: 1.53, $p < 0.05$) and Q2 (3.6%, *n* = 189, OR: 1.20, $p < 0.05$) (see Figure 4.1). Furthermore, the frequencies were less (-9.8%, *n* = 98, OR: 0.53, $p < 0.05$) for Q4 than the age-matched general population (Figure 4.1). There were only trivial differences in birth month distributions for Q3 between the U16s and general populations. Between quartile comparison found differences between all quartiles, the largest observed difference being between Q1 and Q4 (OR: 2.92). However slight decreases in birth distribution occurred between each quartile (Q1vQ2 OR: 1.26, Q1vQ3 OR: 1.72, Q2vQ3 OR: 1.37, Q2vQ4 OR: 2.31, Q3vQ4 OR: 1.69).

4.4.2. State

Like the Under 16s there were substantially different patterns of birth month distributions for State Combine players compared with the general population both by month ($\chi^2$ =38.83, $p < 0.001$, Figure 4.1) and quartile (State, $\chi^2$ = 22.47, $p < 0.001$, Figure 4.1). The main differences between the State players and general population were found in January (4.9%, *n* = 106, OR: 1.69, $p < 0.05$) and November (-2.4%, *n* = 44, OR: 0.67, $p < 0.05$), with no substantial differences in frequency observed for any other month (see Figure 4.1). The State level demonstrated similar patterns as the Under 16s group for Q1; with more births in Q1 (7.2%, *n* = 257, OR: 1.43, $p < 0.05$) than the age-matched general population (Figure 4.1). However, the distributions for State level was less consistent across Q2-Q4 (Q2: *n* = 181, Q3: *n* = 189, Q4:

$n$ = 176), with only trivial differences observed between player birth distributions and the age-matched general population. Comparison between State player birth quartiles found Q1 with substantially more players compared to Q2, Q3 and Q4 (Q1vQ2 OR: 1.58, Q1v Q3 OR: 1.49, Q1v Q4 OR: 1.67). Quartiles Q2-Q4 were all similar in distribution (OR: 0.95-1.12).

4.4.3. National

The distribution of birth month for 18-year-old National Combine players between 1999 and 2016 was substantially different to the general population both by month ($\chi^2$ =129.13, p < 0.001) and quartile ($\chi^2$ = 98.01, p < 0.001) (see Figure 4.1). Furthermore, more players were born in March (2.1%, $n$ = 91, OR: 1.26), June (3.0%, $n$ = 94, OR: 1.40), and July (2.2%, $n$ = 90, OR: 1.29), but less in November and December (-6.8% each, November: $n$ = 9, OR: 0.13, December: $n$ = 11, OR: 0.15, p <0.05) than the general population (Figure 4.1). Every quartile for the National group was substantially different to the age matched general population. Specifically, quartiles 1, 2 and 3 all had more players born (Q1: 5.5%, $n$ = 255, OR: 1.32, Q2: 4.4%, $n$ = 247, OR: 1.25 and Q3: 4.8%, $n$ = 255, OR: 1.27, p < 0.05, Figure 4.1) than the general population, with Q4 having substantially less National players (-14.7%, $n$ = 83, OR: 1.34, p <0.05) born. Comparing between National player birth quartiles, Q1vQ2 (OR: 1.05), Q1vQ3 (OR: 1.00), and Q2vQ3 (OR: 0.95), were all similar. However, Q4 had substantially less player than Q1, Q2 and Q3 (Q1vQ4 OR: 3.86, Q2v Q4 OR: 3.68, Q3v Q4 OR: 3.86).

4.4.4. Age-Combined National 17 and 18-year-olds

A significant difference between the birth month observed and expected 17 and 18-year-old proportions and the Australian general population for each and age-policy period (Pre-2003: $\chi^2$ = 27.10, 2004-2008: $\chi^2$ = 48.23, Post-2009: $\chi^2$ = 69.95, p < 0.05). Similar differences were also found for observed and expected birth quartiles (Pre-2003: $\chi^2$ = 14.53, 2004-2008: $\chi^2$ = 29.31, Post-2009: $\chi^2$ = 54.61, p < 0.05). The greatest monthly difference between observed and expected 17 and 18-year-old proportions and the general population for Pre-2003 was in January (2.7%), March (2.1%), November (-4.3%) and December (-4.1%). The greatest monthly differences for 2004-2008 were found in June (4.7%), February (3.6%), July (3.3%), November (-5.4%) and December (-6.3%). Post-2009 was similar with the largest differences observed for January (3.9%), November (-6.7%) and December (-6.5%), when compared to the general population.

Quartile comparisons for each age-policy period also had significant differences between the birth month observed and expected 17 and 18-year-old proportions and the Australian general population (Pre-2003: $\chi^2 = 14.53$, 2004-2008: $\chi^2 = 29.31$, Post-2009: $\chi^2 = 54.61$, $p < 0.05$. For Pre-2003, the largest difference between observed and expected pooled 17 and 18-year-old players and the general population was found in Q1 (4.8%) and Q4 (-8.0%). Between 2004-2008, the greatest observed difference was noted for Q1 (4.9%), Q3 (5.6%), and Q4 (13.1%), and for Post-2009 being Q1 (8.0%) and Q4 (-14.9%) when compared to the general population.

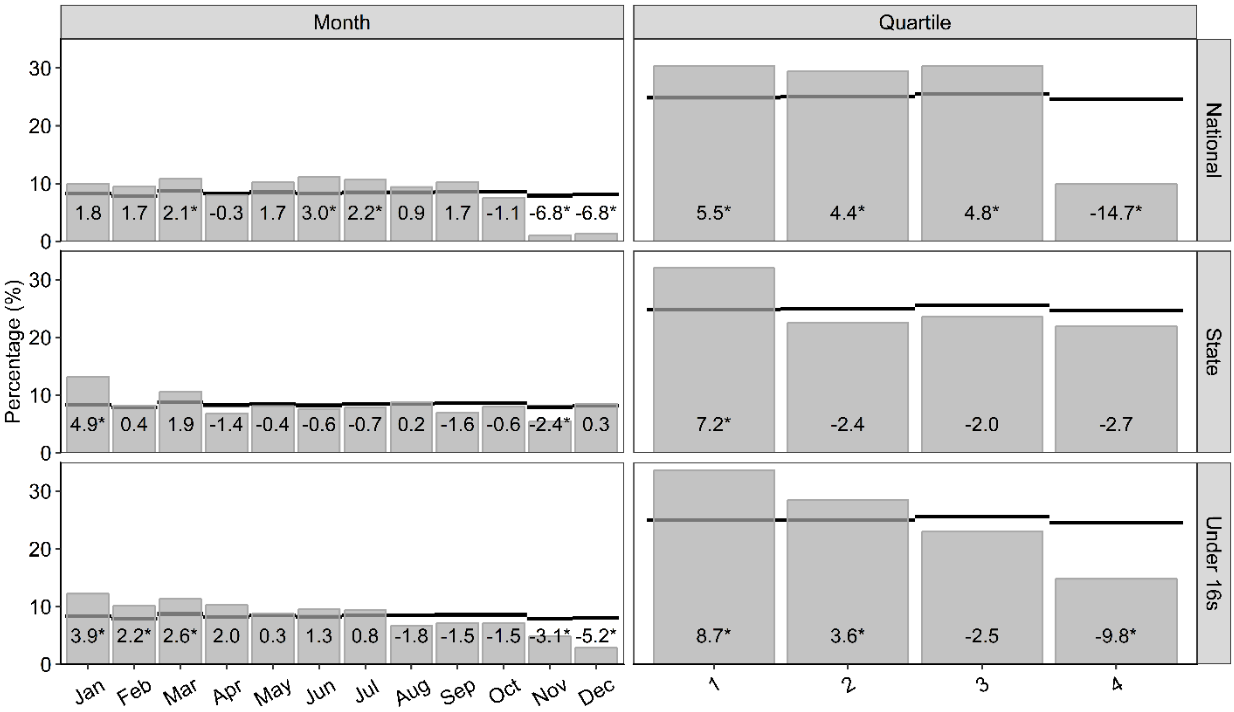


**Figure 4.1.** Birth month and quartile distribution of AF players attending the National, State, and State U16 combine tests between 1999 and 2016 compared with the Australian general population birth distribution (black line). Differences in percentage between players born per month and the Australian population is noted within the bars. * p ≤0.05.

### 4.4.5. Influence of policy changes

The National combine players birth rate distribution was partially impacted by the age-policy changes imposed by the AFL, as differences in birth distribution were not isolated to the first half of the selection year after the policies were modified. However, within the 18-year-old sub-group (Pre-2003, 2004-2008, and Post-2009), substantial differences remained in age-matched birth month distributions across all three policy periods (Pre-2003: $\chi^2 = 29.74$, 2004-2008: $\chi^2 = 46.18$, Post-2009: $\chi^2 = 70.28$, Figure 4.2). Specifically, when compared to the general population, significantly more 18-year-old players were observed to be born in June (6.1%, $n = 28$) and July (4.3%, $n = 25$) during the 2004-2008 age-policy restriction, and in March (3.9%, $n = 55$, $p < 0.05$) of the Post-2009 age restrictions. No other differences in birth distribution between the National 18-year-olds and general population were observed. Furthermore, age-policy changes did not affect player birth distributions for November (Pre-2003: -6.5%, $n = 3$, 2004-2008: -6.9%, $n = 2$, and Post-2009: -6.7%, $n = 5$, $p < 0.05$) or December (Pre-2003: -6.2%, $n = 4$, 2004-2008: -8.1%, $n = 0$, and Pre-2009: -6.5%, $n = 7$, $p < 0.05$), with significantly less players born in these months compared to the general population.

The AFL imposed age-policy changes did not affect birth month distribution for the 17-year-old National players as several months found significant differences between players and the general population. Birth month distributions for the 17-year-old National players found no substantial differences between birth frequencies and the general population for either policy period (Pre-2003: $\chi^2 = 6.53$, 2004-2008: $\chi^2 = 4.17$, Figure 4.2). Similarly, no difference was observed for individual month distribution Pre-2003 or 2004-2008 for the 17-year-old group.

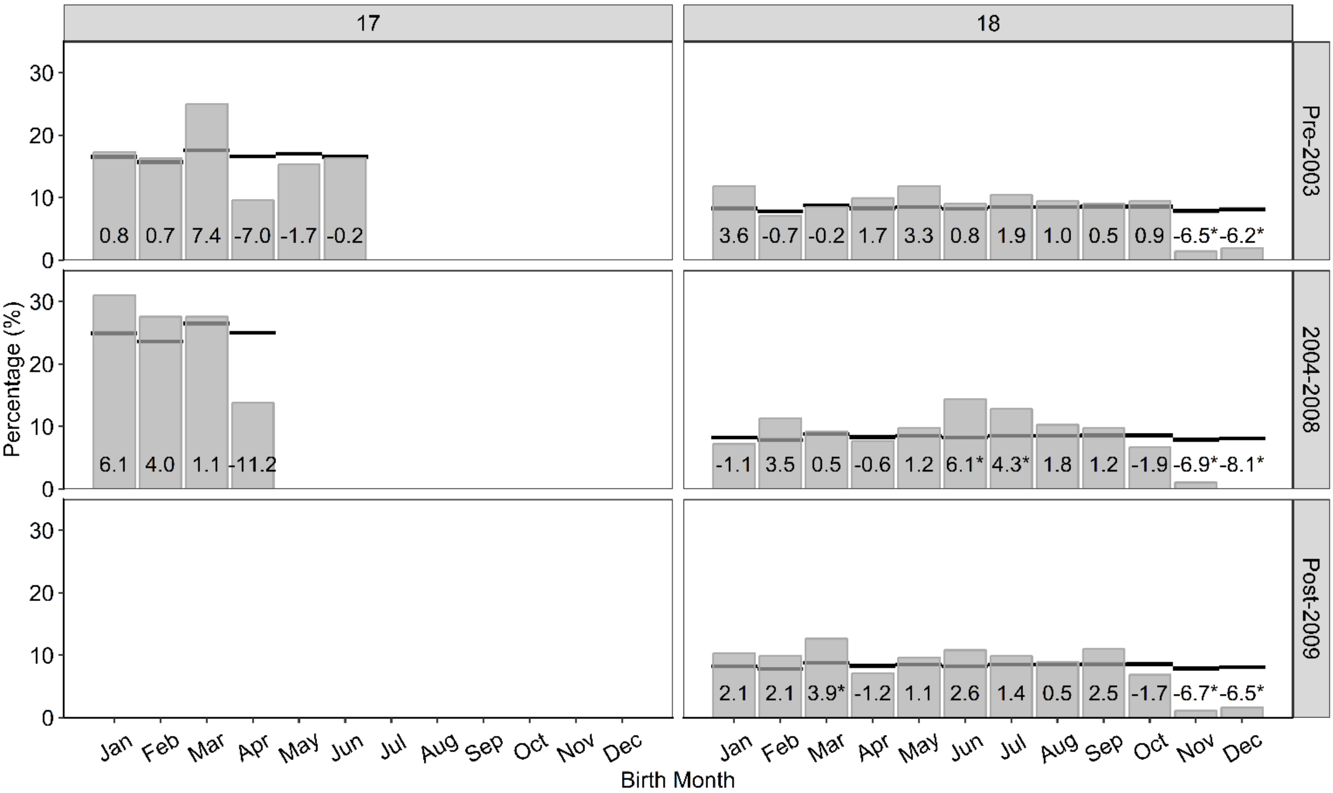


**Figure 4.2.** Effect of the implementation of age-policy changes between 1999 and 2016 on birth month distribution of 17 and 18-year-olds attending the AFL National Draft Combine. Monthly player birth rates are compared with the Australian general population (black line), with the percentage differences noted within the bars. *p ≤0.05.

## 4.5. Discussion

The aim of this study was to identify the origins of the RAE, and effect of age-policy interventions on birth month distributions of AFL players selected to attend the National, State and State U16 combines between 1999 and 2016. This study compared player birth month representation with what would be expected in the absence of the RAE. Testing this required comparison of the birth month distribution against the age-matched Australian general population for each given year. For all three levels of the AFL talent pathway, substantially more players were born earlier in the year than the accompanying age-matched Australian birth rates. Despite policy changes implemented by the AFL that modified the age of players invited to participate in the AFL National Draft Combine, the RAE was also evident in both the State and State U16s levels prior to reaching National level. It should also be noted that age-policy changes did not influence birth distribution at the National level. These findings have implications for the selection of players into the AFL talent pathway as those born earlier in the selection year are more likely to be chosen than those born later in the selection year. Furthermore, age-policy changes may not have an effect on birth distribution at the National level as the RAE is occurring earlier in the AFL talent pathway.

The birth rate distribution favouring earlier months in the year was observed at the State U16 combine levels. As the State U16 combine is considered one of the first talent selection points of the AFL talent pathway, it is evident that RAE effect is occurring for players aged 15 and 16 years. Like other sports and age brackets, AFL players born earlier in the year are more likely to be selected into a State U16 competition (Simmons & Paull, 2001; Till, Cobley, O'Hara, Cooke, & Chapman, 2014; Till et al., 2010). This phenomenon is partially explained by variability in biological maturity of players creating differences in anthropometric measures, running fitness, and match running performance in AF players aged 14-16 years (Gastin & Bennett, 2014). Furthermore, late maturing AF players under 19 years are at a physical disadvantage when compared with their early maturing counterparts (Gastin & Bennett, 2014; Gastin et al., 2013). Similarly, longitudinal evaluations of anthropometric and physical characteristics of adolescent rugby league players indicated early maturing players were larger and exhibited superior physical performances than late maturing players (Till et al., 2014). A similar scenario in junior AFL may explain the occurrence of RAEs within the State U16s competition, as early maturing athletes are more likely to be selected into the AFL's talent pathway.

The RAE was also observed in the State and National level combines, with birth rate of players in these levels favouring the first quartile of the year. However, when comparing by month, the State level players exhibited a more balanced birth rate distribution than the National and State U16 players, with only January showing a higher birth rate for this level. This difference may be caused by the variability in the age range for players attending the State combine, as older players are able to participate. One study reported that the RAE was reversed in mature age (≥ 20 years) AFL draftees (Coutts et al., 2014). Players attending the State combine in this study were approximately 1 year older than those invited to the National combine, therefore the RAE in this level of testing may be confounded by the variable nature of the mature players' attendance.

The age-policy changes imposed by the AFL did influence the birth distribution of the National level players, as substantial differences in birth distribution was not isolated to the first half of the selection year after the policies were modified. However, March, June and July were observed to have a higher player birth rate, with November and December still exhibiting lower birth rates when compared with the general population. This bias was evident when 17 and 18-year-old National players were combined, and when only 18-year-old were grouped for comparison with the expected Australian general population. Delaying player selection has been emphasised as a method of targeting the RAE in team sports such as soccer, rugby, basketball, volleyball and cricket (Andronikos et al., 2016; Till et al., 2014; Woods et al., 2015c). Previous work also found that allocating jumper number according to a players age relative to their team has successfully removed the RAE in junior soccer talent selection (Mann & van Ginneken, 2017). Though the policy changes outlined in this study can only be considered partially successful as birth distribution bias was still evident in several months. Furthermore, the RAE was already present at the State U16s level, which may restrict a late-developing player's access to higher-level coaching and athlete development programs, creating a further talent gap between players (Andronikos et al., 2016; Finnegan et al., 2017; Ford & Williams, 2011). It has also been found that place of birth in conjunction with birth quartile can effect an athletes chance of being selected into a talent development pathway (Finnegan et al., 2017). Unfortunately, the birth location of players in this study was not analysed and may be a limitation. The outcomes in this study demonstrated that whilst policy changes partially addressed the bias in birth distribution at the National level only, the RAE was still evident within the younger talent levels. As such, imposing age-policy restrictions in combination with uniform changes that clearly identify player ages at the local and state competitions, may allow for fewer players to be overlooked for selection into the AFL's talent pathways because of the time of year in which they were born.

### 4.6. Conclusion

This study determined that birth distribution bias exists for AFL players attending the State U16, State and National Combines across a substantial time period (1999 and 2016). Furthermore, it examined the effect of AFL imposed age-policy changes that specifically address the RAE at the National level. A bias in birth distribution towards the first quartile of the year at the State U16, State and National levels was evident in the AFL talent pathway, with players born earlier in the year more likely to be invited to participate at the annual AFL combines. Changes to age-policy were only partially successful within the National 18-year-old sub-group, as RAE bias was no longer evident in the first half of the selection year. However, the RAE was still observed post-policy change, with more players born in the months of June and July, and no change to number of players born in November and December. The selection bias of players born earlier in the year at State U16s level may have a flow on effect into the higher levels of the talent pathway. Therefore, policy changes regarding age selection rules of players attending the National Draft Combine may not affect the RAE prevalence, as the phenomenon was observed to occur at the State U16s, State and the 17-year-old National sub-group levels. The AFL talent pathway should incorporate selection opportunities for players born later in a given selection year, which balances out the RAE's occurring at the junior level.

## 4.7. References


AFL Development. (2016). Participation and talent pathways. Retrieved from http://www.aflcommunityclub.com.au/index.php?id=559

Australian Bureau of Statistics. (2017). Births, by year and month of occurrence, by state. Retrieved from http://stat.data.abs.gov.au/Index.aspx?DataSetCode=BIRTHS_MONTH_OCCURRENCE

Andronikos, G., Elumaro, A. I., Westbury, T., & Martindale, R. J. J. (2016). Relative age effect: implications for effective practice. *Journal of Sports Sciences, 34*(12), 1124-1131. doi:10.1080/02640414.2015.1093647

Baxter-Jones, A. D. (1995). Growth and development of young athletes. *Sports Medicine, 20*(2), 59-64.

Cobley, S., Baker, J., Wattie, N., & McKenna, J. (2009). Annual age-grouping and athlete development. *Sports Medicine, 39*(3), 235-256. doi:10.2165/00007256-200939030-00005

Coutts, A. J., Kempton, T., & Vaeyens, R. (2014). Relative age effects in Australian Football League national draftees. *Journal of Sports Sciences, 32*(7), 623-628. doi:10.1080/02640414.2013.847277

Finnegan, L., Richardson, D., Littlewood, M., & McArdle, J. (2017). The influence of date and place of birth on youth player selection to a National Football Association elite development programme. *Science and Medicine in Football, 1*(1), 30-39. doi:10.1080/02640414.2016.1254807

Ford, P. R., & Williams, M. A. (2011). No relative age effect in the birth dates of award-winning athletes in male professional team sports. *Research Quarterly for Exercise and Sport, 82*(3), 570-573. doi:10.1080/02701367.2011.10599790

Gastin, P. B., & Bennett, G. (2014). Late maturers at a performance disadvantage to their more mature peers in junior Australian football. *Journal of Sport Sciences, 32*(6), 563-571. doi:10.1080/02640414.2013.843016

Gastin, P. B., Bennett, G., & Cook, J. (2013). Biological maturity influences running performance in junior Australian football. *Journal of Science and Medicine in Sport, 16*(2), 140-145. doi:10.1016/j.jsams.2012.05.005

Hurley, W. (2009). Equitable birthdate categorization systems for organized minor sports competition. *European Journal of Operational Research, 192*(1), 253-264. doi:10.1016/j.ejor.2007.09.005

Keogh, J. (1999). The use of physical fitness scores and anthropometric data to predict selection in an elite under 18 Australian rules football team. *Journal of Science and Medicine in Sport, 2*(2), 125-133. doi:10.1016/S1440-2440(99)80192-3

Mann, D. L., & van Ginneken, P. J. M. A. (2017). Age-ordered shirt numbering reduces the selection bias associated with the relative age effect. *Journal of Sports Sciences, 35*(8), 784-790. doi:10.1080/02640414.2016.1189588

Musch, J., & Grondin, S. (2001). Unequal competition as an impediment to personal development: A review of the relative age effect in sport. *Developmental Review, 21*(2), 147-167. doi:10.1006/drev.2000.0516

Musch, J., & Hay, R. (1999). The relative age effect in soccer: Cross-cultural evidence for a systematic discrimination against children born late in the competition year. *Sociology of Sport Journal, 16*(1), 54-64. doi:10.1123/ssj.16.1.54

Newcombe, R. G. (1998). Two-sided confidence intervals for the single proportion: comparison of seven methods. *Statistics in Medicine, 17*(8), 857-872. doi:10.1002/(SICI)1097-0258(19980430)17:8<857::AID-SIM777>3.0.CO;2-E

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2005). Fitness testing and career progression in AFL football. *Journal of Science and Medicine in Sport, 8*(3), 321-332. doi:10.1016/S1440-2440(05)80043-X

Simmons, C., & Paull, G. C. (2001). Season-of-birth bias in association football. *Journal of Sports Sciences, 19*(9), 677-686. doi:10.1080/02640410152475801

Till, K., Cobley, S., O'Hara, J., Cooke, C., & Chapman, C. (2014). Considering maturation status and relative age in the longitudinal evaluation of junior rugby league players. *Scandinavian Journal of Medicine and Science in Sports, 24*(3), 569-576. doi:10.1111/sms.12033

Till, K., Cobley, S., Wattie, N., O'Hara, J., Cooke, C., & Chapman, C. (2010). The prevalence, influential factors and mechanisms of relative age effects in UK Rugby League. *Scandinavian Journal of Medicine and Science in Sports, 20*(2), 320-329. doi:10.1111/j.1600-0838.2009.00884.x van den Honert, R. (2012). Evidence of the relative age effect in football in Australia. *Journal of Sports Sciences, 30*(13), 1365-1374. doi:10.1080/02640414.2012.707329

Wattie, N., Schorer, J., & Baker, J. (2015). The relative age effect in sport: A developmental systems model. *Sports Medicine, 45*(1), 83-94. doi:10.1007/s40279-014-0248-9

Woods, C., Cripps, A., Hopper, L., & Joyce, C. (2016). A comparison of the physical and anthropometric qualities explanatory of talent in the elite junior Australian football development pathway. *Journal of Science and Medicine in Sport, 20*(7), 684-688. doi:10.1016/j.jsams.2016.11.002

Woods, C., Raynor, A. J., Bruce, L., McDonald, Z., & Collier, N. (2015a). Predicting playing status in junior Australian football using physical and anthropometric parameters. *Journal of Science and Medicine in Sport, 18*(2), 225-229. doi:10.1016/j.jsams.2014.02.006

Woods, C., Raynor, J. A., Bruce, L., & McDonald, Z. (2015b). The use of skill tests to predict status in junior Australian football. *Journal of Sports Sciences, 33*(11), 1132-1140. doi:10.1080/02640414.2014.986501

Woods, C., Robertson, S. J., & Gastin, P. B. (2015c). Does relative age distribution influence the physical and anthropometric profiles of drafted under 18 Australian footballers? An investigation between the 2010 and 2013 seasons. *Talent Development and Excellence, 7*(1), 83-90.

# CHAPTER 5 – Study III

# ‘Relationships between physical testing and match activity profiles across the Australian Football League participation pathway’

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

Haycraft, J., Kovalchik, S., Pyne, D. B., & Robertson, S. Relationships between physical testing and match activity profiles across the Australian Football League participation pathway. *International Journal of Sports Physiology and Performance*. 1-23. doi: https://doi.org/10.1123/ijspp.2018-0488.

## 5.1. Abstract

The purpose of this study was to establish levels of association between physical fitness and match activity profiles of players within the Australian Football League (AFL) participation pathway. Players ($n$ = 287, range 10.9 - 19.1 years) were assessed on 20-m sprint, AFL agility, vertical jump (VJ) and running VJ, 20-m multi stage fitness test (MSFT), and Athletic Abilities Assessment (AAA), with match activity profiles obtained from global positioning system (GPS) measures; relative speed, maximal velocity, and relative high speed running (HSR). Correlational analyses revealed moderate relationships between sprint ($r$ = 0.32-0.57, $p \leq 0.05$), and jump test scores ($r$ = 0.34-0.78, $p \leq 0.05$) and match activity profiles in Local U12, Local U14, National U16 and National U18s, except jump tests in National U18s. AFL agility was also moderate-to-strongly associated in Local U12, Local U14, Local U18, and National U16s ($r$ = 0.37-0.87, $p \leq 0.05$), and strongly associated with relative speed in Local U18s ($r$ = 0.84, $p \leq 0.05$). Match relative speed and HSR were moderate-to-strongly associated with 20-m multi-stage fitness test (MSFT) in Local U14, Local U18, and National U18s ($r$ = 0.41-0.95, $p \leq 0.05$), and AAA in Local U12, and Local U18s ($p$ = 0.35-0.67, $p \leq 0.05$). Match activity profile demands increased between Local U12 and National U16s then plateaued. Physical fitness related more strongly to match activity profiles in younger adolescent and National level players. As such, recruiters should consider adolescent physical fitness and match activity profiles as dynamic across the AFL participation pathway.

## 5.2. Introduction

Australian football (AF) is a dynamic team sport that requires players to display high levels of physical fitness in aerobic capacity, speed, agility, power, and strength (Pyne, Gardner, Sheehan, & Hopkins, 2005; Woods, Raynor, Bruce, McDonald, & Collier, 2015b). The Australian Football League's (AFL) participation pathway consists of two streams; i) the local participation pathway, and ii) the talent pathway (Australian Footbal League [AFL], 2016). The former includes teams from local competition, private schools, and school sport academies, while the latter comprises State/National Under (U) 16 and U18 squads (Lockie et al., 2015). Physical fitness of talent pathway players is tested annually at the AFL State and National U16 and U18 combines (Pyne et al., 2005; Pyne, Gardner, Sheehan, & Hopkins, 2006; Woods et al., 2015b), however testing is sporadic within local participation levels (Gastin, Bennett, & Cook, 2013; Tangalos, Robertson, Spittle, & Gastin, 2015). Considering physical fitness and match activity profile can influence a player's selection into the talent pathway from local participation levels, it is important to establish the existing differences between these variables across multiple levels of the AFL participation pathway.

In addition to physical fitness, match activity profiles are now commonly collected during competition in both junior talent squads and senior elite competition (Bauer, Young, Fahrner, & Harvey, 2015; Brewer, Dawson, Heasman, Stewart, & Cormack, 2010; Burgess, Naughton, & Norton, 2012b; Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Gastin et al., 2013). Typically obtained via global positioning system technology, a range of metrics have been reported, including total metreage, total game time, time/distance within speed zones (e.g. standing, walking, jogging, sprinting), relative speed, high intensity efforts, high speed running (HSR), and maximal velocity (Bauer et al., 2015; Brewer et al., 2010; Burgess et al., 2012b; Coutts et al., 2010; Gastin et al., 2013; Wisbey, Montgomery, Pyne, & Rattray, 2010). AFL athletes typically exhibit higher relative speeds and relative high intensity efforts than senior state level players (relative speed: +10 $m.min^{-1}$, high intensity efforts: +0.6 $efforts.min^{-1}$) and talent pathway levels (relative speed: +8-16 $m.min^{-1}$, high intensity efforts: +0.1 $efforts.min^{-1}$) (Brewer et al., 2010; Burgess et al., 2012b). Within the local participation pathway levels (Local U11 to U19), incremental improvements in relative speed and HSR during a game is evident as players progress through competition levels, with early maturing players producing higher relative HSR (>10 $m.min^{-1}$) than late maturing players (Gastin et al., 2013). However, an understanding of the relationship between physical fitness and match activity profiles across the AFL participation pathways levels is also required. Such knowledge would establish specific physical tests coaches and talent scouts should or should not consider for talent identification at specific AFL participation pathway levels.

Any differences between match activity profiles of junior footballers is likely to be impacted by the interactions of three categories of constraints; organismic, task, and environmental (Davids, Araújo, Hristovski, Passos, & Chow, 2012; Vilar, Araújo, Davids, & Button, 2012). Organismic constraints such as growth, maturity, and learning stages of individual players can influence their physical fitness, consequently affecting the stability of competition within local participation and talent pathway levels (Davids et al., 2012). For example, a sudden growth spurt in an individual player can alter motor responses and create muscle asymmetries, leading to variation in fitness and skill level, which subsequently impacts their performance in the game (i.e., environment) (Davids et al., 2012). Furthermore, the variability of organismic constraints of the players may influence the performance environment across the AFL participation pathway, with fluctuations in game structure, and physical demands of players (Vilar et al., 2012). Rule differences between AFL participation pathway levels may also affect the physical demands of the game (Davids et al., 2012; Wattie, Schorer, & Baker, 2015). For example, Local U12s games are restricted to 15 min quarters, played on a smaller grounds, use a smaller football, with a choice between 15v15 or 18v18 players at the coaches discretion (Australian Football League [AFL], 2018). Furthermore, AFL match policy provides recommendations on training foci for local participation pathway levels, with minimal to no focus on physical fitness (AFL, 2018); however, talent pathway levels are provided with fitness training, creating gaps in physical development between tiers of competition (Burgess & Naughton, 2010; Davids et al., 2012). With differences in game play, skill level, game policies, and field size (Silva et al., 2014; Tangalos et al., 2015), the interaction between physical fitness and match activity profiles at different levels of junior AF competition requires investigation.

Physical fitness and match activity profiles of players within the AFL participation pathway may also be influenced by the quality of aerobic capacity, jump ability, speed, agility, and movement ability of team members and competitors (Wattie et al., 2015). The annual AFL Draft Combines at state and national level incorporates the physical fitness testing to assess these physical qualities in talent pathway players; 5-m, 10-m, 20-m sprint, AFL agility, vertical jump (VJ), running VJ (right and left leg), and the 20-m multi-stage fitness test (MSFT) (Pyne et al., 2005; Robertson, Woods, & Gastin, 2015). As a result, physical fitness tests have proven to be useful for tracking career progression, recruiting trends, and players' selection for specific positions into elite AFL competition (Pyne et al., 2005, 2006; Robertson et al., 2015; Woods et al., 2015b). The current AFL Draft Combine test battery has primarily been used to differentiate players based on physical fitness (Pyne et al., 2005; Robertson et al., 2015; Woods et al., 2015b), with movement screenings also employed to assess functional movement skills of players in talent pathways and elite levels (Lockie et al., 2015; McKeown, Taylor-McKeown, Woods, & Ball, 2014). However, grouping of players based on age does not take into consideration the variability of age chronology and biology, contributing to the relative age effect (RAE) in talent squads (Wattie et al., 2015). Considering AFL talent scouts partially rely on the AFL Draft Combine testing battery to determine physical potential of players, quantifying the magnitude in which physical fitness tests relate to match activity profiles between tiers of AFL participation levels would inform recruitment strategies.

The primary aim of this study was to establish the between-player physical fitness and match activity profile relationship at different competition levels within the AFL participation pathway. A secondary aim was to determine the extent to which these relationships differ between each of these competition levels, and how match activity profiles fluctuate as players' progress through the AFL participation pathway.

## 5.3. Methods

This study was a cross-sectional analysis of the AFL participation pathway during the 2017 season, with each player assessed during one physical fitness session and one, two or three games. A total of seven AFL participation pathway levels were chosen for analysis, with four levels (Local U12, Local U14, Local U16, Local U18) from the local participation pathway, and three levels (National U16, State U18, National U18) from the talent pathway. Players that participated in Local, Private School, or School Sport Academy competitions were classified into the following groups based on their age; Local U12 ($n$ = 50), Local U14 ($n$ = 81), Local U16 ($n$ = 37), and Local U18 ($n$ = 15). Age limits were determined using the age grouping policies stipulated by the AFL (AFL, 2018), with players categorised by age between January 1$^{st}$ and December 31$^{st}$ of that competition year (e.g. Local U14 player ≤14 years on January 1$^{st}$). If players competed in talent pathway levels during the testing year they were classified as National U16 ($n$ = 45), State U18 ($n$ = 37), and National U18 ($n$ = 22) according to the age competition level they participated.

Physical fitness testing and match activity profile analyses of players across the AFL participation pathway were conducted between September 2016 and September 2017. The Physical tests were: 5-m, 10-m, and 20-m sprint (s), VJ and running VJ (cm), AFL planned agility test (s), 20-m MSFT (level achieved), and the Athletic Ability Assessment (AAA) score (Pyne et al., 2005, 2006; Robertson et al., 2015; Woods et al., 2015b). Physical fitness tests were conducted according the AFL Draft Combine testing protocols outlined in Woods et al. (2015b). Testing was conducted using the same equipment and testing staff across multiple venues to minimise errors across sessions. Physical fitness sessions for the National U18s were conducted by AFL Academy personnel with the assistance of the lead authors testing staff and equipment, with all data provided to the research team. Physical fitness and movement ability testing sessions followed a 10 min standardised warm-up (Woods et al., 2015b). All participants completed a familiarization trial of each physical fitness test prior to testing. The 5-m, 10-m, 20-m sprint, and AFL agility was collected using a timing gate system (Fusion Smartspeed, Fusion Sport, Australia). Anthropometric data including height (m) and body mass (kg) were collected prior to testing, with the order of testing randomised within each group with the exception of the 20-m MSFT, which was completed last by all players in accordance with AFL Draft Combine testing protocol (Robertson et al., 2015; Woods et al., 2015b). A video was used to demonstrate and provide instructions for all AAA movements (i.e., overhead squat, lunge, push-up, chin-up, and single-leg Romanian deadlift), based on coding criteria provided in Woods, McKeown, Haff, and Robertson (2015a), with all players recorded for movement coding. Four testers coded all AAA videos, with excellent inter-rater agreement between testers (intraclass correlation coefficient: 0.82) (Cicchetti, 1994).

Match activity profiles for each player were measured for one, two, or three games within each participant's competitive season, with an average of 67±80 days between physical testing and game. Data was recorded using a GPS device (Optimeye S5, Catapult Innovations, Australia) worn on the back between the scapulae and recording at a sampling rate of 10 Hz (Bauer et al., 2015). Specific GPS measures of match activity profiles selected for analysis were relative speed ($m.min^{-1}$) (Burgess et al., 2012b; Coutts & Duffield, 2010; Coutts et al., 2010), maximal velocity ($m.sec^{-1}$) (Wisbey et al., 2010), and relative high speed running (HSR) ($m.min^{-1}$) (Bauer et al., 2015; Burgess et al., 2012b; Coutts & Duffield, 2010; Coutts et al., 2010). High speed running was estimated by the amount of on-field time spent ≥14.4 km/h, as per previous GPS measures used for junior AFL players (Gastin et al., 2013). The mean GPS measures across multiple games were calculated for analysis. All match GPS data was collected and coded by the lead author, with the exception of the National U18 group which was provided by the AFL Academy personnel. Ethical approval was obtained from the Victoria University Human Research Ethics Committee, with informed consent provided by participants or their parent/guardian prior to participating in this research.

### 5.3.1. Data analysis

Descriptive statistics of physical fitness and match activity profiles for each AFL level are presented in Table 5.1. The relationships between the physical fitness tests and match activity profiles were analysed using the Pearson's product moment correlation coefficient ($r$), with the relationships between match activity profiles and the total AAA score analysed using the Spearman's rank correlation coefficient ($p$) (Altman & Gardner, 1988). Correlations were performed for all seven AFL levels. Magnitude of effect based on the correlation coefficient was determined as small $r$ = 0.10-0.29, medium: $r$ = 0.30-0.79, or large: $r$ >0.80 (Cohen, 1992). Confidence intervals (CIs) were set at 95% precision. All statistical analysis and figures were produced using RStudio® statistical computing software version 1.1.442 (RStudio, Boston, Massachusetts).

## 5.4. Results

Descriptive data of each AFL level's physical fitness measures and match activity profiles are presented in Table 5.1.

### 5.4.1. Sprints

The magnitude of correlations between sprint (5-m, 10-m, and 20-m) times were largest for all match activity measures in the National U18, National U16, and Local U12 levels ($r$ = 0.32-0.57, $p \leq 0.05$). However little variation in the size of correlations between 5-m and match activity profiles were observed between Local U14 and State U18 levels (Figure 5.1). A gradual decrease in the strength of relationships between 10-m and 20-m sprint and all match activity measures was evident in older Local competition age groups (see Figure 5.1). Larger magnitudes between all match activity measures and all sprint tests were observed for the National U16 and National U18 levels ($r$ = 0.48-0.50, $p \leq 0.05$), with the exception of maximal velocity in National U18.

### 5.4.2. Jump tests

The relationship between VJ and all match activity measures did not vary substantially across the AFL participation pathways levels. Running VJ (left and right) had the largest magnitude with all match activity measures within the Local U12s and Local U14s ($r$ = 0.34-0.78, p ≤ 0.05), with smaller magnitudes observed for all other levels (Figure 5.1).

### 5.4.3. AFL Agility

The strongest associations between AFL agility and match activity measures were observed in Local U18 ($r$ = 0.82-0.87, p ≤ 0.05), followed by Local U12, Local U14, and National U16 ($r$ = 0.37-0.63, p ≤ 0.05). However, the magnitudes between AFL agility and match activity measures varied ($r$ = 0-0.57, p ≥ 0.05) across other levels of the AFL participation pathway (Figure 5.1).

### 5.4.5. 20-m multi-stage fitness test (MSFT)

The 20-m MSFT had the strongest association with match activity measures in the Local U14, Local U18, and National U18 levels ($r$ = 0.41-0.95, p ≤ 0.05), with weaker relationships observed in Local U12, Local U16, National U16, and State U18s (Figure 5.1).

### 5.4.6. Athletic Abilities Assessment (AAA)

The Local U18 level had the largest magnitudes for total AAA score and all match activity measures (p = 0.35-0.67, p ≤ 0.05), with moderate relationships also observed between relative HSR and relative speed in Local U12. Local U14s showed the weakest associations between total AAA score and match activity measures (Figure 5.1).

### 5.4.7. Match Activity Profiles

The AFL participation pathway levels showed a gradual increase in all match measures from Local U12 to National U16 level (see Figure 5.2). However, similar match activity measures were evident between Local U12 and Local U14 players for all three measures. All match activity measures plateaued once players reached the National U16, State U18, and National U18 levels (Figure 5.2). The National U18 group experienced the smallest variation in all match activity measures compared to other AFL participation pathway levels, with less variation in maximal velocity also observed in Local U18 and State U18 players. The largest variation within an AFL participation level was for relative HSR in the National U16 level. The highest match activity measures were recorded in the National U16 level for all three measures; with the lowest being all measures of the Local U14 level.

**Table 5.1.** Descriptive statistics of physical tests and match activity profile measures for all AFL levels. Measures reported as mean ± standard deviation (SD).

| Physical Test | All AFL Levels (*n* = 287) | Local U12 (*n* = 50) | Local U14 (*n* = 81) | Local U16 (*n* = 37) | Local U18 (*n* = 15) | National U16 (*n* = 45) | State U18 (*n* = 37) | National U18 (*n* = 22) |
|---|---|---|---|---|---|---|---|---|
| Age (year) | 15.1 ± 1.9 | 12.4 ± 0.4 | 13.7 ± 0.5 | 16.2 ± 0.5 | 17.5 ± 0.4 | 16.0 ± 0.2 | 17.7 ± 0.7 | 16.4 ± 0.3 |
| Height (cm) | 174.2 ± 13.4 | 160.7 ± 11.3 | 165.9 ± 10.2 | 180.7 ± 7.9 | 180.4 ± 6.3 | 183.5 ± 6.6 | 184.2 ± 8.4 | 187.0 ± 6.9 |
| Mass (kg) | 64.5 ± 14.6 | 50.7 ± 13.0 | 55.0 ± 10.8 | 69.1 ± 7.3 | 72.7 ± 7.9 | 73.2 ± 6.6 | 79.4 ± 9.5 | 75.9 ± 6.9 |
| 20-m MSFT (level) | 11.4 ± 2.1 | 8.4 ± 1.9 | 10.1 ± 1.7 ▫ ᐞ • | 12.0 ± 1.3 | 12.9 ± 1.4 ▫ | 12.9 ± 0.8 | 12.7 ± 1.0 | 12.8 ± 1.3 |
| Vertical Jump (cm) | 51.6 ± 12.2 | 40.4 ± 7.7 ▫ ᐞ | 41.9 ± 8.4 ▫ ᐞ | 59.1 ± 7.9 | 57.3 ± 8.9 | 62.7 ± 7.0 ᐞ | 59.5 ± 5.6 | 60.2 ± 7.0 |
| Running VJ - Right (cm) | 60.8 ± 16.4 | 49.3 ± 14.2 ▫ ᐞ • | 47.9 ± 13.9 ▫ | 66.6 ± 10.6 | 63.2 ± 10.6 | 70.8 ± 12.9 | 74.1 ± 6.7 | 69.3 ± 13.0 |
| Running VJ - Left (cm) | 63.0 ± 15.5 | 50.6 ± 13.3 ▫ ᐞ • | 51.1 ± 10.6 ▫ ᐞ | 71.4 ± 7.5 | 68.8 ± 11.9 | 76.1 ± 9.7 | 69.3 ± 7.3 | 69.6 ± 21.7 ▫ |
| 5-m sprint (sec) | 1.14 ± 0.08 | 1.18 ± 0.08 • | 1.16 ± 0.08 | 1.06 ± 0.07 | 1.09 ± 0.07 | 1.14 ± 0.05 | 1.14 ± 0.04 | 1.09 ± 0.05 |
| 10-m sprint (sec) | 1.94 ± 0.17 | 2.05 ± 0.15▫ | 2.05 ± 0.22 | 1.82 ± 0.08 | 1.86 ± 0.10 | 1.88 ± 0.07 ▫ | 1.88 ± 0.07 | 1.83 ± 0.05 |
| 20-m sprint (sec) | 3.28 ± 0.24 | 3.51 ± 0.21 ▫ ᐞ • | 3.46 ± 0.19 ▫ ᐞ | 3.12 ± 0.14 | 3.13 ± 0.15 | 3.14 ± 0.12 ▫ ᐞ | 3.13 ± 0.10 | 3.08 ± 0.10 |
| AFL Agility (sec) | 9.05 ± 0.60 | 9.52 ± 0.65 ᐞ | 9.62 ± 0.51▫ ᐞ | 8.91 ± 0.31 | 8.98 ± 0.36 ᐞ • | 8.63 ± 0.35 ᐞ • | 8.64 ± 0.30 | 8.74 ± 0.39 |
| Athletic Ability Assessment (Total Score) | 41.4 ± 8.2 | 40.4 ± 8.7 ᐞ • | 37.8 ± 8.5 | 43.4 ± 5.8 | 38.1 ± 6.4 ᐞ • | 41.9 ± 7.1 • | 48.2 ± 5.7 ᐞ | 43.8 ± 5.9 |
| Relative Speed (m.min-1) | 112 ± 21 | 102 ± 20 | 100 ± 19 | 114 ± 15 | 116 ± 16 | 124 ± 17 | 120 ± 17 | 127 ± 19 |
| Maximal Velocity (m.sec-1) | 7.0 ± 0.8 | 6.4 ± 0.5 | 6.5 ± 0.7 | 7.3 ± 0.5 | 7.5 ± 0.5 | 7.6 ± 0.5 | 7.7 ± 0.5 | 7.8 ± 0.4 |
| Relative High Speed Running (m.min-1) | 26 ± 13 | 18 ± 9 | 17 ± 8 | 26 ± 8 | 29 ± 13 | 38 ± 13 | 35 ± 10 | 32 ± 6 |

AFL: Australian Football League, U: under, MSFT: Multi-stage fitness test, VJ: vertical jump. ▫ Significant relationship ≤ 0.05 between test and maximal velocity ($m.sec^{-1}$). ᐞ Significant relationship ≤ 0.05 between test and relative high speed running ($m.min^{-1}$). • Significant relationship ≤ 0.05 between test and relative speed ($m.min^{-1}$).

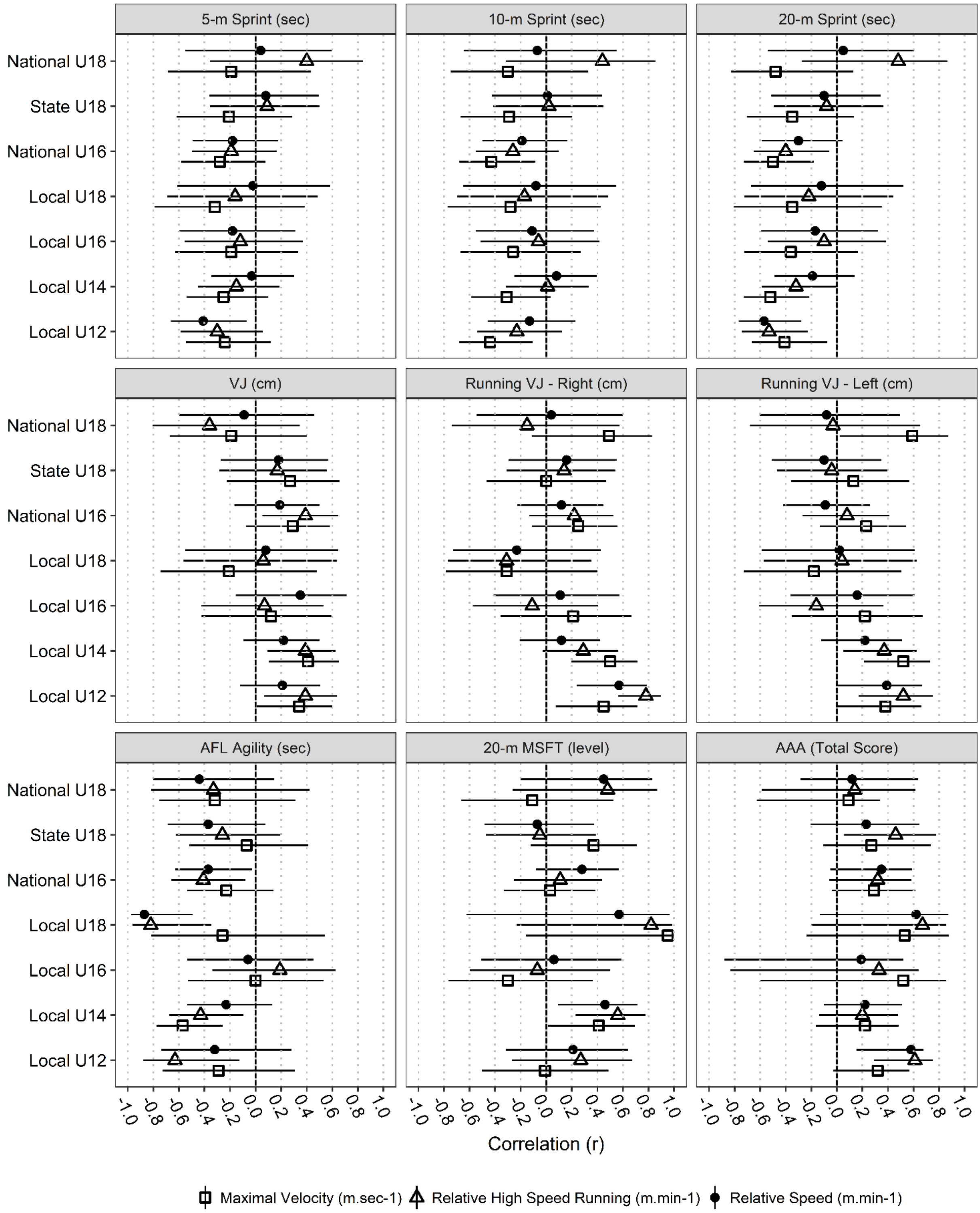


**Figure 5.1.** Relationship between fitness measures and match activity measures for AFL participation pathway levels. Data points represent the Pearson's Correlation Coefficient (*r*) between each test variable, with Total AAA data representing the Spearman's Rank Correlation Coefficient (*p*). Data is presented with 95% confidence intervals. AFL: Australian Football League, U: Under, VJ: Vertical Jump, MSFT: Multi-stage fitness test, AAA: Athletic Abilities Assessment

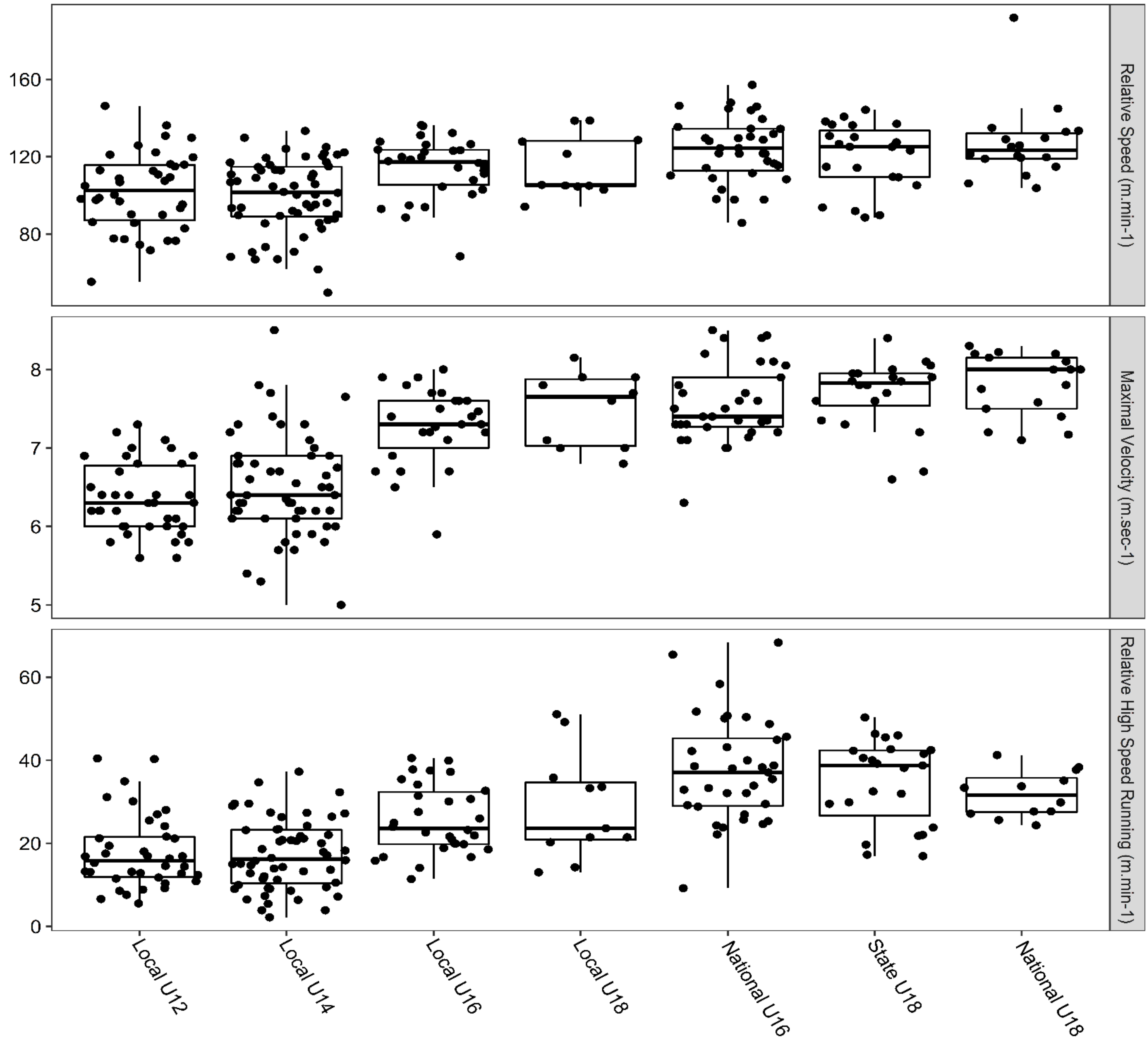


**Figure 5.2.** Match activity profiles of junior AFL players grouped by AFL participation pathway level. Game measures are represented as relative speed (m.min$^{-1}$), maximal velocity (m.sec$^{-1}$), and relative high speed running (m.min$^{-1}$). U: Under

## 5.5. Discussion

This study identified moderate-to-large relationships between fitness tests and match activity profiles across the AFL participation pathway. Physical fitness tests were more appropriate in relation to match activity profiles of early adolescent AFL players compared to older players within the local levels. Secondly, players within the talent pathway typically had stronger links between their fitness test scores and match activity profiles in the National levels, but not in State levels. Match demands increase as players progressed through the local participation pathway, with all measures plateauing once players entered the talent pathway. Relative HSR in the National U16 level had the largest disparity between players compared to other match activity measures, with all National U18 measures showing the least difference. Physical fitness tests while relevant for player selection into AFL talent pathways may be important for selection into National junior teams.

The task constraints of fitness tests (i.e. aerobic, jumps, speed, agility, movement ability) in players within the National U16, National U18, and Local U12 levels has a greater relationship with match activity profiles than other AFL levels. Higher physical fitness within the talent pathway may be a result of the provision of specialist coaching and training, resulting in stronger relationships with match activity profiles (AFL, 2018; Davids et al., 2012; Vilar et al., 2012). Similar outcomes have been observed in rugby and soccer, with higher levels of physical fitness associated with greater player involvement in high-intensity match activities (Gabbett, Kelly, & Pezet, 2007; Helgerud, Engen, Wisløff, & Hoff, 2001). The stronger associations between physical fitness and match activity profiles in Local U12 players may be explained by the organismic constraints of growth, maturity, and learning stages (Davids et al., 2012). While physical development was not assessed in this study, it may be assumed that players within the Local U12s are more homogenous in their stages of development as they have not yet entered, or are in the early stages of puberty compared with other participation pathway levels (Gastin et al., 2013). Furthermore, the Local U12 level is one of the entry levels into AFL competition, therefore players would be at similar stages of learning (Davids et al., 2012). As such, players may rely more on their physical fitness, specifically speed and jump ability, in game situations because they have not yet developed their football and game sense skills (Davids et al., 2012; Gastin et al., 2013; Tangalos et al., 2015; Wattie et al., 2015). Furthermore, the variability in organismic constraints and subsequent environmental constraints during a game may explain the weaker relationship between physical fitness and match activity profiles between the Local

U14 and Local U18 levels (Gastin et al., 2013). Variation in the maturity and growth of players is likely to contribute to the heterogeneity in physical fitness and match activity profiles.

Sprint tests in this study showed the strongest relationships with match activity measures in Local U12, National U16, and National U18, however a smaller association was observed in all other levels. Previously, junior soccer and AFL talent pathway players who were faster over the 5-m to 30-m were more likely to be selected into higher levels of competition than non-talent pathway players (Pyne et al., 2005; Robertson et al., 2015; Waldron & Murphy, 2013). Furthermore, all correlations between jump ability and match activity profiles were similar across the AFL participation pathway levels, with the exception of Local U12 running VJ (right). This outcome supports the assertion that VJ and running VJ does not clearly relate to career progression in drafted National U18 players, or contribute to a player's chance of selection into higher levels of competition within the talent pathway (Pyne et al., 2005; Robertson et al., 2015). The strongest reported relationship was between the AFL agility test and relative speed in the Local U18 group, but this decreased once players entered the talent pathway levels. Other studies also reported that the AFL agility test does not clearly discriminate between AFL drafted and non-drafted players (Burgess, Naughton, & Hopkins, 2012a; Pyne et al., 2005), and similarly may not differentiate between talented players. However, running endurance and running speed discriminated between playing standards and career progression in State U18 and National U18 players (Veale, Pearce, & Carlson, 2010; Young & Pryor, 2007); however this study reported only moderate associations between 20-m MSFT and match activity measures in National U18s.

Movement screening has been popular in several court and field sports. While movement screenings have been used in AFL studies as an injury prevention (Chalmers et al., 2017) and talent identification tool (Gaudion, Kenji, Wade, Harry, & Carl, 2017; Woods, Banyard, McKeown, Fransen, & Robertson, 2016; Woods et al., 2015a), the AAA was only associated with relative speed and relative HSR in Local U12 and Local U18 levels. Players require strong movement foundations that underlie sport-specific movements such as running, jumping, pushing and pulling (McKeown et al., 2014). While the AAA does not relate to match activity in talent pathway levels, a developing player's ability to perform functional movements correctly may translate to improved performance in local competitions. Sprint tests may be valid for talent selection into AFL National U16 and National U18 squads, but not State level. Furthermore, the AFL agility and 20-m MSFT tests may be useful for talent identification across talent pathway; however jump ability and AAA may not as important to base talent selection decisions.

The talent pathway players showed higher match activity profiles than local participation pathway levels, however all three match activity measures plateaued upon entering the talent pathway. This outcome may be attributed to the ground size, as local participation pathway games are not required to compete on a full size oval (AFL, 2018; Davids et al., 2012). Consequently, talent pathway players are required to cover more ground than local participation pathway levels. Furthermore, the National U16 group exhibited the largest variation in match activity profiles. This is not surprising considering the National U16 age group is an entry point into the AFL talent pathway, therefore it is assumed players have had limited exposure to specialised coaching and fitness training (Burgess & Naughton, 2010; Davids et al., 2012). Interestingly, the Local U14s showed the lowest measures of match activity profiles and not the Local U12s. This may be a result of difference in the organismic constrains in this age group (Davids et al., 2012). A sudden growth spurt is more likely to occur in Local U14s as adolescent male athletes have been found to reach the Tanner 5 stage of maturity at 13.5 to 15.3 years, with Tanner 1-2 stages ranging from 11 – 13.8 years (Jones, Hitchen, & Stratton, 2000). As such, a Local U14 player may be experiencing altered motor responses and muscle asymmetries caused by growth spurts, leading to variation in fitness and skill level, which subsequently impacts their match activity profile (Davids et al., 2012). The development of AFL expertise requires players to master key physical, technical, and tactical elements, with time spent in competition being integral for game development (Baker, Côté, & Abernethy, 2003). Players in the State U18 and National U18 levels may be more efficient during games because they experience less variability in organismic and environmental constraints than local participation pathway and National U16 players (Davids et al., 2012; Vilar et al., 2012). These players may have had the opportunity to develop their football/game skills and physical fitness leading to a higher standard of play from their team and opposition, which reduces congestion and yields higher match activity profiles than local participation pathway levels.

A limitation of this study is that it did not investigate state senior or elite level AFL players; therefore, comparison with junior talent level players was not conducted. However, at the junior talent level, match activity measures that show significant positive correlations with a National U18 player's earlier draft selection into elite AFL are relative game speed, HSR distance and HSR percent of game time (Woods, Veale, Collier, & Robertson, 2017). While game performance at the senior level was not included in this study, future research is recommended to provide elite-level talent selectors and coaches greater insight into the physical requirements needed for players to successfully transition into an elite AFL career. Another potential limitation is the tendency for GPS devices to underestimate distance and speed measures during straight line running, multi-directional changes, and variable movement patterns found in team field sports (coefficient of variation between 2 and 35%) (Duffield, Reid, Baker, & Spratford, 2010; Vickery et al., 2014). It is important that practitioners understand this limitation of GPS technology when interpreting the results, despite it being one of the most practical and time-efficient methods for match activity analysis (Vickery et al., 2014). Furthermore, the number of games recorded for match activity profiles is another limitation of this study as the data may not be representative of match outputs produced over the duration of a football season. For example, winning margin and match result influences physical outputs during a match at the elite level, with higher outputs reported in loses (Sullivan et al., 2014). It is not known whether this extends to other AFL participation pathway levels, as other contextual factors such as playing position, player orientation, match objective, ground size, and team/opposition skill levels also possible influencers of match activity profiles (Couceiro, Dias, Araújo, & Davids, 2016; Davids et al., 2012; Vilar et al., 2012). Future research should focus on incorporating these contextual factors and how they influence match activity profiles across the football seasons for each level of the AFL participation pathway. Finally, this study is an observational study and therefore causal links between physical fitness and match activity profiles cannot be made.

## 5.6. Conclusions

Fitness and match activity profiles in adolescent AFL players are dynamic as they move through the development pathway. Fitness is more strongly related to match activity profiles in younger players, and those in National talent competitions. Sprint, agility and aerobic endurance tests should be useful for talent selection into National talent competition. Furthermore, match activity demands do not increase once players reach the talent pathway levels. Some physical fitness tests may be limited for player selection into AFL talent pathways, but others are useful for selection into junior National teams. Finally, talent scouts and coaches should focus on long-term physical fitness and match activity profiles in adolescent players during their development, instead of talent selection based on cross-sectional assessments.

## 5.7. References


AFL Community. (2018). Australian football match policy. Retrieved from http://www.aflcommunityclub.com.au/index.php?id=32

AFL Development. (2016). Participation and talent pathways. Retrieved from http://www.aflcommunityclub.com.au/index.php?id=559

Altman, D. G., & Gardner, M. J. (1988). Statistics in medicine: calculating confidence intervals for regression and correlation. *British Medical Journal (Clinical Research ed.), 296*(6631), 1238-1242.

Baker, J., Côté, J., & Abernethy, B. (2003). Sport-specific practice and the development of expert decision-making in team ball sports. *Journal of Applied Sport Psychology, 15*(1), 12-25. doi:10.1080/10413200305400

Bauer, A. M., Young, W., Fahrner, B., & Harvey, J. (2015). GPS variables most related to match performance in an elite Australian football team. *International Journal of Performance Analysis in Sport, 15*(1), 187-202. doi:10.1080/24748668.2015.11868786

Brewer, C., Dawson, B., Heasman, J., Stewart, G., & Cormack, S. (2010). Movement pattern comparisons in elite (AFL) and sub-elite (WAFL) Australian football games using GPS. *Journal of Science and Medicine in Sport, 13*(6), 618-623. doi:10.1016/j.jsams.2010.01.005

Burgess, D., & Naughton, G. (2010). Talent development in adolescent team sports: a review. *International journal of Sports Physiology and Performance, 5*(1), 103-116. doi:10.1123/ijspp.5.1.103

Burgess, D., Naughton, G., & Hopkins, W. (2012a). Draft-camp predictors of subsequent career success in the Australian Football League. *Journal of Science and Medicine in Sport, 15*(6), 561-567. doi:10.1016/j.jsams.2012.01.006

Burgess, D., Naughton, G., & Norton, K. (2012b). Quantifying the gap between under 18 and senior AFL football: 2003 and 2009. *International Journal of Sports Physiology and Performance, 7*(1), 53-58. doi:10.1123/ijspp.7.1.53

Chalmers, S., Fuller, J. T., Debenedictis, T. A., Townsley, S., Lynagh, M., Gleeson, C., Zacharia, A., Thomson, S., & Magarey, M. (2017). Asymmetry during preseason Functional Movement Screen testing is associated with injury during a junior Australian football season. *Journal of Science and Medicine in Sport, 20*(7), 653-657. doi:10.1016/j.jsams.2016.12.076

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155-159.

Couceiro, M. S., Dias, G., Araújo, D., & Davids, K. (2016). The ARCANE project: how an ecological dynamics framework can enhance performance assessment and prediction in football. *Sports Medicine, 46*(12), 1781-1786. doi:10.1007/s40279-016-0549-2

Coutts, A. J., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport, 13*(1), 133-135. doi:10.1016/j.jsams.2008.09.015

Coutts, A. J., Quinn, J., Hocking, J., Castagna, C., & Rampinini, E. (2010). Match running performance in elite Australian Rules football. *Journal of Science and Medicine in Sport, 13*(5), 543-548. doi:10.1016/j.jsams.2009.09.004

Davids, K., Araújo, D., Hristovski, R., Passos, P., & Chow, J. Y. (2012). Ecological dynamics and motor learning design in sport. In N. J. Hodges & A. M. Williams (Eds.), *Skill Acquisition in Sport: Research, Theory and Practice* (2nd ed., pp. 112-130). New York: Routledge.

Duffield, R., Reid, M., Baker, J., & Spratford, W. (2010). Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *Journal of Science and Medicine in Sport, 13*(5), 523-525. doi:10.1016/j.jsams.2009.07.003

Gabbett, T., Kelly, J., & Pezet, T. (2007). Relationship between physical fitness and playing ability in rugby league players. *Journal of Strength and Conditioning Research, 21*(4), 1126-1133. doi:10.1519/r-20936.1

Gastin, P. B., Bennett, G., & Cook, J. (2013). Biological maturity influences running performance in junior Australian football. *Journal of Science and Medicine in Sport, 16*(2), 140-145. doi:10.1016/j.jsams.2012.05.005

Gaudion, S. L., Kenji, D., Wade, S., Harry, B. G., & Carl, W. T. (2017). Identifying the physical fitness, anthropometric and athletic movement qualities discriminant of developmental level in elite junior Australian football: Implications for the development of talent. *Journal of Strength and Conditioning Research, 31*(7), 1830-1839. doi:10.1519/jsc.0000000000001682

Helgerud, J., Engen, L. C., Wisløff, U., & Hoff, J. (2001). Aerobic endurance training improves soccer performance. *Medicine and science in sports and exercise, 33*(11), 1925-1931.

Jones, M. A., Hitchen, P. J., & Stratton, G. (2000). The importance of considering biological maturity when assessing physical fitness measures in girls and boys aged 10 to 16 years. *Annals of Human Biology, 27*(1), 57-65. doi:10.1080/030144600282389

Lockie, R. G., Schultz, A. B., Jordan, C. A., Callaghan, S. J., Jeffriess, M. D., & Luczo, T. M. (2015). Can selected functional movement screen assessments be used to identify movement deficiencies that could affect multidirectional speed and jump performance? *Journal of Strength and Conditioning Research, 29*(1), 195-205. doi:10.1519/JSC.0000000000000613

McKeown, I., Taylor-McKeown, K., Woods, C., & Ball, N. (2014). Athletic Ability Assessment: A movement assessment protocol for athletes. *International Journal of Sports Physical Therapy, 9*(7), 862-873.

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2005). Fitness testing and career progression in AFL football. *Journal of Science and Medicine in Sport, 8*(3), 321-332. doi:10.1016/S1440-2440(05)80043-X

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2006). Positional differences in fitness and anthropometric characteristics in Australian football. *Journal of Science and Medicine in Sport, 9*(1), 143-150. doi:10.1016/j.jsams.2005.10.001

Robertson, S., Woods, C., & Gastin, P. (2015). Predicting higher selection in elite junior Australian Rules football: The influence of physical performance and anthropometric attributes. *Journal of Science and Medicine in Sport, 18*(5), 601-606. doi:10.1016/j.jsams.2014.07.019

Silva, P., Aguiar, P., Duarte, R., Davids, K., Araújo, D., & Garganta, J. (2014). Effects of pitch size and skill level on tactical behaviours of association football players during small-sided and conditioned games. *International Journal of Sports Science and Coaching, 9*(5), 993-1006.

Sullivan, C., Bilsborough, J. C., Cianciosi, M., Hocking, J., Cordy, J., & Coutts, A. J. (2014). Match score affects activity profile and skill performance in professional Australian Football players. *Journal of Science and Medicine in Sport, 17*(3), 326-331. doi:10.1016/j.jsams.2013.05.001

Tangalos, C., Robertson, S., Spittle, M., & Gastin, P. B. (2015). Predictors of individual player match performance in junior Australian football. *International Journal of Sports Physiology and Performance, 10*(7), 853-859. doi:10.1123/ijspp.2014-0428

Veale, J., Pearce, A. J., & Carlson, J. S. (2010). The Yo-Yo Intermittent Recovery Test (Level 1) to discriminate elite junior Australian football players. *Journal of Science and Medicine in Sport, 13*(3), 329-331. doi:10.1016/j.jsams.2009.03.006

Vickery, W. M., Dascombe, B. J., Baker, J. D., Higham, D. G., Spratford, W. A., & Duffield, R. (2014). Accuracy and reliability of GPS devices for measurement of sports-specific movement patterns related to cricket, tennis, and field-based team sports. *Journal of Strength and Conditioning Research, 28*(6), 1697-1705. doi:10.1519/jsc.0000000000000285

Vilar, L., Araújo, D., Davids, K., & Button, C. (2012). The role of ecological dynamics in analysing performance in team sports. *Sports Medicine, 42*(1), 1-10. doi:10.2165/11596520-000000000-00000

Waldron, M., & Murphy, A. (2013). A comparison of physical abilities and match performance characteristics among elite and subelite under-14 soccer players. *Pediatric Exercise Science, 25*(3), 423-434. doi:10.1123/pes.25.3.423

Wattie, N., Schorer, J., & Baker, J. (2015). The relative age effect in sport: A developmental systems model. *Sports Medicine, 45*(1), 83-94. doi:10.1007/s40279-014-0248-9

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

Woods, C., Banyard, H. G., McKeown, I., Fransen, J., & Robertson, S. (2016). Discriminating talent identified junior Australian footballers using a fundamental gross athletic movement assessment. *Journal of Sports Science and Medicine, 15*(3), 548-553.

Woods, C., McKeown, I., Haff, G. G., & Robertson, S. (2015a). Comparison of athletic movement between elite junior and senior Australian football players. *Journal of Sports Sciences, 34*(1260-1265), 1-6. doi:10.1080/02640414.2015.1107185

Woods, C., Raynor, A. J., Bruce, L., McDonald, Z., & Collier, N. (2015b). Predicting playing status in junior Australian football using physical and anthropometric parameters. *Journal of Science and medicine in Sport, 18*(2), 225-229. doi:10.1016/j.jsams.2014.02.006

Woods, C., Veale, J. P., Collier, N., & Robertson, S. (2017). The use of player physical and technical skill match activity profiles to predict position in the Australian Football League draft. *Journal of Sports Sciences, 35*(4), 325-330. doi:10.1080/02640414.2016.1164334

Young, W. B., & Pryor, L. (2007). Relationship between pre-season anthropometric and fitness measures and indicators of playing performance in elite junior Australian Rules football. *Journal of Science and Medicine in Sport, 10*(2), 110-118. doi:10.1016/j.jsams.2006.06.003

# CHAPTER 6 – Study IV

# ‘Classification of players across the Australian Rules football participation pathway based on physical characteristics’

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

Haycraft, J., Kovalchik, S., Pyne, D. B., & Robertson, S. Classification of players across the Australian Rules football participation pathway based on physical characteristics. *International Journal of Sports Physiology and Performance*. In Review.

## 6.1. Abstract

This study investigated the utility of physical fitness and movement ability tests to differentiating and classifying players into AFL participation pathway levels. Players (n = 293, age 10.9 – 19.1 years) completed the following tests; 5-m, 10-m and 20-m sprint, AFL planned agility, vertical jump (VJ), running vertical jump, 20-m Multi-Stage Fitness Test (MSFT), and Athletic Ability Assessment (AAA). A multivariate analysis of variance between AFL participation pathway levels was conducted, and a classification tree determined the extent players could be allocated to relevant levels. The magnitude of differences between physical fitness and movement ability were age-level dependent, with the largest standardised effects (ES) between Local U12, Local U14s, and older levels for most physical fitness tests (ES: -4.64 to 5.02), except the 5-m and 10-m sprint. The 20-m, 5-m, AFL agility, 20-m MSFT, overhead squat, and running VJ (right) contributed to the classification model, with 57% overall accuracy reported (43% under cross-validation). National U16 players were easiest to classify (87%), and National U18 hardest (0%). Physical fitness and movement ability pattern fluctuations between players should be considered by coaches/selectors when administering short-term talent identification and development programs to specific AFL levels, with a long-term development focus.

## 6.2. Introduction

The Australian Football League (AFL) is a professional sport that implements a draft and salary cap system to facilitate equitable competition. On this basis, talent identification and development of players requires consideration from both performance and economic perspectives (Pearson, Naughton, & Torode, 2006). The current AFL participation pathway involves two streams: the local participation pathway and the talent pathway (Australian Football League [AFL], 2016), with the former consisting of; school/clubs/community teams (5-11 years of age), junior schools/clubs (12-14 years), youth schools/clubs (15-18 years), and open age league/associations (>18 years), and latter comprising a smaller cohort of talent identified junior players (AFL, 2016). Generally, player selection into the talent pathway is based on objective test outcomes such as physical fitness and skills testing, and subjective match performance assessments conducted by coaches and talent scouts (Burgess, Naughton, & Norton, 2012). Players may be selected into senior competitions from either the participation or talent pathways, with elite players primarily selected through the annual AFL National Draft (Pyne, Gardner, Sheehan, & Hopkins, 2005). While the structure of the AFL participation pathway may provide clear local participation and talent pathways for players, no studies have assessed the differences in physical fitness profiles between multiple levels of the local participation and talent pathways. Understanding the physical differences between local and participation pathways is important for short-term development plans that are appropriate for each AFL level, but also build the foundations for long-term player development.

Talent identification and development are multi-dimensional, encompassing aspects of physical fitness (Pearson et al., 2006), tactical and technical skills (Baker, Côté, & Abernethy, 2003), psychological characteristics (MacNamara, Button, & Collins, 2010), and socio-cultural influences (Burke & Woolcock, 2012; Côté, 1999). However, traditional talent identification in professional sports is typically cross-sectional in nature, with selection of junior athletes based on current sport performances, physical fitness, and anthropometric characteristics (Martindale, Collins, & Daubney, 2005). The predictability and usefulness of cross-sectional talent identification models is often poor because they usually involve player selection for short-term success in junior competition, not long-term player development (Davids, Araújo, Vilar, Renshaw, & Pinder, 2013; Martindale et al., 2005; Vaeyens, Lenoir, Williams, & Philippaerts, 2008). Combining pressure for short-term success within junior competition, and the natural variability of performance and development of adolescent athletes can influence player likelihood of selection/deselection into talent pathways (Martindale et al., 2005).

Match performance of adolescent players is influenced by their physical and anthropometric maturity, with early maturing players generally selected into the talent pathway, placing late maturing players at a selection disadvantage (Veale, Pearce, Koehn, & Carlson, 2008; Woods, Raynor, Bruce, McDonald, & Collier, 2015b; Young & Pryor, 2007). This selection bias, known as the relative age effect (RAE), results in more players born in the first half of the selection year being invited to junior state and national combines, or drafted into elite AFL teams (Coutts, Kempton, & Vaeyens, 2014). The representative selection policies used by the AFL may have some limitations to athlete retention because they lack the flexibility that account for athlete development long-term (Martindale et al., 2005; Vaeyens et al., 2008). However, research is limited in establishing the validity of tracking athletes longitudinally over time for improved talent identification and development of elite athletes (Elferink-Gemser, Visscher, Lemmink, & Mulder, 2007; Falk, Lidor, Lander, & Lang, 2004; Till, Cobley, O'Hara, Chapman, & Cooke, 2013). This shortcoming may be attributable to the lack of patience in long-term athlete development programs as they require the sacrifice of short-term performance outcomes valued by junior coaches and clubs (Martindale et al., 2005). Further, development of players is typically non-linear with multiple factors influencing football performance (Martindale et al., 2005; Vaeyens et al., 2008). As such, the use of non-linear analysis to classify players as opposed to linear methods may identify varying combinations of physical fitness attributes which contribute to a player's likelihood of selection into AFL talent pathways.

The annual AFL National Draft Combine physical testing battery forms part of the AFL's talent identification process and includes the following; 20-m sprint, vertical jump (VJ) variations, AFL planned agility run, and multi-stage fitness test (MSFT) (Pyne et al., 2005; Robertson, Woods, & Gastin, 2015; Woods et al., 2015b). These tests have proven to be useful for tracking career progression, recruiting trends, and selecting players for specific positions (Pyne et al., 2005; Pyne, Gardner, Sheehan, & Hopkins, 2006). Substantial differences in 20-m sprint, VJ, and 20-m MSFT evident between selected and non-selected players at state and national levels within the AFL talent pathway (Veale et al., 2008; Woods et al., 2015b; Young & Pryor, 2007). Similar findings were reported between AFL drafted and junior state level players in 20-m sprint, AFL agility, VJ, and 20-m MSFT (Pyne et al., 2005; Robertson et al., 2015). Additionally, the Athletic Abilities Assessment (AAA) has been used to assess functional movement skills of players with the purpose of classification into talent pathway or senior elite levels, with higher level players performing better in the AAA compare to lower level players

(Gaudion, Kenji, Wade, Harry, & Carl, 2017; Woods, Banyard, McKeown, Fransen, & Robertson, 2016a; Woods, McKeown, Haff, & Robertson, 2015a; Woods, McKeown, Keogh, & Robertson, 2017). Furthermore, the AAA has shown moderate-to-large discriminant validity between elite AFL starters and non-starters, with starters achieving higher overall tests scores than non-starters (Garrett, McKeown, Burgess, Woods, & Eston, 2018). However, the pattern of differences in physical fitness profiles at multiple stages across the AFL participation pathway is needed to inform short-term coaching strategies and talent selection processes, and formulation of long-term selection and development priorities of players.

The primary aim of this study was to establish physical fitness and movement ability profiles of developing players at each level of the AFL participation pathway. A secondary aim was to determine the extent to which these profiles could be used to classify players into their corresponding pathway level. Additionally, we sought to establish whether physical fitness and movement ability tests were less accurate at identifying players within specific AFL participation pathway levels.

### 6.3. Methods

This study was a cross-sectional analysis of the male AFL participation pathway between 2016 and 2018 seasons, with each player assessed at one physical fitness testing session. All players (n = 293, age range 10.9 – 19.1 years) were recruited from the AFL participation pathway, with seven AFL participation pathway levels identified for analysis (Figure 1); four local participation pathway levels (Local U12, Local U14, Local U16, and Local U18), and three talent pathway levels (National U16, State U18, National U18). All clubs were recruited through Victoria University's industry partnership with the AFL Research Board. Local participation pathway players were classified as those participating in local, private school, or school sport academy competitions. Players were further classified into the following groups based on their age; Local U12 (n = 50), Local U14 (n = 94), Local U16 (n = 29), and Local U18 (n = 15) with age limits determined by age grouping policies stipulated by the AFL.(2018) For example, players were categorized by age based on the calendar year (January 1$^{st}$ to December 31$^{st}$) of that competition year (e.g., Local U12 player ≤12 years on January 1$^{st}$). Players competing in talent pathway levels during the testing year were classified as National U16 (n = 45), State U18 (n = 38), and National U18 (n = 22) according to the age level they competed.

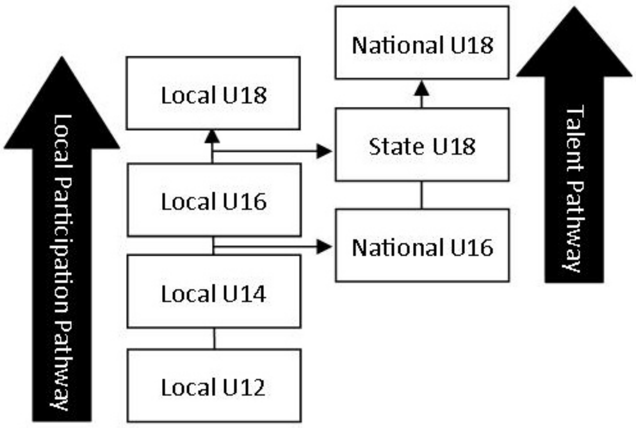


**Figure 6.1.** Schematic diagram of the AFL participation pathway outlining the competition hierarchy, and flow of players within the local participation and talent pathway levels. U: Under

Physical fitness testing of players across the AFL participation pathway was conducted between September 2016 and April 2018. Physical tests were: 5-m, 10-m, and 20-m sprint (s), VJ and running VJ (cm), AFL planned agility test (s), 20-m MSFT (level achieved), and the AAA score, with all testing completed according to the standardized AFL Draft Combine protocols outlined in Woods et al. (2015b). The AAA protocol consisted of the overhead squat, lunge (left and right), push-up, chin-up, and single-leg Romanian Deadlift (RDL) (left and right) (Woods et al., 2015a). Four testers coded all AAA videos, with excellent inter-rater agreement between testers (intraclass correlation coefficient: 0.82) (Cicchetti, 1994). Physical testing sessions followed a 10 min standardised warm-up (Woods et al., 2015b). Anthropometric data including height (m) and body mass (kg) were collected prior to testing, with the order of testing randomized within each group with the exception of the 20-m MSFT, which was completed last by all players in line with AFL Draft Combine testing protocols (Robertson et al., 2015; Woods et al., 2015b). Ethical approval was obtained from the Victoria University Human Research Ethics Committee, with informed consent provided by participants or their parent/guardian prior to participating in this research.

### 6.3.1. Data analysis

Descriptive statistics were obtained for each of the 11 tests across the seven pathway levels. To determine the extent to which test scores differed between each level, a multivariate analysis of variance (MANOVA) was undertaken. All assumptions of the MANOVA were required to be met for players to be included in this analysis (n = 154). Critical p-value for consideration of differences was reduced to 0.005 via the Bonferonni correction given multiple comparisons. Post-hoc comparisons between ability levels were undertaken using a Games-Howell test, given that nine of the eleven tests failed the Levene's test of equality of variances. Cohen's effect sizes (*d*) were also obtained for each comparison, with ≥0.2 described as trivial, ≥0.5 as moderate, and ≥0.8 as large effects (Cohen, 1988).

To determine the extent to which players could be classified into their respective ability level, a classification tree was constructed using the IMB SPSS Statistics software V25 (Version 25.0, IBM Corporation, USA). To minimize overfitting, the minimum number of cases in order for a node to develop was set to 10, while the maximum tree depth was set to 10. A confusion matrix was outputted to determine the extent to which players from each level were classified accurately. Ten-fold cross validation was undertaken, with overall classification accuracy outputted for both training and cross-validated sets. Figures 2, 3, and Supplementary Figure 1 were produced using the *ggplot2* package within the RStudio® statistical computing software version 1.1.453 (RStudio, Boston, Massachusetts).

## 6.4. Results

### 6.4.1. Physical Fitness Testing

Descriptive statistics of players' physical fitness tests and movement ability scores are presented in Figures 6.2 and 6.3, with differences between AFL participation pathway levels represented by effect sizes in Figure 6.4. The effect size difference and 95% Confidence Intervals (CIs) between AFL participation levels for each physical fitness and movement ability test are outlines in Appendix B (Table B.1. and B.2.). A gradual increase in physical fitness for all tests occurs with each progression in local pathway levels (Local U12 to Local U18), with test performance remaining homogenous across talent pathway levels (National U16 to National U18) (Figure 6.2). Movement ability was similar across all AFL participation levels for all AAA exercises, with the exception of the State U18s scoring higher on the overhead squat and left lunge (Figure 6.3).

Comparison between AFL participation pathway levels indicated that the magnitude of the difference between physical fitness and movement ability was age-dependent. For example, smaller differences were evident between National U18 and State U18 (ES: -1.43 to 0.68), compared to National U18 and Local U12 (ES: -4.24 to 4.23) (Figure 6.4). However, no substantial differences between Local U12 and Local U14 for any physical fitness or movement ability test were observed. The 20-m sprint was the only test that exhibited substantial differences between Local U12 and Local U14s and all other AFL participation pathway levels (ES: -4.24 to -1.91). However, no difference was evident for 5-m sprint time between the Local U12 and Local U14s when compared to the other AFL participation levels, except for the Local U14 and National U18s (ES: -1.21). The Local U12s were slower compared to the National U18s for 10-m sprint time (ES: -2.45), with no differences observed for any other level. Local U14s showed slower 10-m sprint times compared to all other AFL participation levels except the Local U16 (ES: -1.89 to -1.44).

The Local U12s showed large differences from all AFL participation pathway levels for the AFL agility, VJ, running VJ (left and right), and 20-m MSFT (ES: -4.64 to 5.02) (Figure 6.4). However, no differences were observed between Local U12 and Local U18s for the AFL agility and running VJ (left), or Local U16s for 20-m MSFT. The Local U14 showed no differences compared to other participation pathway levels (i.e., Local U12, Local U16, and Local U18) for AFL agility, VJ, running VJ, or 20-m MSFT. However, compared to the talent pathway levels (i.e., National U16, State U18, and National U18) the Local U14s test performance was lower for these physical fitness tests (ES: -2.66 to 3.17).

### 6.4.2. Athletic Ability Assessment

The MANOVA comparison of movement ability between AFL participation pathway levels indicated that the State U18 level had higher squat scores than the Local U12, Local U14, and National U16 (ES: 1.24 to 2.07) (Figure 6.4). State U18s also displayed higher lunge scores (right) compared to Local U12 and Local U14 (ES: 1.33 to 2.18), and for left lunge scores than Local U12, Local U14, Local U18, and National U16 levels (ES: 1.11 to 2.60). National U16 also showed higher left lunge scores compared to Local U14 players (ES: 0.80). Lower push-up and chin-up scores were observed between the Local U12 and Local U14s when compared to the State U18s, and State U18 and National U18s (ES: 1.38 to 2.38), with Local U14 also having lower chin-up scores (ES: 1.40) than National U16. Local U14s also had lower single-leg RDL scores (right and left) compared to the National U16 and State U18 levels (ES: 0.98 to 1.28).

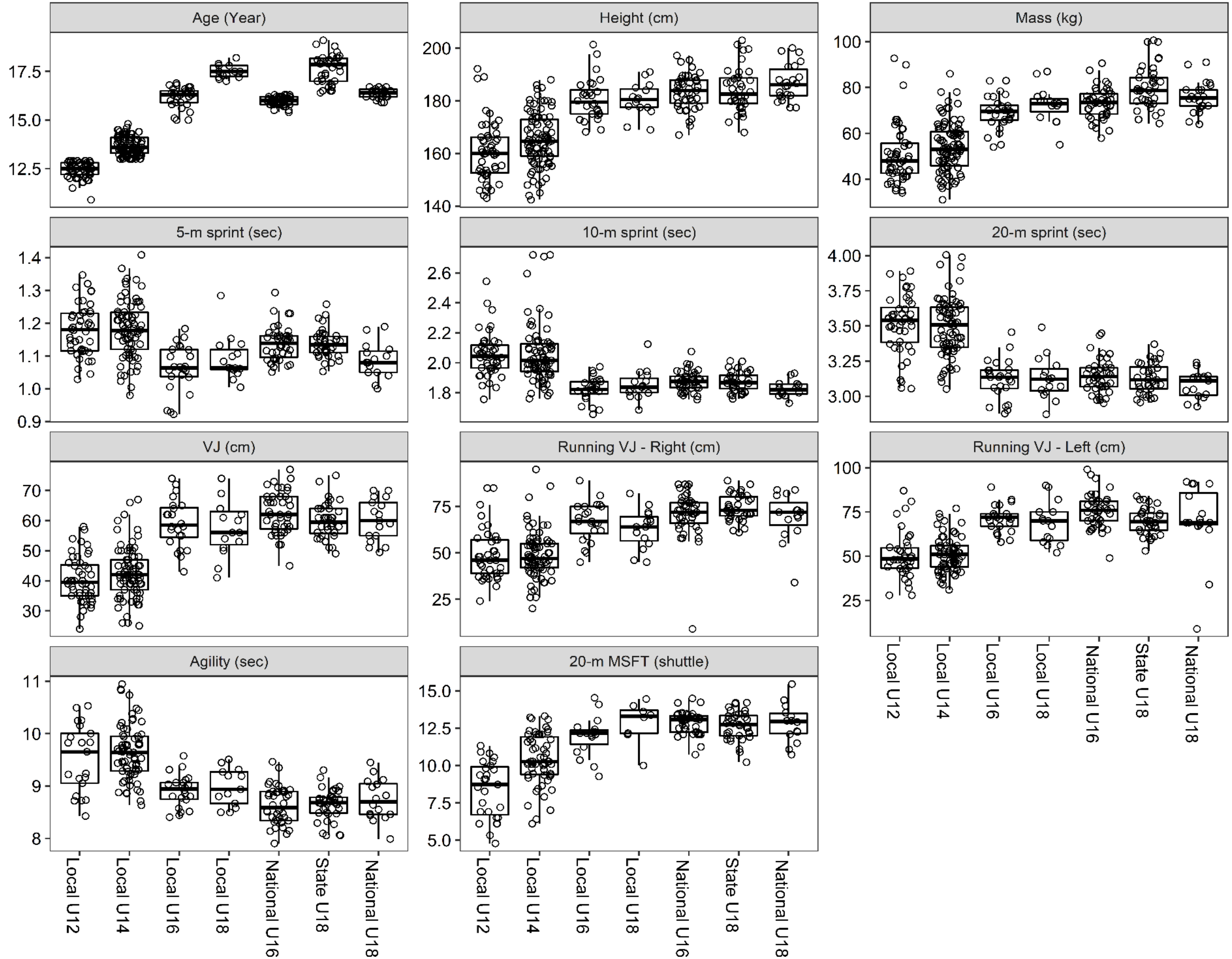


**Figure 6.2.** Physical fitness attributes of all AFL participation pathway levels included in the classification tree. U: Under

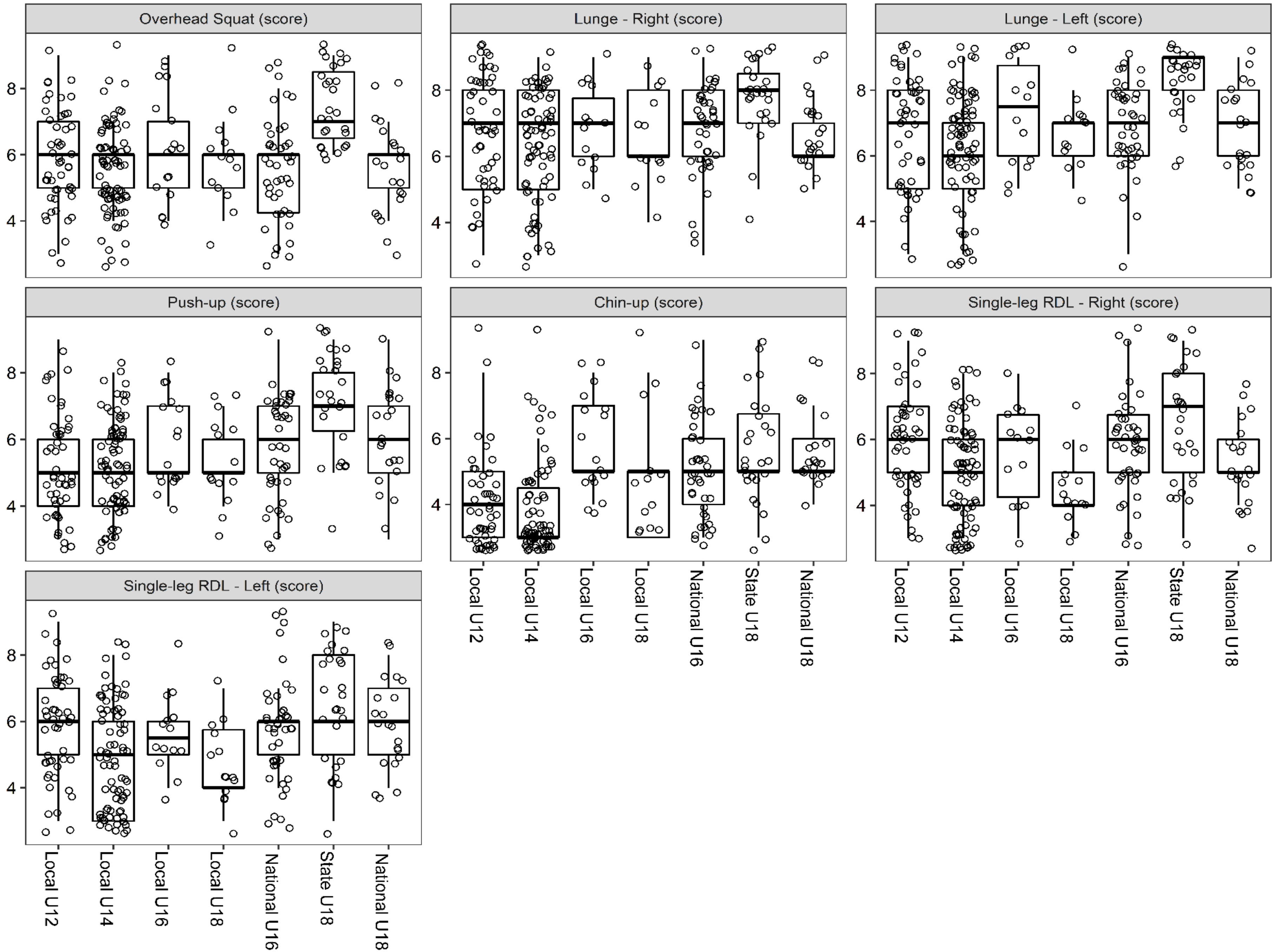


**Figure 6.3.** Movement ability characteristics of all AFL participation pathway levels included in the classification tree. U: Under

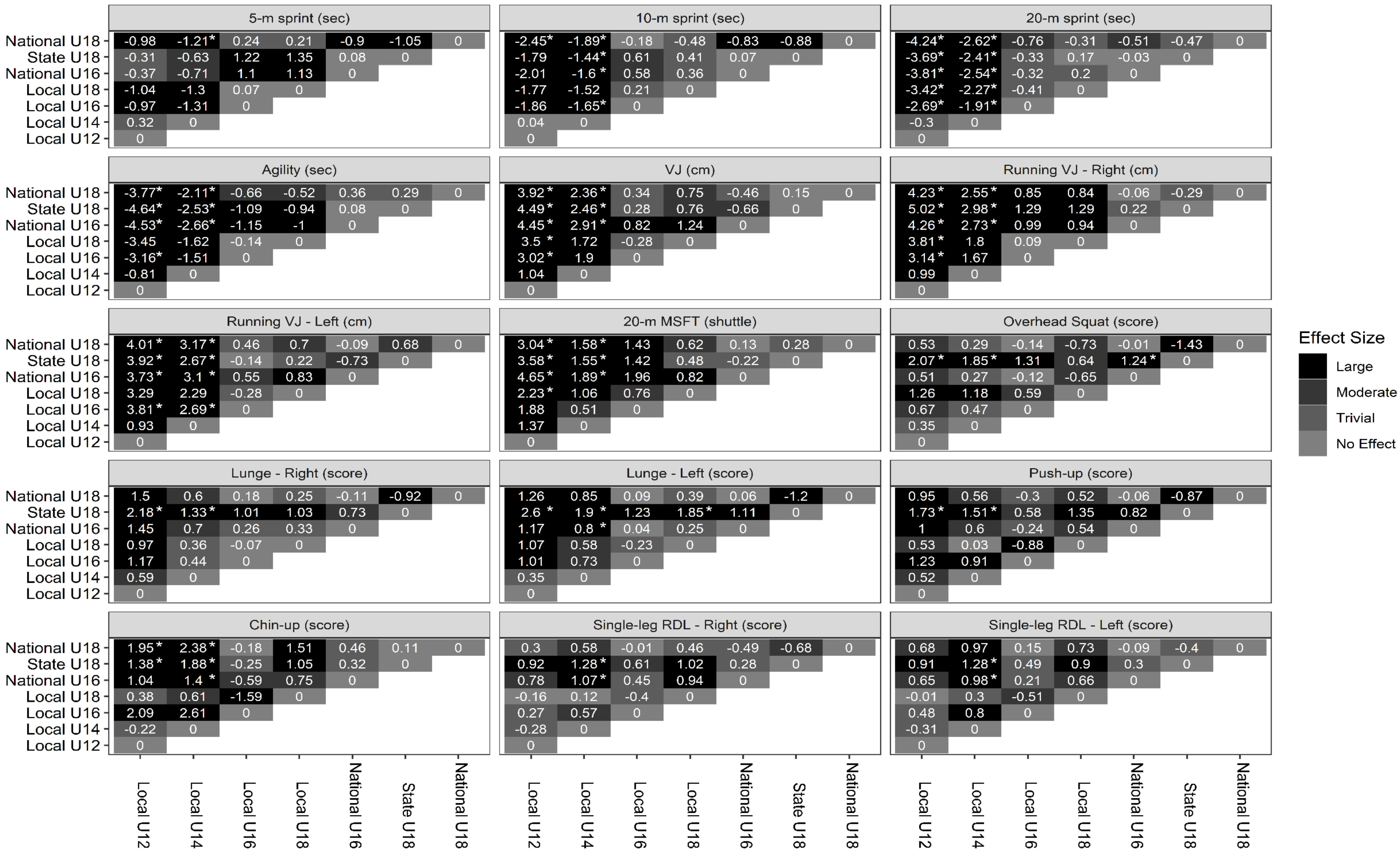


**Figure 6.4.** Multivariate analysis of variance (MANOVA) between AFL participation levels, physical fitness and movement ability tests. Values are presented as the effect size (ES) between levels, with * denoting a significant difference ($p \leq 0.005$) between levels. Threshold values to interpret the magnitude of the ES are; ≥0.2 trivial, ≥0.5 moderate, and ≥0.8 large. MSFT: Multi-Stage Fitness Test, RDL: Romanian Deadlift, U: Under, VJ = Vertical Jump

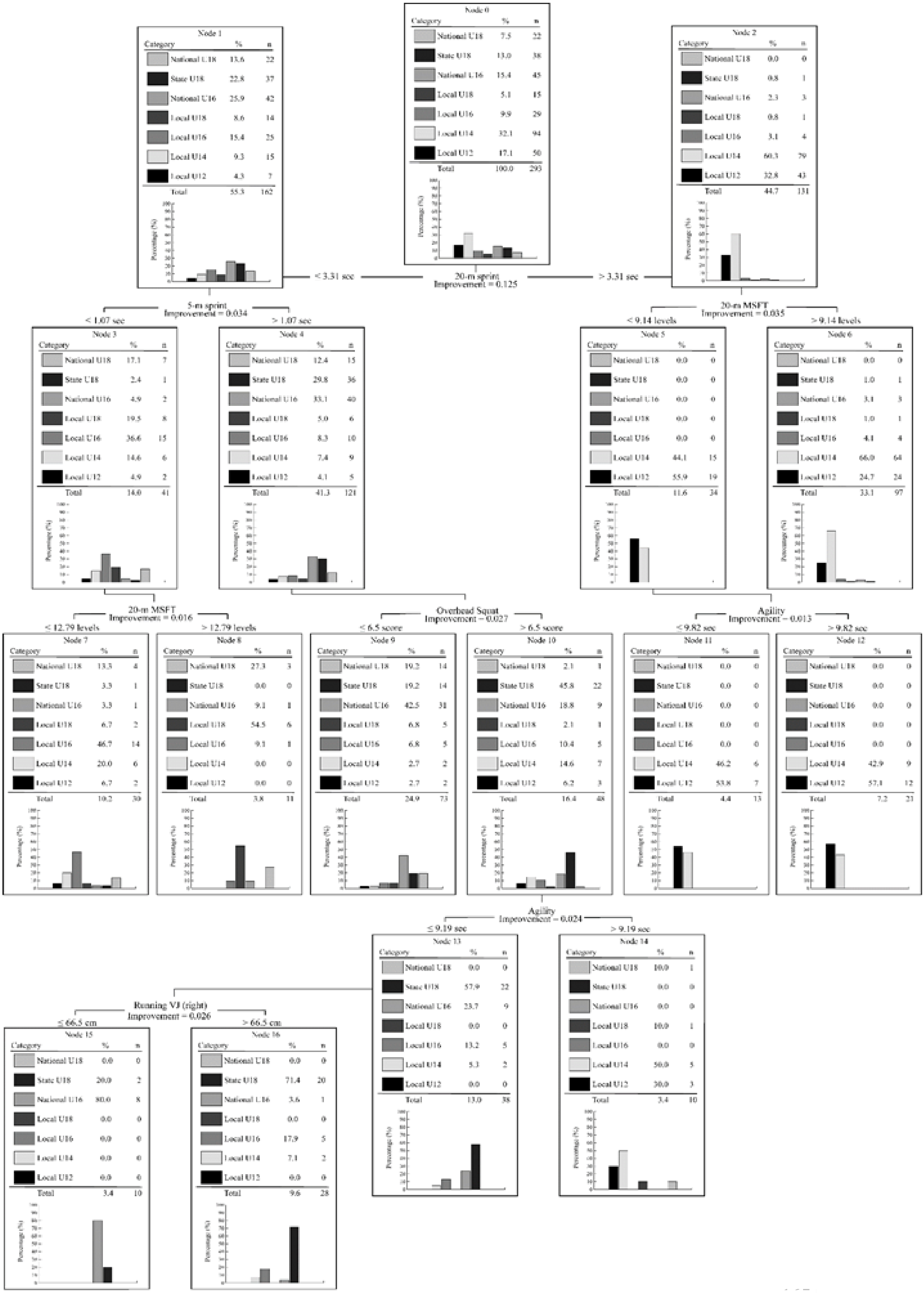


**Figure 6.5.** Classification tree for AFL participation pathway levels, physical fitness tests, and movement ability variables, where n = number of players classified at each level within each node. RVJR: Running Vertical Jump (Right Leg), U: Under

### 6.4.3. Classification of Players by Fitness and Movement Ability

The utility of the fitness test scores and AAA measures to classify players into respective age groups and levels is shown in Figure 5. It appears that 20-m, 5-m, AFL agility, 20-m MSFT, overhead squat, and running VJ (right) were the only tests identified within the classification model. For example, Local U12 and U14 were mostly identified as having 20-m sprint >3.31 sec, 20-m MSFT >9.2 shuttles, and AFL agility >9.82 sec. The National U16 and State U18 were mostly classified if they had: 20-m sprint <3.31 sec, 5-m sprint >1.07 sec, overhead squat score <6.5, AFL agility <9.19 sec. The State U18 and National U16 were differentiated by running VJ (right), with more State U18 classified with a jump height >66.5 cm, and more National U16 classified with a jump height <66.5 cm. The confusion matrix outputted from the training model is shown in Table 1. An overall classification accuracy of 57% was derived. The National U16 level players were most accurately classified based on the 11 tests (87%), whereas National U18 were the most difficult to classify (0%). A reduction in model performance was evident under 10-fold cross-validation, with overall classification accuracy reduced to 43%.

**Table 6.1**. Confusion matrix for the classification-tree model outlined in Figure 6.5.

| Observed | Local U12 | Local U14 | Local U16 | Local U18 | National U16 | State U18 | National U18 | Classification Rate |
|---|---|---|---|---|---|---|---|---|
| **Local U12** | 19 | 27 | 2 | 0 | 2 | 0 | 0 | **38%** |
| **Local U14** | 15 | 69 | 6 | 0 | 2 | 2 | 0 | **73%** |
| **Local U16** | 0 | 4 | 14 | 1 | 5 | 5 | 0 | **48%** |
| **Local U18** | 0 | 2 | 2 | 6 | 5 | 0 | 0 | **40%** |
| **National U16** | 0 | 3 | 1 | 1 | 39 | 1 | 0 | **87%** |
| **State U18** | 0 | 1 | 1 | 0 | 16 | 20 | 0 | **53%** |
| **National U18** | 0 | 1 | 4 | 3 | 14 | 0 | 0 | **0%** |
| **Overall Percentage** | **12%** | **37%** | **10%** | **4%** | **28%** | **10%** | **0%** | **57%** |

## 6.5. Discussion

Physical fitness and movement profile(s) gradually improved with each progression in competition level within the local participation level, however no change was observed between talent pathway levels (i.e., National U16, State U18, and National U18). Movement ability of players across the entire AFL participation pathway remained homogenous, with the exception of higher overhead squat and left lunge scores for the State U18s. The only physical fitness and movement ability tests that contributed to the classification model were the 20-m, 5-m, AFL agility, 20-m MSFT, overhead squat, and running VJ (right). Furthermore, the model accurately classified over half of the players into the correct AFL participation pathway levels based on these physical fitness and movement ability tests. The National U16 players were the easiest to classify, however no National U18 players were correctly classified based on these tests. Once players enter the National U16s level of the talent pathway, physical fitness and movement ability becomes less important in classifying players.

The largest within-level physical fitness tests performance variation was in the Local U12 and U14 levels, with these levels different to most of the AFL participation levels on all tests. Players within the Local U12 and Local U14s are not exposed to structured physical training at the recommendation of the AFL match policy guidelines (AFL, 2018). Consequently, the larger variation in performance within the Local U12 and U14s may be attributed to substantial between-subject variations in biological maturity of players within this group. Comparisons between physical fitness test performances and the Tanner stages of maturity in adolescent male athletes indicates that the Tanner 5 stage of maturity occurs at $14.4 \pm 0.9$ years, with Tanner 1 occurring at $11.4 \pm 0.4$ years and Tanner 2 at $11.9 \pm 0.7$ years (Jones, Hitchen, & Stratton, 2000). In junior soccer (U13-U16s) the biological maturity of players was positively correlated with jump, sprint, agility, and aerobic endurance performance across similar tests used in this study (Meylan, Cronin, Oliver, & Hughes, 2010; Vaeyens et al., 2006). This effect may explain the expected physical fitness and movement differences between the Local U12, Local U14 and the older levels within the AFL participation pathway, as the younger players may be in the early stages of physical development.

Given almost half of the players were not able to be accurately classified based solely on physical fitness and movement ability, it appears that other factors are important in successful junior football. This is not surprising, given it is well established that successful elite players overcome a variety of organismic, environmental and task constraints (Vaeyens et al., 2008;

Vaeyens et al., 2006). The inclusion of skills testing (i.e., kicking and handball tests), and performance measures such as decision making ability and match performance indicators (i.e., game statistics and match activity profiles) may improve the accuracy of the model (Davids et al., 2013; Vaeyens et al., 2006). Once entering the AFL talent pathway players' physical fitness and movement ability becomes more homogenous, with the model identifying the hardest level to classify was the National U18s. The lower ability to differentiate players between older levels of the AFL talent pathway may result from other factors such as skill level; whereas younger and less skilled players may rely more on their physical fitness attributes in training and matches. Analysis of skills between State U18 and Local U18 AFL players indicated the State-level U18 players had greater skill execution (accuracy) in dominant and non-dominant kicking and handballing tests (Woods, Raynor, Bruce, & McDonald, 2015c). Furthermore, a review of physical maturity and soccer skills in a relatively homogenous group of junior players indicated more biologically mature players expressed higher skill levels that may have resulted in more hours of practice experience (Meylan et al., 2010). Within the AFL talent pathway other factors such as skills, psychological, and sociocultural influences may affect selection into higher talent competitions (Baker et al., 2003; MacNamara et al., 2010), in combination with physical fitness and movement ability.

The exclusion of physical fitness and movement tests from the classification model (i.e., 10-m sprint, VJ, left running VJ, and AAA tests) suggests the limited importance these tests have in AFL talent identification. This outcome supports previous assertions that VJ and running VJ do not clearly relate to elite career progression in National U18 players, or contribute markedly to a player's chance of selection into higher levels of competition within the talent pathway (Pyne et al., 2005; Robertson et al., 2015). The non-linear analysis confirmed the inability of the VJ tests and movement tests to effectively differentiate between players. Similarly, movement assessments appear limited for talent identification within the AFL participation pathway as only the overhead squat score was included in the classification tree. These results contradict previous reports indicating AAA had moderate discriminant validity between selected and non-selected State U18 players, and starters and non-starters in elite AFL players, with overhead squat, lunge, and single-leg Romanian deadlift (left) showing significant differences between selected and non-selected players (Woods et al., 2016; Woods et al., 2015a). The movements that form the AAA screening are considered foundational movements that underpin sport-specific movements such as: lower body and trunk stability, and triple extension patterns of the hip, knee, and ankle required from sprinting, jumping and change of direction (Woods et al., 2015a; Woods et al., 2017). Unsurprisingly, the Local U12 and U14s performed lower on the AAA screening which may be indicative of training restrictions, and subsequent training age reductions, imposed by the AFL. However the outcomes of this study quantify the gap in movement abilities between the local and talent pathways, providing strength and conditioning practitioners within the talent pathway a baseline for incorporating short-term programs that target foundational athletic movement skills (Garrett et al., 2018). Furthermore, differences in movement ability between elite and talent pathway players in previous studies highlight the importance of developing movement ability for long-term success (Gaudion et al., 2017; Woods et al., 2016a; Woods et al., 2015a). While the AAA screening may have not contributed directly to the classification of players in this study, the movement ability of players may influence other performance factors (not reported here) such as technical skills (i.e., kicking and tackling) and match activity profiles.

The classification model included AFL agility which contradicts earlier reports. The extent to which the AFL agility test can clearly discriminate between AFL drafted and non-drafted players', or between talent pathway levels has been reported as questionable (Pyne et al., 2005). However, AFL agility time was included in the classification tree and therefore may be useful for selecting Local level players into the talent pathway but not for selection into elite competition. Furthermore, the inclusion of the 20-m MSFT in this model also supports running endurance tests for differentiating between playing standards and career progression in State U18 and National U18 players (Young & Pryor, 2007). Linear analysis approaches may be constrained by a single function, and therefore may not be able to adequately identify differing physical fitness and movement ability patterns across multiple AFL participation pathway levels (Robertson et al., 2015). Non-linear approaches provide greater insight for coaches and talent selectors as they account for the patterns of physical fitness and movement ability differences across the AFL participation pathway.

### 6.6. Conclusion

This study characterized the physical fitness and movement profile(s) of developing players, the extent in which they differ between AFL participation pathway levels, and the degree to which they could classify players into specific pathway levels. All physical fitness and movement ability tests were strongest at differentiating Local U12 and Local U14 from all AFL participation pathway levels; however differences were smaller for movement ability tests than physical fitness tests. The classification model indicated the 20-m and 5-m sprint, AFL agility, 20-m MSFT, squat, and running VJ (right) produced the highest accuracy in classifying players. National U16s were more accurately classified based on physical attributes, with the National U18 least accurate. Talent scouts and coaches should consider with a combination of physical fitness and movement ability with other skill, psychological and sociocultural factors when selecting individual players into the AFL talent pathway.

## 6.7. References


AFL Community. (2018). Australian football match policy. Retrieved from http://www.aflcommunityclub.com.au/index.php?id=32

AFL Development. (2016). Participation and talent pathways. Retrieved from http://www.aflcommunityclub.com.au/index.php?id=559

Baker, J., Côté, J., & Abernethy, B. (2003). Sport-specific practice and the development of expert decision-making in team ball sports. *Journal of Applied Sport Psychology, 15*(1), 12-25. doi:10.1080/10413200305400

Burgess, D., Naughton, G., & Norton, K. (2012b). Quantifying the gap between under 18 and senior AFL football: 2003 and 2009. *International Journal of Sports Physiology and Performance, 7*(1), 53-58. doi:10.1123/ijspp.7.1.53

Burke, M., & Woolcock, G. (2012). *The impacts of transport accessibility and remoteness on Australian Football League (AFL) talent production: findings from the 'Talent Tracker' project.* Paper presented at the Australasian Transport Research Forum (ATRF), 35th, 2012, Perth, Western Australia, Australia.

Cicchetti, D. V. (1994). Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychological assessment, 6*(4), 284-290. doi: http://dx.doi.org/10.1037/1040-3590.6.4.284

Cohen, J. (1988). Statistical power analysis for the behavioral sciences. 2nd: Hillsdale, NJ: erlbaum.

Côté, J. (1999). The influence of the family in the development of talent in sport. *Sport Psychologist, 13*(4), 395. doi:10.1123/tsp.13.4.395

Coutts, A. J., Kempton, T., & Vaeyens, R. (2014). Relative age effects in Australian Football League national draftees. *Journal of Sports Sciences, 32*(7), 623-628. doi:10.1080/02640414.2013.847277

Davids, K., Araújo, D., Vilar, L., Renshaw, I., & Pinder, R. (2013). An ecological dynamics approach to skill acquisition: implications for development of talent in sport. *Talent Development and Excellence, 5*(1), 21-34.

Elferink-Gemser, M. T., Visscher, C., Lemmink, K. A., & Mulder, T. (2007). Multidimensional performance characteristics and standard of performance in talented youth field hockey players: a longitudinal study. *Journal of Sport Sciences, 25*(4), 481-489. doi:10.1080/02640410600719945

Falk, B., Lidor, R., Lander, Y., & Lang, B. (2004). Talent identification and early development of elite water-polo players: a 2-year follow-up study. *Journal of Sports Sciences, 22*(4), 347-355. doi:10.1080/02640410310001641566

Garrett, J. M., McKeown, I., Burgess, D. J., Woods, C. T., & Eston, R. G. (2018). A preliminary investigation into the discriminant and ecological validity of the athletic ability assessment in elite Australian Rules football. *International Journal of Sports Science & Coaching, 13*(5), 679-686. doi: https://doi.org/10.1177/1747954117736168

Gaudion, S. L., Kenji, D., Wade, S., Harry, B. G., & Carl, W. T. (2017). Identifying the physical fitness, anthropometric and athletic movement qualities discriminant of developmental level in elite junior Australian football: Implications for the development of talent. *Journal of Strength and Conditioning Research, 31*(7), 1830-1839. doi:10.1519/jsc.0000000000001682

Jones, M. A., Hitchen, P. J., & Stratton, G. (2000). The importance of considering biological maturity when assessing physical fitness measures in girls and boys aged 10 to 16 years. *Annals of Human Biology, 27*(1), 57-65. doi:10.1080/030144600282389

MacNamara, Á., Button, A., & Collins, D. (2010b). The role of psychological characteristics in facilitating the pathway to elite performance part 2: Examining environmental and stage-related differences in skills and behaviors. *Sport Psychologist, 24*(1), 74-96. doi:10.1123/tsp.24.1.74

Martindale, R. J. J., Collins, D., & Daubney, J. (2005). Talent development: A guide for practice and research within sport. *Quest, 57*(4), 353-375. doi:10.1080/00336297.2005.10491862

Meylan, C., Cronin, J., Oliver, J., & Hughes, M. (2010). Talent identification in soccer: The role of maturity status on physical, physiological and technical characteristics. *International Journal of Sports Science and Coaching, 5*(4), 571-592. doi:10.1260/1747-9541.5.4.571

Pearson, D., Naughton, G. A., & Torode, M. (2006). Predictability of physiological testing and the role of maturation in talent identification for adolescent team sports. *Journal of Science and Medicine in Sport, 9*(4), 277-287. doi:10.1016/j.jsams.2006.05.020

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2005). Fitness testing and career progression in AFL football. *Journal of Science and Medicine in Sport, 8*(3), 321-332. doi:10.1016/S1440-2440(05)80043-X

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2006). Positional differences in fitness and anthropometric characteristics in Australian football. *Journal of Science and Medicine in Sport, 9*(1), 143-150. doi:10.1016/j.jsams.2005.10.001

Robertson, S., Back, N., & Bartlett, J. D. (2015a). Explaining match outcome in elite Australian Rules football using team performance indicators. *Journal of Sports Sciences, 34*(7), 637-644. doi:10.1080/02640414.2015.1066026

Till, K., Cobley, S., O'Hara, J., Chapman, C., & Cooke, C. (2013a). An individualized longitudinal approach to monitoring the dynamics of growth and fitness development in adolescent athletes. *Journal of Strength and Conditioning Research, 27*(5), 1313-1321. doi:10.1519/JSC.0b013e31828a1ea7

Vaeyens, R., Lenoir, M., Williams, A. M., & Philippaerts, R. M. (2008). Talent identification and development programmes in sport. *Sports Medicine, 38*(9), 703-714.

Vaeyens, R., Malina, R. M., Janssens, M., Van Renterghem, B., Bourgois, J., Vrijens, J., & Philippaerts, R. M. (2006). A multidisciplinary selection model for youth soccer: the Ghent Youth Soccer Project. *British Journal of Sports Medicine, 40*(11), 928-934. doi:10.1136/bjsm.2006.029652

Veale, J., Pearce, A. J., Koehn, S., & Carlson, J. S. (2008). Performance and anthropometric characteristics of prospective elite junior Australian footballers: A case study in one junior team. *Journal of Science and Medicine in Sport, 11*(2), 227-230. doi:10.1016/j.jsams.2006.12.119

Woods, C., Banyard, H. G., McKeown, I., Fransen, J., & Robertson, S. (2016). Discriminating talent identified junior Australian footballers using a fundamental gross athletic movement assessment. *Journal of Sports Science and Medicine, 15*(3), 548-553.

Woods, C., McKeown, I., Haff, G. G., & Robertson, S. (2015a). Comparison of athletic movement between elite junior and senior Australian football players. *Journal of Sports Sciences, 34*(1260-1265), 1-6. doi:10.1080/02640414.2015.1107185

Woods, C., McKeown, I., Keogh, J., & Robertson, S. (2017). The association between fundamental athletic movements and physical fitness in elite junior Australian footballers. *Journal of Sports Sciences, 36*(4), 1-6. doi:10.1080/02640414.2017.1313996

Woods, C., Raynor, A. J., Bruce, L., McDonald, Z., & Collier, N. (2015b). Predicting playing status in junior Australian football using physical and anthropometric parameters. *Journal of Science and Medicine in Sport, 18*(2), 225-229. doi:10.1016/j.jsams.2014.02.006

Woods, C., Raynor, J. A., Bruce, L., & McDonald, Z. (2015c). The use of skill tests to predict status in junior Australian football. *Journal of Sports Sciences, 33*(11), 1132-1140. doi:10.1080/02640414.2014.986501

Young, W. B., & Pryor, L. (2007). Relationship between pre-season anthropometric and fitness measures and indicators of playing performance in elite junior Australian Rules football. *Journal of Science and Medicine in Sport, 10*(2), 110-118. doi:10.1016/j.jsams.2006.06.003

# CHAPTER 7 – Discussion and Conclusions

## 7.1. Overview

Australian Football is a popular field-based team sport played in numerous structured leagues across Australia and internationally. Like most professional sporting organisations, the AFL has implemented TID and development programs focusing on player recruitment and retention to ensure the future success of their sport (Abbott & Collins, 2002; Pankhurst & Collins, 2013). One key TID program is the annual AFL Draft Combine testing at junior state and national levels of the AFL participation pathways, with the main purpose of assessing players' physical fitness and skill qualities (Pyne, Gardner, Sheehan, & Hopkins, 2005, 2006; Robertson, Woods, & Gastin, 2015; Woods, Raynor, Bruce, McDonald, & Collier, 2015). While physical fitness testing has proven useful for tracking career progression, recruiting trends, and players' selection for specific positions into elite AFL competition, the validity of these tests to identify talented junior AF players is unclear. Over the span of a player's development, the dynamic nature of interactions between organismic, environmental and task constraints requires players to continually evolve their physical fitness and skills to meet the changing demands of their sport (Davids, Araújo, Hristovski, Passos, & Chow, 2012; Newell, 1991; Wattie, Schorer, & Baker, 2015). Despite this, the TID process in AFL has remained cross-sectional through the prediction of a player's potential success via subjective assessments of game performances, in combination with objective inputs such as physical fitness, match activity profiles, and skills testing (Burgess, Naughton, & Norton, 2012; Woods, Joyce, & Robertson, 2016). Additionally, the common practice of annually age-grouping teams to balance competition between players potentially contributes to selection bias among players of differing skill and biological maturity levels across the AFL participation pathway (Cobley, Baker, Wattie, & McKenna, 2009; Wattie et al., 2015).

A body of research has been used to investigate the physical fitness in AF players at differing stages of the AFL participation pathway; however, these studies have not previously been consolidated into one systematic review. Furthermore, differences in physical fitness characteristics across the entire AFL participation pathway have not been reported systematically. The RAE has been analysed across talent pathway and senior elite levels (Coutts, Kempton, & Vaeyens, 2014; Cripps, Hopper, Joyce, & Veale, 2015), with a marked selection bias evident towards older players. Unfortunately, the success of age-policy changes imposed by the AFL to address the RAE in talent pathway levels has not been measured, despite their possible influence on TID and development. Research was also lacking in the relationships between physical fitness and match activity profiles of developing AF players.

The main aim of this thesis was to establish the magnitude of associations between physical fitness and match activity profiles across multiple AFL participation pathway levels. Finally, non-linear data analysis to characterise physical fitness profiles of developing players for each level of the AFL participation pathway has yet to be undertaken in AFL TID research. The validity of physical fitness and movement ability tests to successfully classify AF players into appropriate competition levels required further investigation. The conceptual development of this thesis aimed to improve industry practice by providing empirical evidence to support player selection and development decisions across the AFL participation pathway.

## 7.2. Summary and Conclusion

There were three overarching aims of this doctoral investigation. The first was to model physical fitness attributes of AF players at each stage of the AFL participation pathway, while systematically accounting for the underlying RAE and physical match activity profiles. A secondary aim was to provide a comprehensive and detailed assessment of the associations between physical fitness testing and physical match activity within junior levels of the AFL participation pathway. The final aim was to provide recommendations on enhancing talent identification processes for talent selectors and coaches. The specific aims and results pertaining to each study are briefly outlined below, with the main practical applications for TID and development across the AFL participation pathway discussed.

### 7.2.1. Study I

*"Physical characteristics of players within the Australian Football League development pathway: A systematic review"*

This systematic review was essential in summarising studies reporting physical fitness and movement ability assessments in AFL. Specifically, the review highlighted the specific AFL participation pathway levels where information regarding the physical fitness and movement ability attributes of players was lacking. No previous study has presented the physical development characteristics of players as they transitioned through the entire AFL participation pathway. Considering that player development and growth can affect the physical attributes of players, and their subsequent selection into talent development programs, this review served to identify specific AFL participation pathway levels requiring further investigation for Studies III and IV.

Of particular interest in this review were the physical tests currently used in the AFL Draft Combine, as these assessments are used regularly for TID of players into talent pathways and elite competitions. A total of 27 articles met the inclusion/exclusion criteria after assessment using a customised PRISMA statement. Elite AFL data was only reported for the 20-m sprint and VJ, with no other physical test results available for this level. As expected, Elite AFL players had the fastest reported mean 20-m sprint time, with Local level players the slowest. Interestingly, all other sprint performances were similar across the talent pathway levels (State U16 – Elite AFL). The State U18s had, counterintuitively, greater jump heights than senior level players for VJ, with the lowest jump heights reported for Local U10s. Moreover, jump heights across the AFL talent pathway were largely similar. AFL planned agility times were only available for the talent pathway levels with times similar across all groups. As such further investigation into change of direction capacity across the local participation pathway was suggested.

Additionally, the 20-m MSFT mean scores were only reported from Local U10s to National Draft Camp levels of the AFL participation pathway, with similar test scores between all AFL levels reported. A linear increase of one shuttle per AFL level was evident within the local participation pathway as players progressed. This trend plateaued when players entered the talent pathway. Finally, players within the talent pathway levels performed better in all physical tests than local participation players. However, when assessing differences between talent pathway levels, players tended to exhibit similar mean test scores for each physical test. It appears physical tests more effectively discriminated between players within the local participation pathway but were less useful within the talent pathway. Additionally, as players transition through the participation pathway their performance on physical fitness assessments increases. While this study provided a brief overview to coaches and talent selectors on the dynamic changes in physical fitness and movement ability assessments, the extent to which these assessments related to match activity and talent selection required further investigation in Study III and IV.

### 7.2.2. Study II

*"The influence of age-policy changes on the relative age effect across the Australian Rules football talent pathway"*

This retrospective cross-sectional analysis focused on the birth distribution of players attending the annual AFL Draft Combines at the State U16, State, and National Draft levels between 1999 and 2016. A marked bias in birth distribution towards the first quartile of the year was identified in players attending the State U16, State, and National Combines. Players born earlier in the selection year were more likely to be invited to participate at the annual AFL combines, with 59% of players across all levels born in the first half of the year. Age-policy changes implemented to target RAE's were only partially successful within the 18-year-old sub-group of National level players, with RAE bias remaining evident in the first half of the selection year. However, the RAE was still observed post-policy change, with more players born in the months of June and July, and no change to number of players born in November and December. It appears that selection bias towards players born earlier in the selection year at State U16s level may have a flow-on effect into the higher levels of the talent pathway. Policy changes regarding age selection rules for players attending the National Draft Combine may not affect the RAE prevalence in this level, as the phenomenon was already evident at the State U16s, State and the 17-year-old National sub-group levels. The outcomes of this study have implications for AFL talent pathway selection policies that focus on providing multiple selection opportunities for players born later in a given selection year, and potentially reduce the risk of overlooking late developing talented players within the local participation football.

### 7.2.3. Study III

*"Relationships between physical testing and match activity profiles across the Australian Football League participation pathway"*

Physical fitness and match activity profiles in adolescent AFL players appear to continually change as they transition through the participation pathway. Physical fitness tests were more strongly related to match activity profiles in younger players, and those in National talent competitions ($r$ = 0.32-0.95, $p \leq 0.05$). Specifically, sprint, agility and aerobic endurance running were all reported to be viable TID tests for player selection into National squads. As such, players that exhibit higher measures in these specific physical fitness tests may be of interest to coaches and talent selectors. When comparing match activity profiles of players across the AFL participation pathway, profiles plateaued upon entering the talent pathway levels. Therefore, match activity profiles of talent pathway players may be a result of other contextual factors such as individual, team and opponent skill levels, standardised ground sizes, and less variation in biological maturation. The vertical jump was identified as limited in identifying talented players for selection into AFL talent pathways; however other tests in the AFL Draft combine battery are useful for selection into National teams. The findings of this study highlight the dynamic changes in physical fitness and movement ability of players across multiple levels of the AFL participation pathway. Coaches and talent scouts should avoid cross-sectional player selection for short-term competition success, and focus on long-term player development.

#### 7.2.4. Study IV

*"Classification of players across the Australian Rules football participation pathway based on physical fitness characteristics"*

This study confirmed that physical fitness and movement ability test performance were age-dependent. Specifically, the largest difference in test performance was between Local U12 and State U18 levels for running VJ, for 20-m sprint between Local U12 and Local U14s and all AFL participation pathway levels, and for AFL agility compared to talent pathway levels (i.e., National U16, State U18, and National U18) (ES: -4.64 to 5.02). Additionally, Local U12 and Local U14 scored lower on all movement ability tests compared to other AFL participation pathway levels. The classification model indicated the combination of 20-m and 5-m sprint, AFL agility, 20-m MSFT, squat, and running VJ (right) produced the highest accuracy, resulting in 57% of players accurately classified into the appropriate AFL participation pathway level. National U16s were more accurately classified based on physical attributes (87%), however no National U18 players were classified based on these tests. It seems that factors other than physical and movement abilities contribute to player progression into higher talent levels of the AFL participation pathway. Talent scouts and coaches should consider other contextual factors (i.e., skill level, psychological, and socio-cultural influences) in combination with physical fitness and movement development abilities when selecting individual players into the AFL talent pathway. Fluctuations in physical fitness and movement ability patterns between players' identified in this study may be used to inform short-term TID and development programs that are specific to each AFL level, whilst also building the foundations for long-term player development into elite competition.

## 7.3. Practical Implications of the Research

A theme throughout this doctoral investigation was to provide improved practical guidelines for AFL coaches and talent selectors to allow more informed TID and development decisions regarding players across the AFL participation pathways. A specific focus was improving the selection of players into the AFL's talent pathway from the local participation pathway levels. The AFL's cross-sectional TID process will require regular evaluation to prioritise long-term player development opportunities, over short-term competition success.

This doctoral investigation highlights both the magnitude and pattern of physical development differences between players grouped by age, and talent levels of the AFL participation pathways for coaches and talent selectors. Study I provides coaches and practitioners important insights into the ability and limitations of specific tests within the AFL Draft Combine test battery to differentiate between AFL participation pathway levels. For example, VJ and running VJ tests were homogenous across the talent pathway levels and deemed limited in their ability to differentiate between players within these levels. However, VJ and running VJ performance were only reported if measured via a Vertec™ jump protocol which is restricted to recording absolute jump height (Woods et al., 2015). In contrast, force plates or timing mat jump protocols provide more contextual information about jump performance such as: flight time:contraction time (FT:CT) ratio, and vertical ground reaction forces (Cormack, Newton, McGulgan, & Doyle, 2008). While absolute jump height was similar across the talent pathway levels, the inclusion of jump protocols into the AFL Draft Combine test battery that measure FT:CT and vertical ground reaction forces may provide greater insight into differences in lower body power output between AFL participation pathway levels (Cormack et al., 2008; Nibali, Chapman, Robergs, & Drinkwater, 2013). This approach should provide more practical information for physical preparation practitioners within the talent pathway, allowing for individual resistance training programs that can improve a player's strength, power, speed, and agility.

The findings of the RAE study (Study II) are important for policy makers when developing, evaluating and updating talent identification and development within physically demanding sports like AFL. It was clear that age-policy changes only partially addressed the RAE within the National level of the talent pathway, with a flow-on effect possibly occurring from the State U16 levels. For policy makers, other methods for eradicating the RAE need to be identified, evaluated and implemented at all AFL participation pathway levels. For example, when local level players are numbered according to their relative age within a team, selectors are more likely to overlook the physical development of players. For talent selectors and coaches, re-visiting local levels may potentially identify talented players that were previously overlooked based on their physical maturity. Regarding the long-term football development of players, this study provides insights to selection bias associated with the variation in physical development. As such, coaches and support staff can implement an individual player approach when managing football programs. For example, sectioning players into similar development levels to ensure that all players are progressing based on individual physical development, rather than chronological age grouping. The outcomes of Study II warranted further exploration of between-level differences in physical fitness, movement ability, and match activity characteristic in Studies III and IV.

Study III's comparison of physical characteristics provided insight into the magnitude that physical fitness testing relates to match activity profiles. Specifically, the 20-m sprint, AFL agility, and 20-m MSFT performance were moderate-to-strongly related to match activity profiles in the National U18 level. From a coach or talent selector's perspective, a National U18 player who performs highly on these physical fitness tests, but is not producing the expected match activity profiles, can be flagged for further investigation into the contextual reasons why they are not performing in matches. A lower match activity profile might reflect that the opposition (coaches and players) identify this player as a threat and defensively tag them to restrict their match impact. Alternatively, this player may be physically superior, but their skills require further development to provide a meaningful impact within matches. In any case, the affordability and availability of GPS technologies in recent times allows coaches and selectors to include match activity profiling in their TID. The GPS data provides objective data to make informed decisions by quantifying an individual player's physical activities during a match, and whether they are able to fully utilise their physical fitness attributes.

Interestingly, the inability of physical fitness and movement ability tests to classify National U18 players in Study IV highlights the need to seek more contextual information when selecting players. For example, a 15-year-old who scores as highly as an 18-year-old player on their physical fitness characteristics should be further investigated by coaches and talent selectors. For example, it may be necessary for players residing in regional locations to play in higher age competitions to fill player shortages, forcing them to adapt more quickly to higher competition against older players. It is not surprising that spatial patterns associated with AFL talent selection show regional areas across Australia producing a higher talent yield than metropolitan areas, despite the likely increased access to more specialised AFL coaching and programs in metropolitan areas (Woolcock & Burke, 2013). Similar scenarios have been reported in ice-hockey and basketball, with professional players more likely to originate from smaller communities instead of dense metropolitan areas (Baker & Logan, 2007; Baker, Schorer, Cobley, Schimmer, & Wattie, 2009; Côté, Macdonald, Baker, & Abernethy, 2006). Additionally, the differing physical fitness characteristics of players may result from their participation in other sports (Berry, Abernethy, & Cote, 2008). For example, a 15-year-old who also competes in basketball may exhibit similar 5-m, AFL agility, and jump scores compared to an 18 year-old that has specialised early in AFL. This 15-year-old and/or 18-year-old could be flagged by talent selectors and coaches to investigate the players' sporting backgrounds as they present with physical fitness and movement abilities that are above/below their age level. Classifying players to specific AFL participation pathway levels using physical fitness and movement ability scores allows coaches and talent selectors to identify over-performing or under-performing players at a given level, and in conjunction with other contextual information. Collectively a systematic approach to player assessment should facilitate more informed decisions about a player's selection or de-selection from talent squads.

### 7.4. Limitation of the Doctoral Investigation

First, the results in this thesis are limited to junior male pathway players and cannot be applied directly to TID of players into elite senior competitions. Specifically, the policy changes in Study II were restricted to the National level players, with these changes only partially successful at reducing birth distribution bias. Whether these age-policy changes would be successful at targeting the prevalence of the RAE at the State U16s and State levels remains unclear. Including other contextual information such as place of birth may effect a player's chance of selection into a talent development pathway (Finnegan, Richardson, Littlewood, & McArdle, 2017). Unfortunately, this information was not analysed in Study II and may be a limitation.

Additionally, Studies III and IV exclude state senior or elite level AFL players; therefore, comparisons with junior talent level players could not be conducted. It is unlikely that the contributions of physical fitness and movement attributes of experienced adult players would be directly comparable to those observed within the junior levels. Therefore, inferences regarding the use of these tests to assist the selection of elite senior players are unable to be made. The magnitude of the relationship between physical fitness, movement ability, and the combination of attributes that classify senior elite players remains unclear. Furthermore, there are potential limitations regarding the inclusion of the AAA as a potential test for TID. Firstly, the scale ranking used to score movement permits the possibility of attaining the same score without being sensitive enough to specific differences in between players' movement ability. Therefore, differences in AFL participation pathway levels movement ability may actually produce relatively homogenised movement scores based on the ordinal ranking scale (Garrett, McKeown, Burgess, Woods, & Eston, 2018). Additionally, training age of players can attribute to the variation in movement skill, particularly for players familiar with the AAA movements (Garrett et al., 2018). As such, the subjective nature of the AAA and training experience of players should be considered by coaches and support staff if using this assessment for TID purposes.

Only including physical fitness, movement ability, and match activity profile variables in Study III and IV of this doctoral investigation is another limitation. Previously, a multi-dimensional assessment of State U18 AF players reported that selected players out-performed non-selected players on physical fitness tests (height, VJ, 20-m MSFT), technical assessments (kicking and handballing), and perceptual-cognitive tests (video decision-making task) (Woods, Raynor, Bruce, McDonald, & Robertson, 2016). Considering the findings from Study II demonstrate the prevalence of the RAE within the talent pathway, this has implications for practitioners when considering physical characteristics of players. The nature of this research forms the physical component of a larger AFL Research Board project inclusive of the following tests; kicking distance, a video decision-making task, grit questionnaire, and sport development history questionnaire. However, on preliminary analysis the reliability and validity of decision-making task, grit scores, and sport development history questionnaires were deemed questionable given the age ranges of the players and the test validity itself, particularly for the sport development history of players. Furthermore, the kicking distance test was considered, however this data formed part of another researcher's project and was not able to be included within these studies. As such, these factors were excluded from the analyses and it remains unclear the influence these factors have on TID and development across the AFL participation pathway levels.

It should also be noted, that while GPS technology used in Study III is useful for quantifying match activity profiles, distance, and speed measures during straight line running, multi-directional changes, and variable movement patterns in team field sports can be underestimated

(Duffield, Reid, Baker, & Spratford, 2010; Vickery et al., 2014). Additionally, quantifying match external load from accelerometers should provide contextual information pertaining impact loads (i.e., tackling, bumping, jumping, change of direction) experienced by developing AFL players (Colby, Dawson, Heasman, Rogalski, & Gabbett, 2014; Cormack, Mooney, Morgan, & McGuigan, 2013). Furthermore, the number of games recorded for match activity profiles is another limitation of this study as the data may not be fully representative of match outputs produced over an entire football season. For the sub-sample (n=72) of participants in Study III, the variation in GPS measures across multiple games is presented in Figure A.1. (Appendix A), as seen from the figure most GPS measures were consistent between matches for all levels. Additionally, influences on match activity profiles are multifactorial and not solely dependent on physical fitness. For example, previous research has shown that match result may be influential on running at the elite level (Sullivan et al., 2014), however it is not known whether this extends to other AFL participation pathway levels. Other contextual factors are arguably as important, if not more so than match outcome, such as playing position, player orientation, match objective, ground size, team and opposition skill levels (Couceiro, Dias, Araújo, & Davids, 2016; Davids et al., 2012; Vilar, Araújo, Davids, & Button, 2012; Wattie et al., 2015). Unfortunately, these factors were beyond the scope of this research, as such it is important for coaches and talent scouts to understand these limitations when interpreting the results of Study III.

### 7.5. Future Research Directions

The physical testing battery used in the AFL National Draft Combine and common movement ability tests analysed in Study I, III and IV identified that particular tests (i.e., VJ test and AAA movements) do not relate strongly to match activity or level classification of players. While some of these tests were valid measures for classifying players into AFL participation pathway levels, future investigation should focus on representative testing protocols that are more specific to the physical demands of AFL, for example small-sided games (Corbett et al., 2017; Robertson & Farrow, 2017). Furthermore, the application of machine learning techniques such as rule induction has been used in AFL research to determine the representativeness of practice to replicate match conditions (Robertson & Farrow, 2017), and the physical fitness parameters that best classified a players chance of being drafted to elite AFL teams (Robertson et al., 2015). Additionally, the nature of this research forming the physical component of a larger AFL

Research Board project allows the investigation of the multi-dimensional factors of TID and development inclusive of technical and tactical skills, psychological, sociocultural influences, and the RAE. As such, machine learning analysis coupled with improved access, to and affordability of, performance measuring tools (i.e., GPS and video analysis), video-based decision-making tasks, psychological questionnaires, sport development history, and player demographics should facilitate future research into constraint interactions at multiple levels of the AFL participation level that have previously been unobservable. Researchers can then determine whether current AFL testing protocols relate strongly to match performance outcomes and identify other contextual factors indicative of a talented player.

This doctoral investigation was limited to the junior male AFL participation pathways. The magnitude that physical fitness and movement ability assessments contribute to senior state and elite level competition requires further investigation. Future research to quantify the gap between the junior and senior elite levels would ensure players that exhibit qualities required to succeed at the elite level are selected, and not who plateau once their physical maturation is complete. Moreover, it is important to establish the differences between junior and senior elite players to reduce the risk of early deselection. For example, understanding the physical fitness, technical and tactical skill gaps an 18-year-old AFL Draftee requires to fill in order to be competitive at the senior elite level will inform the development of individual training plans for newly drafted players. The practical implications for coaches, players, and physical preparation staff centres on individualised training and skill development timelines based on the development patterns of players, while minimising risks of overtraining and/or burnout, and early deselection of draftees.

A finding from the systematic review was the limited research into upper and lower body strength testing. Whilst the AAA screening may have not contributed directly to the classification of players in this thesis, the movements within the AAA are commonly used in resistance training programs for the purpose of improving strength, power, speed, and agility (Baker, 1996; Kotzamanidis, Chatzopoulos, Michailidis, Papaiakovou, & Patikas, 2005). Moreover, the push-up and chin-up component include a repetition target that can be used as an estimate measure of a player's maximal upper-body strength (Portas, Parkin, Roberts, & Batterham, 2016). Based on this research and the relevant literature, it is reasonable that AAA measures may be useful for determining the readiness of players at different ages to progress into basic strength training programs, and subsequent strength profiling in future research. The appropriateness of strength testing within the local participation pathway is limited by the players low scores on AAA movements, however there is merit in strength testing of talent pathways in future research based on their movement ability scores.

The introduction of the female AFLW participation pathway provides the opportunity to extend this work to female football TID and development. Physical fitness testing, movement ability, and match activity profile findings in Studies III and IV could also be relevant for female pathways. Including all areas of football TID and development into the modelling (i.e., representative AFL skills testing, socio-economic, and psychological characteristics) would provide more informed insight into the multiple constraints that influence whether a player will be successful at the elite level. Finally, this research is not limited to AFL, with the methods applicable to other sport development pathways, for the purpose of providing more informed TID and development protocols across multiple sports.

## 7.6. References


Abbott, A., & Collins, D. (2002). A theoretical and empirical analysis of a 'state of the art' talent identification model. *High Ability Studies, 13*(2), 156-178. doi:10.1080/1359813022000048798

Baker, D. (1996). Improving vertical jump performance through general, special, and specific strength training: A brief review. *Journal of Strength and Conditioning Research, 10*(2), 131-136. doi: 10.1519/1533-4287(1996)010<0131:IVJPTG>2.3.CO;2

Baker, J., & Logan, A. J. (2007). Developmental contexts and sporting success: birthdate and birthplace effects in national hockey league draftees 2000-2005. *British Journal of Sports Medicine, 41*(8), 515-517. doi:10.1136/bjsm.2006.033977

Baker, J., Schorer, J., Cobley, S., Schimmer, G., & Wattie, N. (2009). Circumstantial development and athletic excellence: the role of date of birth and birthplace. *European Journal of Sport Science, 9*(6), 329-339. doi:10.1080/17461390902933812

Berry, J., Abernethy, B., & Cote, J. (2008). The contribution of structured activity and deliberate play to the development of expert perceptual and decision-making skill. *Journal of Sport and Exercise Psychology, 30*(6), 685-708. doi:10.1123/jsep.30.6.685

Burgess, D., Naughton, G., & Norton, K. (2012). Quantifying the gap between under 18 and senior AFL football: 2003 and 2009. *International Journal of Sports Physiology and Performance, 7*(1), 53-58. doi:10.1123/ijspp.7.1.53

Cobley, S., Baker, J., Wattie, N., & McKenna, J. (2009). Annual age-grouping and athlete development. *Sports Medicine, 39*(3), 235-256. doi:10.2165/00007256-200939030-00005

Corbett, D. M., Bartlett, J. D., O'connor, F., Back, N., Torres-Ronda, L., & Robertson, S. (2017). Development of physical and skill training drill prescription systems for elite Australian Rules football. *Science and Medicine in Football, 2*(1), 1-7. doi:10.1080/24733938.2017.1381344

Cormack, S. J., Mooney, M. G., Morgan, W., & McGuigan, M. R. (2013). Influence of neuromuscular fatigue on accelerometer load in elite Australian football players. *International journal of Sports |Physiology and Performance, 8*(4), 373-378. doi: https://doi.org/10.1123/ijspp.8.4.373

Cormack, S. J., Newton, R. U., McGulgan, M. R., & Doyle, T. L. A. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *International Journal of Sports Physiology and Performance, 3*(2), 131-144. doi: https://doi.org/10.1123/ijspp.3.2.131

Côté, J., Macdonald, D. J., Baker, J., & Abernethy, B. (2006). When "where" is more important than "when": Birthplace and birthdate effects on the achievement of sporting expertise. *Journal of Sports Sciences, 24*(10), 1065-1073. doi:10.1080/02640410500432490

Couceiro, M. S., Dias, G., Araújo, D., & Davids, K. (2016). The ARCANE project: how an ecological dynamics framework can enhance performance assessment and prediction in football. *Sports Medicine, 46*(12), 1781-1786. doi:10.1007/s40279-016-0549-2

Coutts, A. J., Kempton, T., & Vaeyens, R. (2014). Relative age effects in Australian Football League national draftees. *Journal of Sports Sciences, 32*(7), 623-628. doi:10.1080/02640414.2013.847277

Cripps, A. J., Hopper, L. S., Joyce, C., & Veale, J. (2015). Pathway efficiency and relative age in the Australian Football League talent pathway. *Talent Development and Excellence, 7*(1), 3-11.

Davids, K., Araújo, D., Hristovski, R., Passos, P., & Chow, J. Y. (2012). Ecological dynamics and motor learning design in sport. In N. J. Hodges & A. M. Williams (Eds.), *Skill acquisition in sport: Research, theory and practice* (2nd ed., pp. 112-130). New York: Routledge.

Duffield, R., Reid, M., Baker, J., & Spratford, W. (2010). Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *Journal of Science and Medicine in Sport, 13*(5), 523-525. doi:10.1016/j.jsams.2009.07.003

Finnegan, L., Richardson, D., Littlewood, M., & McArdle, J. (2017). The influence of date and place of birth on youth player selection to a National Football Association elite development programme. *Science and Medicine in Football, 1*(1), 30-39. doi:10.1080/02640414.2016.1254807

Garrett, J. M., McKeown, I., Burgess, D. J., Woods, C. T., & Eston, R. G. (2018). A preliminary investigation into the discriminant and ecological validity of the athletic ability assessment in elite Australian Rules football. *International Journal of Sports Science & Coaching, 13*(5), 679-686. doi: https://doi.org/10.1177/1747954117736168

Kotzamanidis, C., Chatzopoulos, D., Michailidis, C., Papaiakovou, G., & Patikas, D. (2005). The effect of a combined high-intensity strength and speed training program on the running and jumping ability of soccer players. *Journal of Strength and Conditioning Research, 19*(2), 369-375.

Newell, K. M. (1991). Motor skill acquisition. *Annual Review of Pychology, 42*(1), 213-237. doi:10.1146/annurev.ps.42.020191.001241

Nibali, M. L., Chapman, D. W., Robergs, R. A., & Drinkwater, E. J. (2013). A rationale for assessing the lower-body power profile in team sport athletes. *Journal of Strength and Conditioning Research, 27*(2), 388-397. doi:10.1519/JSC.0b013e3182576feb

Pankhurst, A., & Collins, D. (2013). Talent identification and development: The need for coherence between research, system, and process. *Quest, 65*(1), 83-97. doi:10.1080/00336297.2012.727374

Portas, M. D., Parkin, G., Roberts, J., & Batterham, A. M. (2016). Maturational effect on Functional Movement Screen™ score in adolescent soccer players. *Journal of Science and Medicine in Sport, 19*(10), 854-858. doi: https://doi.org/10.1016/j.jsams.2015.12.001

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2005). Fitness testing and career progression in AFL football. *Journal of Science and Medicine in Sport, 8*(3), 321-332. doi:10.1016/S1440-2440(05)80043-X

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2006). Positional differences in fitness and anthropometric characteristics in Australian football. *Journal of Science and Medicine in Sport, 9*(1), 143-150. doi:10.1016/j.jsams.2005.10.001

Robertson, S., & Farrow, D. (2017). *A rule induction framework to measure the representativeness of skill practice and performance.* Paper presented at the Complex Systems in Sport, International Congress Linking Theory and Practice, Barcelona.

Robertson, S., Woods, C., & Gastin, P. (2015). Predicting higher selection in elite junior Australian Rules football: The influence of physical performance and anthropometric attributes. *Journal of Science and Medicine in Sport, 18*(5), 601-606. doi:10.1016/j.jsams.2014.07.019

Sullivan, C., Bilsborough, J. C., Cianciosi, M., Hocking, J., Cordy, J., & Coutts, A. J. (2014). Match score affects activity profile and skill performance in professional Australian Football players. *Journal of Science and Medicine in Sport, 17*(3), 326-331. doi:10.1016/j.jsams.2013.05.001

Vickery, W. M., Dascombe, B. J., Baker, J. D., Higham, D. G., Spratford, W. A., & Duffield, R. (2014). Accuracy and reliability of GPS devices for measurement of sports-specific movement patterns related to cricket, tennis, and field-based team sports. *Journal of Strength and Conditioning Research, 28*(6), 1697-1705. doi:10.1519/jsc.0000000000000285

Vilar, L., Araújo, D., Davids, K., & Button, C. (2012). The role of ecological dynamics in analysing performance in team sports. *Sports Medicine, 42*(1), 1-10. doi:10.2165/11596520-000000000-00000

Wattie, N., Schorer, J., & Baker, J. (2015). The relative age effect in sport: A developmental systems model. *Sports Medicine, 45*(1), 83-94. doi:10.1007/s40279-014-0248-9

Woods, C., Joyce, C., & Robertson, S. (2016). What are talent scouts actually identifying? Investigating the physical and technical skill match activity profiles of drafted and non-drafted U18 Australian footballers. *Journal of Science and Medicine in Sport, 19*(5), 419-423. doi:10.1016/j.jsams.2015.04.013

Woods, C., Raynor, A. J., Bruce, L., McDonald, Z., & Collier, N. (2015). Predicting playing status in junior Australian football using physical and anthropometric parameters. *Journal of Science and medicine in Sport, 18*(2), 225-229. doi:10.1016/j.jsams.2014.02.006

Woods, C. T., Raynor, A. J., Bruce, L., McDonald, Z., & Robertson, S. (2016). The application of a multi-dimensional assessment approach to talent identification in Australian football. *Journal of Sports Sciences, 34*(14), 1340-1345. doi:10.1080/02640414.2016.1142668

Woolcock, G., & Burke, M. (2013). Measuring spatial variations in sports talent development: the approach, methods and measures of 'Talent Tracker'. *Australian Geographer, 44*(1), 23-39. doi:10.1080/00049182.2013.765346

# CHAPTER 8 – Appendices

# Appendix A – Variation in match activity profiles figure (Chapters 5 & 7)

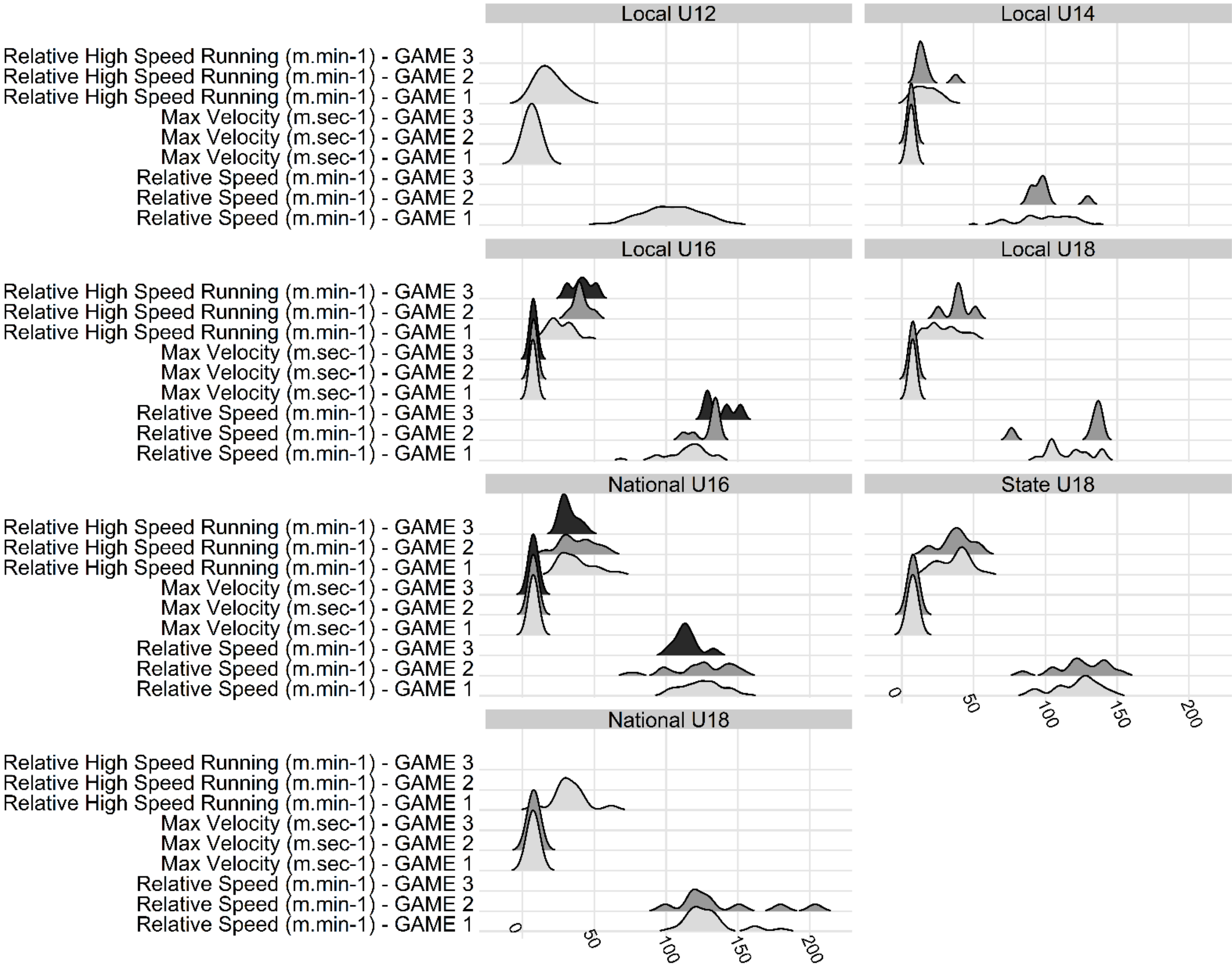


**Fig. A.1.** Variation in match activity profiles for multiple games across for each AFL participation pathway level. *U:* Under

## Appendix B – Effect size (95% Confidence Intervals) tables (Chapter 6)

**Table B.1.** Effect size differences (95% CI) between physical fitness tests of AFL participation pathway levels.

| **5-m sprint** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Local U12** | **Local U14** | **Local U16** | **Local U18** | **National U16** | **State U18** | **National U18** |
| Local U12 | | 0.32 (-0.35-0.98) | -0.97 (-1.95-0.05) | -1.04 (-2.17-0.13) | -0.37 (-1.05-0.32) | -0.31 (-1.02-0.42) | -0.98 (-1.87--0.05) |
| Local U14 | | | -1.31 (-2.09--0.52) | -1.30 (-2.25--0.34) | -0.71 (-1.14--0.27) | -0.63 (-1.12--0.13) | -1.21 (-1.86--0.55)* |
| Local U16 | | | | 0.07 (-1.05-1.19) | 1.10 (0.13-2.02) | 1.22 (0.18-2.21) | 0.24 (-0.66-1.12) |
| Local U18 | | | | | 1.13 (-0.11-2.29) | 1.35 (-0.01-2.63) | 0.21 (-0.84-1.24) |
| National U16 | | | | | | 0.08 (-0.42-0.58) | -0.90 (-1.55--0.24) |
| State U18 | | | | | | | 1.05 (0.25-1.82) |
| National U18 | | | | | | | |
| **10-m sprint** | | | | | | | |
| | **Local U12** | **Local U14** | **Local U16** | **Local U18** | **National U16** | **State U18** | **National U18** |
| Local U12 | | 0.04 (-0.61-0.69) | -1.86 (-3.05--0.62) | -1.77 (-3.05--0.44) | -2.01 (-3.09--0.9) | -1.79 (-2.82--0.72) | -2.45 (-3.76--1.1)* |
| Local U14 | | | -1.65 (-2.45--0.83)* | -1.52 (-2.48--0.55) | -1.6 (-2.11--1.08)* | -1.44 (-1.99--0.88)* | -1.89 (-2.59--1.17)* |
| Local U16 | | | | 0.21 (-0.92-1.33) | 0.58 (-0.25-1.38) | 0.61 (-0.26-1.45) | -0.18 (-1.06-0.71) |
| Local U18 | | | | | 0.36 (-0.62-1.30) | 0.41 (-0.61-1.39) | -0.48 (-1.53-0.63) |
| National U16 | | | | | | 0.07 (-0.43-0.57) | -0.83 (-1.48--0.17) |
| State U18 | | | | | | | 0.88 (0.11-1.62) |
| National U18 | | | | | | | |

| 20-m sprint. | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Local U12** | **Local U14** | **Local U16** | **Local U18** | **National U16** | **State U18** | **National U18** |
| Local U12 | | -0.30 (-0.96-0.37) | -2.69 (-4.14--1.19)* | -3.42 (-5.21--1.58)* | -3.81 (-5.57--2.03)* | -3.69 (-5.42--1.93)* | -4.24 (-6.22--2.23)* |
| Local U14 | | | -1.91 (-2.73--1.07)* | -2.27 (-3.28--1.24)* | -2.54 (-3.18--1.89)* | -2.41 (-3.07--1.74)* | -2.62 (-3.4--1.82)* |
| Local U16 | | | | -0.41 (-1.53-0.74) | -0.32 (-1.09-0.47) | -0.33 (-1.13-0.50) | -0.76 (-1.7-0.23) |
| Local U18 | | | | | 0.20 (-0.75-1.13) | 0.17 (-0.81-1.13) | -0.31 (-1.34-0.76) |
| National U16 | | | | | | -0.03 (-0.53-0.47) | -0.51 (-1.14-0.13) |
| State U18 | | | | | | | 0.47 (-0.23-1.16) |
| National U18 | | | | | | | |

| AFL Agility | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Local U12** | **Local U14** | **Local U16** | **Local U18** | **National U16** | **State U18** | **National U18** |
| Local U12 | | -0.81 (-1.53--0.06) | -3.16 (-4.78--1.5)* | -3.45 (-5.25--1.6) | -4.53 (-6.58--2.46)* | -4.64 (-6.75--2.51)* | -3.77 (-5.57--1.94)* |
| Local U14 | | | -1.51 (-2.3--0.7) | -1.62 (-2.58--0.64) | -2.66 (-3.31--2)* | -2.53 (-3.21--1.84)* | -2.11 (-2.84--1.37)* |
| Local U16 | | | | -0.14 (-1.25-0.98) | -1.15 (-2.09--0.16) | -1.09 (-2.04--0.09) | -0.66 (-1.58-0.3) |
| Local U18 | | | | | -1.00 (-2.11-0.18) | -0.94 (-2.05-0.25) | -0.52 (-1.58-0.6) |
| National U16 | | | | | | 0.08 (-0.42-0.58) | 0.36 (-0.27-0.99) |
| State U18 | | | | | | | -0.29 (-0.96-0.4) |
| National U18 | | | | | | | |

| 20-m Multi-Stage Fitness Test | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Local U12** | **Local U14** | **Local U16** | **Local U18** | **National U16** | **State U18** | **National U18** |
| Local U12 | | 1.37 (0.47-2.23) | 1.88 (0.63-3.07) | 2.23 (0.77-3.63)* | 4.65 (2.53-6.75)* | 3.58 (1.87-5.27)* | 3.04 (1.48-4.56)* |
| Local U14 | | | 0.51 (-0.24-1.26) | 1.06 (0.11-2.00) | 1.89 (1.33-2.44)* | 1.55 (0.98-2.11)* | 1.58 (0.89-2.25)* |
| Local U16 | | | | 0.76 (-0.45-1.92) | 1.96 (0.68-3.2) | 1.42 (0.31-2.47) | 1.43 (0.25-2.55) |
| Local U18 | | | | | 0.82 (-0.29-1.86) | 0.48 (-0.56-1.47) | 0.62 (-0.52-1.7) |
| National U16 | | | | | | -0.22 (-0.72-0.28) | 0.13 (-0.5-0.76) |
| State U18 | | | | | | | -0.28 (-0.95-0.4) |
| National U18 | | | | | | | |

| Vertical Jump | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Local U12** | **Local U14** | **Local U16** | **Local U18** | **National U16** | **State U18** | **National U18** |
| Local U12 | | 1.04 (0.23-1.81) | 3.02 (1.41-4.59)* | 3.50 (1.63-5.32)* | 4.45 (2.41-6.47)* | 4.49 (2.42-6.54)* | 3.92 (2.03-5.78)* |
| Local U14 | | | 1.9 (1.06-2.72) | 1.72 (0.74-2.69) | 2.91 (2.21-3.60)* | 2.46 (1.78-3.13)* | 2.36 (1.59-3.11)* |
| Local U16 | | | | -0.28 (-1.4-0.86) | 0.82 (-0.07-1.67) | 0.28 (-0.54-1.08) | 0.34 (-0.57-1.23) |
| Local U18 | | | | | 1.24 (-0.04-2.45) | 0.76 (-0.36-1.81) | 0.75 (-0.43-1.86) |
| National U16 | | | | | | -0.66 (-1.18--0.14) | -0.46 (-1.09-0.18) |
| State U18 | | | | | | | -0.15 (-0.82-0.53) |
| National U18 | | | | | | | |

| Running Vertical Jump (right) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Local U12** | **Local U14** | **Local U16** | **Local U18** | **National U16** | **State U18** | **National U18** |
| Local U12 | | 0.99 (0.19-1.75) | 3.14 (1.48-4.75)* | 3.81 (1.83-5.74)* | 4.26 (2.3-6.2)* | 5.02 (2.73-7.29)* | 4.23 (2.22-6.21)* |
| Local U14 | | | 1.67 (0.85-2.47) | 1.80 (0.81-2.77) | 2.73 (2.05-3.39)* | 2.98 (2.23-3.72)* | 2.55 (1.76-3.33)* |
| Local U16 | | | | 0.09 (-1.03-1.21) | 0.99 (0.05-1.88) | 1.29 (0.23-2.30) | 0.85 (-0.16-1.81) |
| Local U18 | | | | | 0.94 (-0.22-2.03) | 1.29 (-0.04-2.54) | 0.84 (-0.37-1.98) |
| National U16 | | | | | | 0.22 (-0.28-0.72) | -0.06 (-0.69-0.57) |
| State U18 | | | | | | | 0.29 (-0.40-0.96) |
| National U18 | | | | | | | |

| Running Vertical Jump (left) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Local U12** | **Local U14** | **Local U16** | **Local U18** | **National U16** | **State U18** | **National U18** |
| Local U12 | | 0.93 (0.15-1.68) | 3.81 (1.91-5.67)* | 3.29 (1.49-5.03) | 3.73 (1.98-5.46)* | 3.92 (2.07-5.74)* | 4.01 (2.09-5.9)* |
| Local U14 | | | 2.69 (1.77-3.59)* | 2.29 (1.26-3.3) | 3.10 (2.37-3.82)* | 2.67 (1.96-3.37)* | 3.17 (2.3-4.03)* |
| Local U16 | | | | -0.28 (-1.4-0.86) | 0.55 (-0.28-1.34) | -0.14 (-0.93-0.66) | 0.46 (-0.47-1.36) |
| Local U18 | | | | | 0.83 (-0.29-1.88) | 0.22 (-0.76-1.18) | 0.70 (-0.47-1.80) |
| National U16 | | | | | | -0.73 (-1.25--0.2) | -0.09 (-0.72-0.54) |
| State U18 | | | | | | | -0.68 (-1.39-0.05) |
| National U18 | | | | | | | |

* denoting a significant difference ($p \leq 0.005$) between levels. Threshold values to interpret the magnitude of the ES are; ≥0.2 trivial, ≥0.5 moderate, and ≥0.8 large. CI: Confidence Interval, U: Under

**Table B.2.** Effect size differences (95% CI) between Athletic Ability Assessment movements of AFL participation pathway levels.

**Overhead Squat**

| | Local U12 | Local U14 | Local U16 | Local U18 | National U16 | State U18 | National U18 |
|---|---|---|---|---|---|---|---|
| Local U12 | | 0.35 (-0.33-1.01) | 0.67 (-0.30-1.61) | 1.26 (0.05-2.42) | 0.51 (-0.20-1.20) | 2.07 (0.91-3.19)* | 0.53 (-0.32-1.35) |
| Local U14 | | | 0.47 (-0.28-1.22) | 1.18 (0.23-2.12) | 0.27 (-0.15-0.68) | 1.85 (1.25-2.44)* | 0.29 (-0.32-0.90) |
| Local U16 | | | | 0.59 (-0.59-1.73) | -0.12 (-0.88-0.65) | 1.31 (0.24-2.33) | -0.14 (-1.02-0.75) |
| Local U18 | | | | | -0.65 (-1.64-0.41) | 0.64 (-0.44-1.66) | -0.73 (-1.84-0.45) |
| National U16 | | | | | | 1.24 (0.66-1.80)* | -0.01 (-0.64-0.62) |
| State U18 | | | | | | | 1.43 (0.54-2.29) |
| National U18 | | | | | | | |

**Lunge (right)**

| | Local U12 | Local U14 | Local U16 | Local U18 | National U16 | State U18 | National U18 |
|---|---|---|---|---|---|---|---|
| Local U12 | | 0.59 (-0.12-1.28) | 1.17 (0.11-2.19) | 0.97 (-0.19-2.09) | 1.45 (0.52-2.35) | 2.18 (0.98-3.34)* | 1.5 (0.45-2.51) |
| Local U14 | | | 0.44 (-0.31-1.19) | 0.36 (-0.56-1.28) | 0.70 (0.26-1.13) | 1.33 (0.78-1.87)* | 0.6 (-0.02-1.22) |
| Local U16 | | | | -0.07 (-1.19-1.05) | 0.26 (-0.52-1.02) | 1.01 (0.04-1.94) | 0.18 (-0.71-1.06) |
| Local U18 | | | | | 0.33 (-0.64-1.27) | 1.03 (-0.19-2.17) | 0.25 (-0.81-1.28) |
| National U16 | | | | | | 0.73 (0.20-1.25) | -0.11 (-0.74-0.52) |
| State U18 | | | | | | | 0.92 (0.14-1.67) |
| National U18 | | | | | | | |

**Lunge (left)**

| | Local U12 | Local U14 | Local U16 | Local U18 | National U16 | State U18 | National U18 |
|---|---|---|---|---|---|---|---|
| Local U12 | | 0.35 (-0.33-1.01) | 1.01 (-0.02-2.00) | 1.07 (-0.11-2.20) | 1.17 (0.31-1.99) | 2.6 (1.26-3.91)* | 1.26 (0.27-2.21) |
| Local U14 | | | 0.73 (-0.03-1.48) | 0.58 (-0.35-1.50) | 0.80 (0.36-1.24)* | 1.90 (1.29-2.50)* | 0.85 (0.22-1.48) |
| Local U16 | | | | -0.23 (-1.35-0.90) | 0.04 (-0.72-0.8) | 1.23 (0.19-2.22) | 0.09 (-0.80-0.97) |
| Local U18 | | | | | 0.25 (-0.71-1.18) | 1.85 (0.25-3.38)* | 0.39 (-0.70-1.43) |
| National U16 | | | | | | 1.11 (0.55-1.66) | 0.06 (-0.57-0.69) |
| State U18 | | | | | | | 1.20 (0.36-2.00) |
| National U18 | | | | | | | |

| Push-up | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Local U12** | **Local U14** | **Local U16** | **Local U18** | **National U16** | **State U18** | **National U18** |
| Local U12 | | 0.52 (-0.18-1.20) | 1.23 (0.15-2.26) | 0.53 (-0.56-1.6) | 1.00 (0.19-1.78) | 1.73 (0.68-2.74)* | 0.95 (0.03-1.83) |
| Local U14 | | | 0.91 (0.14-1.67) | 0.03 (-0.89-0.95) | 0.60 (0.17-1.03) | 1.51 (0.95-2.06)* | 0.56 (-0.06-1.17) |
| Local U16 | | | | -0.88 (-2.06-0.35) | -0.24 (-1.00-0.54) | 0.58 (-0.29-1.41) | -0.30 (-1.18-0.6) |
| Local U18 | | | | | 0.54 (-0.49-1.51) | 1.35 (-0.01-2.63) | 0.52 (-0.6-1.58) |
| National U16 | | | | | | 0.82 (0.28-1.35) | -0.06 (-0.69-0.57) |
| State U18 | | | | | | | 0.87 (0.10-1.61) |
| National U18 | | | | | | | |

| Chin-up | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Local U12** | **Local U14** | **Local U16** | **Local U18** | **National U16** | **State U18** | **National U18** |
| Local U12 | | -0.22 (-0.87-0.44) | 2.09 (0.78-3.35) | 0.38 (-0.7-1.44) | 1.04 (0.22-1.83) | 1.38 (0.43-2.29)* | 1.95 (0.76-3.09)* |
| Local U14 | | | 2.61 (1.7-3.5) | 0.61 (-0.32-1.53) | 1.4 (0.9-1.89)* | 1.88 (1.27-2.47)* | 2.38 (1.61-3.14)* |
| Local U16 | | | | -1.59 (-2.94--0.17) | -0.59 (-1.39-0.25) | -0.25 (-1.05-0.56) | -0.18 (-1.06-0.71) |
| Local U18 | | | | | 0.75 (-0.34-1.77) | 1.05 (-0.18-2.2) | 1.51 (0.03-2.91) |
| National U16 | | | | | | 0.32 (-0.19-0.82) | 0.46 (-0.18-1.09) |
| State U18 | | | | | | | -0.11 (-0.78-0.56) |
| National U18 | | | | | | | |

| Single leg Romanian deadlift (right) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Local U12** | **Local U14** | **Local U16** | **Local U18** | **National U16** | **State U18** | **National U18** |
| Local U12 | | -0.28 (-0.93-0.39) | 0.27 (-0.65-1.18) | -0.16 (-1.22-0.9) | 0.78 (0.02-1.51) | 0.92 (0.09-1.72) | 0.30 (-0.52-1.11) |
| Local U14 | | | 0.57 (-0.19-1.32) | 0.12 (-0.8-1.04) | 1.07 (0.6-1.53)* | 1.28 (0.74-1.81)* | 0.58 (-0.04-1.2) |
| Local U16 | | | | -0.40 (-1.52-0.75) | 0.45 (-0.36-1.23) | 0.61 (-0.26-1.45) | -0.01 (-0.89-0.87) |
| Local U18 | | | | | 0.94 (-0.22-2.03) | 1.02 (-0.2-2.16) | 0.46 (-0.64-1.51) |
| National U16 | | | | | | 0.28 (-0.23-0.78) | -0.49 (-1.12-0.15) |
| State U18 | | | | | | | 0.68 (-0.05-1.39) |
| National U18 | | | | | | | |

| Single leg Romanian deadlift (left) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Local U12** | **Local U14** | **Local U16** | **Local U18** | **National U16** | **State U18** | **National U18** |
| Local U12 | | -0.31 (-0.97-0.36) | 0.48 (-0.47-1.4) | -0.01 (-1.07-1.05) | 0.65 (-0.09-1.36) | 0.91 (0.08-1.7) | 0.68 (-0.19-1.52) |
| Local U14 | | | 0.8 (0.04-1.56) | 0.3 (-0.62-1.22) | 0.98 (0.52-1.43)* | 1.28 (0.74-1.81)* | 0.97 (0.33-1.6) |
| Local U16 | | | | -0.51 (-1.64-0.65) | 0.21 (-0.56-0.97) | 0.49 (-0.36-1.31) | 0.15 (-0.74-1.03) |
| Local U18 | | | | | 0.66 (-0.4-1.66) | 0.9 (-0.27-2.00) | 0.73 (-0.45-1.84) |
| National U16 | | | | | | 0.3 (-0.21-0.8) | -0.09 (-0.72-0.54) |
| State U18 | | | | | | | 0.4 (-0.30-1.08) |
| National U18 | | | | | | | |

* denoting a significant difference (p ≤ 0.005) between levels. Threshold values to interpret the magnitude of the ES are; ≥0.2 trivial, ≥0.5 moderate, and ≥0.8 large. CI: Confidence Interval, U: Under

**Appendix C – Published Chapters 3 & 4**

## C.1. Study I, Chapter 3

Haycraft, J., Kovalchik, S., Pyne, D. B., & Robertson, S. (2017). Physical characteristics of players within the Australian Football League participation pathways: a systematic review. *Sports Medicine Open*, 3(1), 46-62. doi:10.1186/s40798-017-0109-9

Haycraft et al. Sports Medicine - Open (2017) 3:46
DOI 10.1186/s40798-017-0109-9

Sports Medicine - Open

SYSTEMATIC REVIEW

Open Access

# Physical characteristics of players within the Australian Football League participation pathways: a systematic review

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## Abstract

**Background:** Australian football (AF) players require endurance, strength, speed, and agility to be successful. Tests assessing physical characteristics are commonly used for talent identification; however, their ability to differentiate between players across the Australian Football League's (AFL) participation pathway remains unclear. The objective of this review was to quantify the physical characteristics of male AF players across the AFL participation pathway.

**Methods:** A search of databases was undertaken. Studies examining tests of physical performance were included, with 27 meeting the inclusion/exclusion criteria. Study appraisal was conducted using a checklist of selection criteria.

**Results:** The 20-m sprint time was the most reported test, followed by vertical jump (VJ), AFL planned agility, and 20-m multi-stage fitness test (MSFT). The fastest times for 20-m sprint were for Elite AFL players (range 2.94–3.13 s), with local-level players the slowest (3.22–4.06 s). State Junior Under (U) 18s (58–66 cm) had higher jumps than senior players, with the lowest jumps reported for Local U10s (mean 31 cm). No elite-level data were reported for the AFL planned agility or 20-m MSFT. AFL planned agility times were only reported for talent pathway levels, with large performance variability evident across all levels (8.17–9.12 s). Only mean 20-m MSFT scores were reported from Local U10s to National Draft Camp (6.10–13.50 shuttles).

**Conclusions:** Talent pathway players exhibit similar mean test scores irrespective of the physical test, with the exception of 20-m sprint and VJ. Physical tests can discriminate between local participation level players but are less useful within the AFL talent pathway.

**Keywords:** Australian rules football, Physical performance, Talent identification, Sport development pathway

## Key points

Players forming the AFL talent pathway performed better in all physical tests than players within the AFL local participation pathway.

Players within the AFL talent pathway demonstrate similar physical performances across junior talent levels irrespective of the physical test, with the exception of 20-m sprint and vertical jump tests.

Physical tests will more effectively discriminate levels of competition between AFL local participation pathway players but are less useful within the AFL talent pathway.

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## Background

Australian football (AF) is a popular team sport in Australia, with selection of players across the participation pathway partially based on physical characteristics and subjective evaluation of playing ability [1]. Game motion analyses indicate that AF is an intermittent team sport characterised by both high-intensity (high-speed running, sprinting, acceleration, agility) and low-intensity activities (standing, walking, jogging) [2–8]. A player's ability to progress through to and perform at the elite level requires high levels of aerobic endurance, speed, strength, power, and agility [8].

The physical performance and anthropometric characteristics of AF players have been well documented, with common physical assessments including sprinting, vertical jumps, agility, and multi-stage fitness tests (MSFT) [9–13].

These tests also form part of the annual Australian Football League (AFL) National Draft Combine, where players are evaluated prior to the National Draft. Small-to-moderate ($r = 0.27$–$0.31$) positive relationships between physical fitness and career progression have been reported in various AF player cohorts [9]. These physical assessments have been primarily conducted not only to inform the selection of players for professional contracts and specific positions, but also to elucidate longitudinal recruiting trends [14].

A review of AF physical performance studies identified a variety of physical test outcomes for players from senior elite, national junior, and state junior levels of AF competition [8]. However, to date, the magnitude of differences in physical performance characteristics along the AFL participation pathway (Fig. 1) has not been reported. Given the prevalence of test use for talent identification and player physical development within the AFL pathway, a review of the relevant literature would help inform recruitment practices [8]. Furthermore, a variety of speed [15–22], agility [12, 23, 24], power [25–31], strength [25, 32–35], movement quality [22, 36–38], and aerobic [15, 39–41] tests have been analysed using AF player samples; however, these tests are not administered using the standardised AFL National Combine protocols. With a large number of studies reporting physical performance measures of AF players across the AFL participation pathway, a review of relevant studies is needed to provide an overview of players' physical characteristics. Furthermore, a detailed analysis of physical performance measures would provide team coaches and support staff (i.e. strength and conditioning coaches and sport science advisors) benchmarks to inform the physical preparation of players at each level of the AFL participation pathway.

The current AFL participation pathway (Fig. 1) involves two streams that funnel athletes into state and elite senior competitions: the *local participation* pathway and the *talent* pathway [42]. Generally, the majority of players transition through the state-based local participation pathway via the following teams: school/clubs/community (5–11 years of age), junior schools/clubs (12–14 years), youth schools/clubs (15–18 years), to open age league/associations (> 18 years) [43]. The talent pathway runs parallel to the local participation pathway, with a smaller cohort of more elite junior players

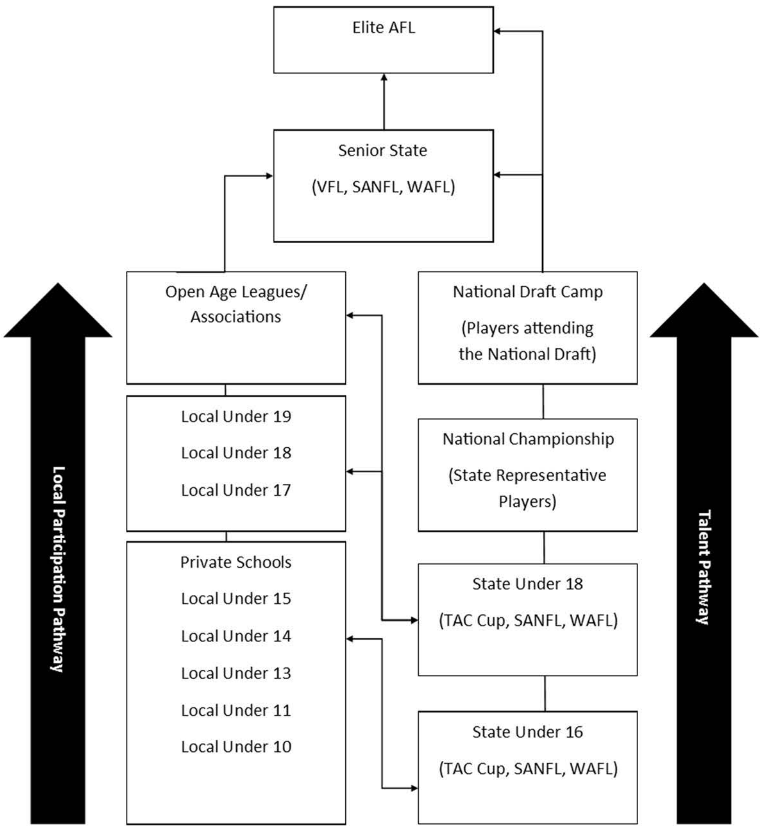


**Fig. 1** The AFL participation pathway adapted from AFL Development [42, 43]. AFL Australian Football League, TAC Transport Accident Commission (Victorian State Junior Football League), VFL Victorian Football League, SANFL South Australian National Football League, WAFL Western Australian Football League

selected for talent pathway squads based on their objective test outcomes and subjective match performance assessments conducted by coaches and talent scouts [44]. The talent pathway is a national program consisting of regional development squads where talented players can transition through to Under (U) 14–16s state championship teams and national U16s and U18s championship teams [42]. Furthermore, talented AF players may be selected for AFL state academies, sporting centres of excellence, and the National AFL academy [10, 42–44]. Players are selected into senior state AF competitions from either the local participation or talent pathways, with elite players primarily selected through the annual AFL National Draft [9]. While the structure of the AFL participation pathway may provide clear local participation and talent pathways for players, no studies have assessed the physical differences between the levels within both pathways using standardised testing methods.

The aim of this article was to conduct a systematic review of the physical test performance of AF players and establish a comprehensive model of differences in physical performance along the AFL local and talent pathways that informs talent selection, recruitment, and fitness program design.

## Methods

### Design

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement was used for this systematic review. The PRISMA allows for improved quality of reporting and evaluation of literature for systematic reviews [45]. Studies investigating physical performance tests for speed, change of direction (COD), power, strength, aerobic, anaerobic capacity, and movement quality of male AF players were assessed for potential inclusion. A detailed outline of the search strategy, and criteria used for inclusion/exclusion of studies for review, is shown in Fig. 2.

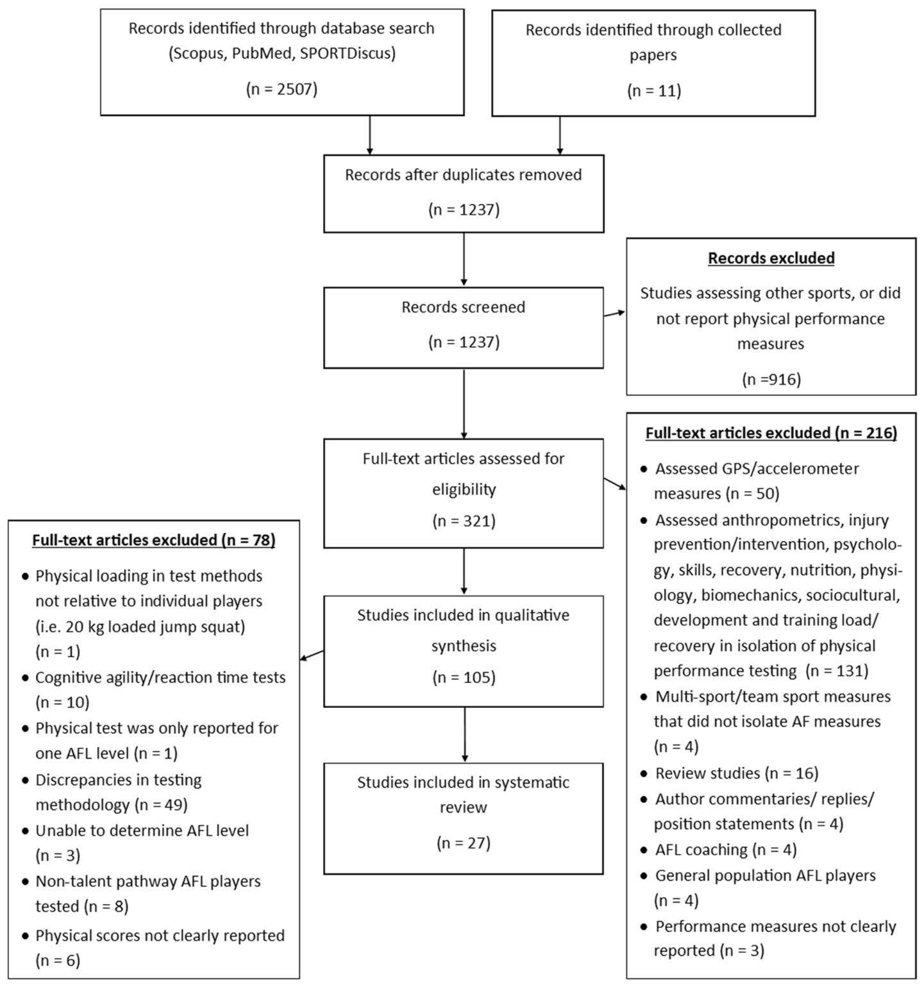


**Fig. 2** PRISMA flow diagram of study search strategy for systematic review of AFL development pathway. AF Australian Football, AFL Australian Football League, GPS Global Positioning System

### Search strategy
A literature search was conducted between August 2015 and March 2017 using SPORTDiscus, PubMed, and Scopus. Key search terms utilised in the search were multiple combinations of AND/OR phrases that included 'Australian', 'football', 'physical', 'performance', and 'talent'. Studies were also identified by examination of citations listed in the collected publications [45].

### Inclusion criteria
The initial search revealed multiple studies as far back as 1970 that investigated physical performance measures of football players. However, no studies prior to 1999 met the inclusion criteria (below) for this review. The final search process specified articles published between 1999 and March 2017. Inclusion criteria for physical performance tests of AF players were as follows: (i) each study had been peer-reviewed and written in English, (ii) abstracts of articles were available, (iii) articles that reported multiple test results were included where results could be extracted and reported in isolation of other tests, and (iv) the testing methods used to collect physical performance data were outlined in detail by the authors.

### Exclusion criteria
Studies were excluded from this review when (i) no physical performance measures for AF players were reported, (ii) AF-specific data were not clearly identifiable, (iii) the article was a review study or author commentary/reply, (iv) the article was an AF coaching-specific study, or (v) the authors tested AF players who had competed in the local participation pathway open age leagues/associations.

### Data extraction
The author list and publication date were recorded for each study identified during the database search. All articles identified in the search were coded as 'Yes' or 'No' to identify those meeting, or possibly meeting, the inclusion/exclusion criteria. Specifically, sample size, participant characteristics (age, height, and body mass), reported player level within the AFL participation pathway, whether the inclusion/exclusion criteria were reported, and the methodology of physical tests were assessed. Articles were further excluded from this review based on the characteristics detailed in the PRISMA statement (Fig. 2).

### Analysis
Mean and standard deviation of the physical performance test measures were extracted using a customised Microsoft Excel™ (Microsoft Corporation, Santa Rosa, CA, USA) spreadsheet. All data from each study were extracted by the lead author (JH). The magnitude of differences in testing values between each of the participation levels was summarised and displayed using forest plots. These plots were developed for each physical test and player group reported by studies across the multiple AFL participation pathway levels. Each point in the forest plot displays the mean and 95% confidence interval (CI) for a specific player group. Any group whose mean score was not contained within the range of the CIs for any other group within the same AFL level was deemed an outlier. Plots were produced using the RStudio® statistical computing software version 1.0.136 (RStudio, Boston, MA, USA). A formal meta-analysis was explored but not presented in the report because exploratory analysis indicated substantial between-study heterogeneity evident in the majority of analyses.

## Results
### Overview of studies
The initial search process yielded 2507 articles, 1237 were screened and 321 underwent a detailed review for eligibility. Data was extracted from 27 studies that met the inclusion/exclusion criteria (Fig. 2). This data included all reported performance measures for the following physical tests: anaerobic power, aerobic power, speed, strength, power, and COD. Extracted physical data was further classified into AFL participation pathway levels based on the team levels reported in each study. Player data was obtained from the following AFL participation pathway levels: 'Elite AFL', 'Senior State', 'National Draft Camp', 'National Championship', 'State Junior U18', 'Private School', and Local 'U19', 'U18', 'U17', 'U15', 'U13', 'U11', and 'U10'.

### Speed
Of the 27 articles reviewed, 20 reported 20-m sprint time across all levels of the AFL participation pathway, with the exception of Private School players. The mean 20-m sprint times across the local participation were observed for the following levels: Local U10 (4.00 s), Local U11 (range 3.90–4.06 s), Local U12 (3.70 s), Local U13 (range 3.70–3.82 s), Local U14 (3.40 s), Local U15 (range 3.30–3.57 s), Local U17 (3.33 s), and Local U19 (3.20 s). Observed mean times were not only slower among the local participation groups, when compared with talent pathway groups, but also more variable (Fig. 3). For example, the difference in the range between means for U15 players was nearly 0.30 s and more than 0.10 s for U13, suggesting greater (variation) inconsistency in sprint performance at the lowest levels of the AFL participation pathway. The slowest observed mean sprint time was reported for the Local U11 group. All mean times from the Local U18 level and below were 3.30 s or slower.

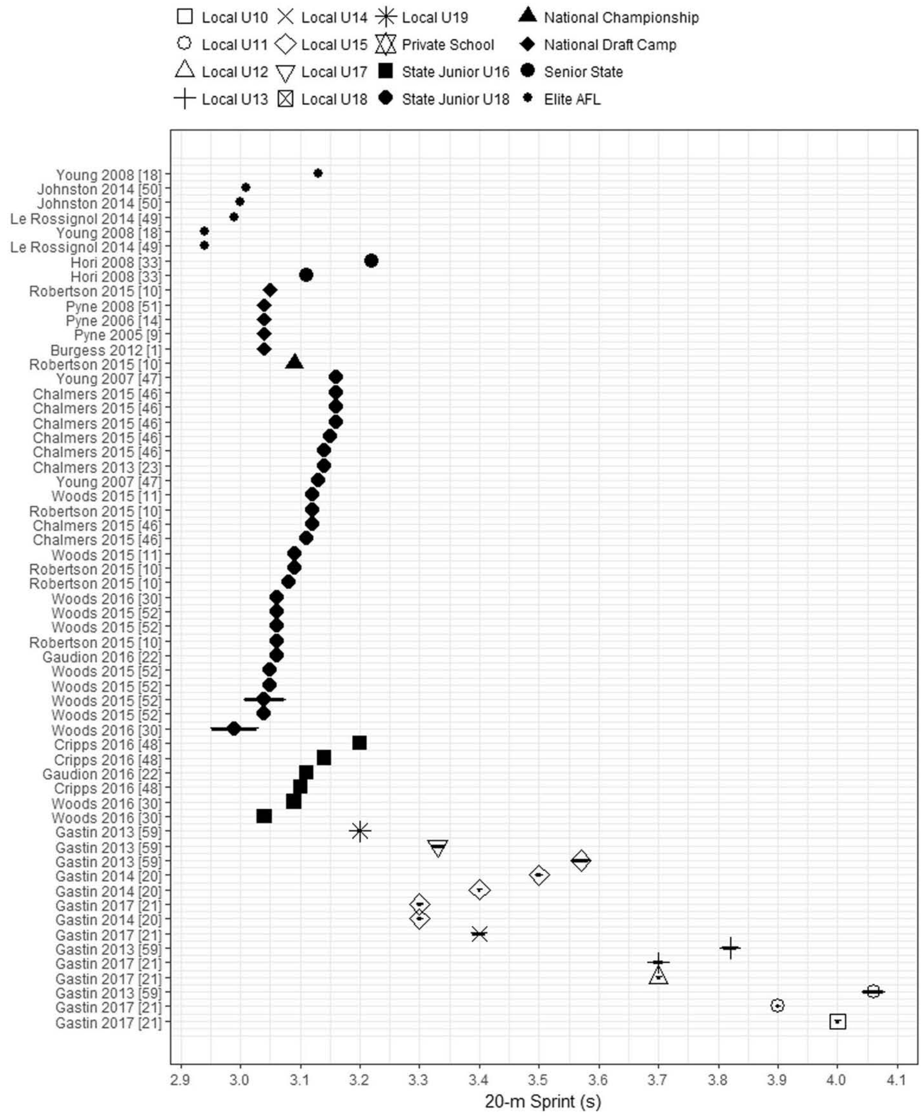


**Fig. 3** Mean and CIs of reported 20-m sprint times across the AFL participation pathway levels. Values are ordered by position in AFL participation pathway, then by sample size reported for each group. All players' levels are shown in the legend for consistency though not all levels may have data on the charted performance measure. AFL Australian Football League, U Under

A substantially faster 20-m sprint time is evident as players transition through the AFL participation pathway from Local U10s to Elite AFL competition. The mean range of elite AFL players' 20-m sprint times was 2.94–3.13 s (Fig. 3). However, one group reported by Young et al. [18] was deemed an outlier within this level, and after removal, the mean range for Elite AFL players was 2.94–3.01 s. The most similar AFL levels in reported 20-m sprint time means and CIs were the State Senior (range 3.11–3.22 s), National Draft Camp (range 3.04–3.05 s), National Championship (mean 3.09 s), State Junior U18s (range 2.99–3.16 s), and State Junior U16s (range 3.04–3.20 s). Multiple studies in these AFL levels had similar 20-m sprint results.

### Change of direction

The AFL planned agility time was stated in 13 (48%) of the 27 studies. Only one study reported local participation pathway levels (Private School), with all others reporting talent pathway levels. The Private School players' mean AFL planned agility time was 8.86 s. Within the talent pathway, no study reported mean AFL planned agility times for Elite AF players, one group reported for State Senior players (range 8.17–8.99 s), four for National Draft Camp (range 8.57–8.63 s), three for National Championship (range 8.61–9.08 s), six reported for State Junior U18 (range 8.37–9.12 s), and one reported for State Junior U16 (8.58 s). The fastest reported AFL planned agility time was recorded for State

Senior level players (Fig. 4); however, the range for mean agility time within the four groups was split, with two groups having a mean time range of 8.17–8.27 s and another two ranged between 8.90 and 8.99 s. The slowest reported mean AFL planned agility time was observed for State Junior U18 players (9.12 s) (see Fig. 4). There was a high degree of variability in the State Junior U18 mean times, with three group times for State Junior U18s (Chalmers and Magarey [46] and two by Young and Pryor [47]) above 8.80 s. All other groups reported mean agility times between 8.37 and 8.74 s. The most consistent mean agility times were observed for the National Draft Camp (range 8.57–8.63 s). The National Championship level reported mean agility times (total range 8.61–9.08 s) were consistent across three of the four reported groups (range 8.61–8.67 s), with one outlier observed reported by Young et al. [24]. All groups' mean agility time and CIs for AFL talent and local participation pathway levels overlapped; as such AFL planned agility performance is similar across these levels.

### Jump tests

Vertical jump performance of AF players was reported in 15 of the 27 reviewed studies (56%), with a number of studies excluded due to variation in testing methods. Only one study reported jump means for Elite and State Senior AF players, respectively, with three studies reporting National Draft level, two studies for National Championship, eight for State Junior U18s, three for State Junior U16s levels, and one for Local U15, U14, U13, U12, U11, and U10s (see Fig. 5).

The lowest reported vertical jump (VJ) means were within the local participation pathway, with a gradual increase in jump height observed with every age competition level increase. The reported jump means within the local participation pathway were as follows: Local

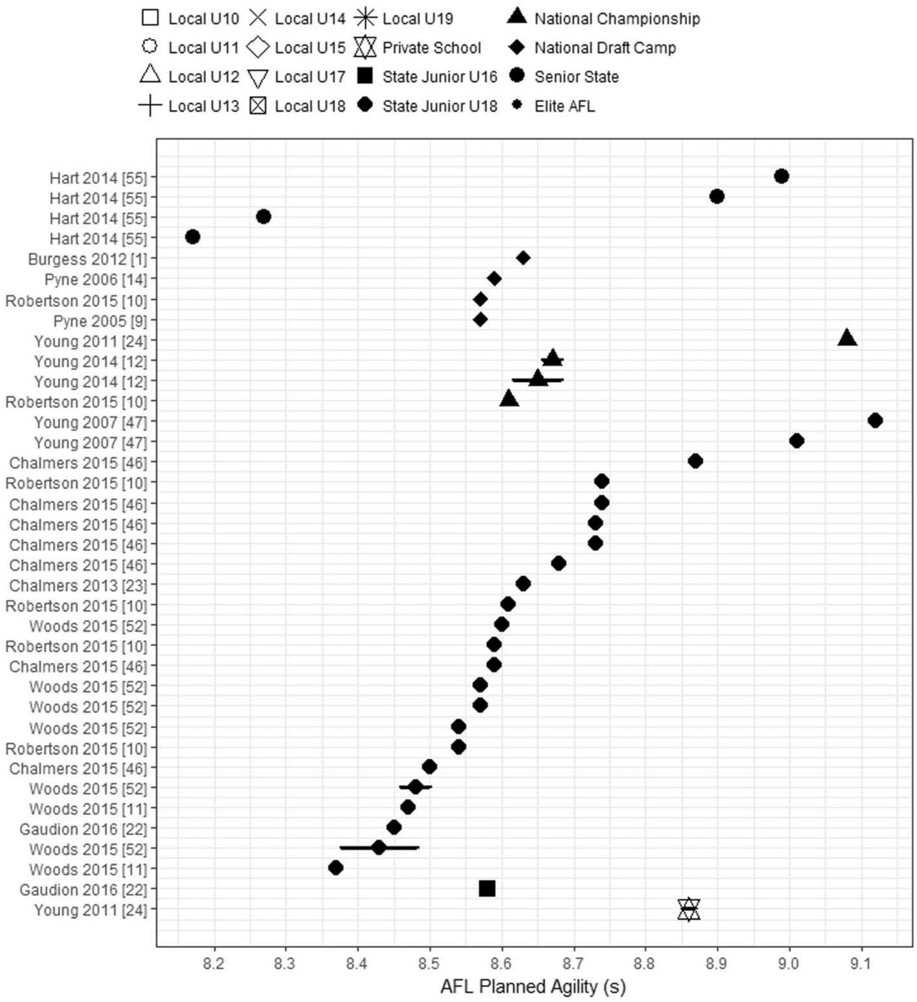


**Fig. 4** Mean and CIs of reported AFL planned agility times across the AFL participation pathway levels. Values are ordered by position in AFL participation pathway, then by sample size reported for each group. All players' levels are shown in the legend for consistency though not all levels may have data on the charted performance measure. AFL Australian Football League, U Under

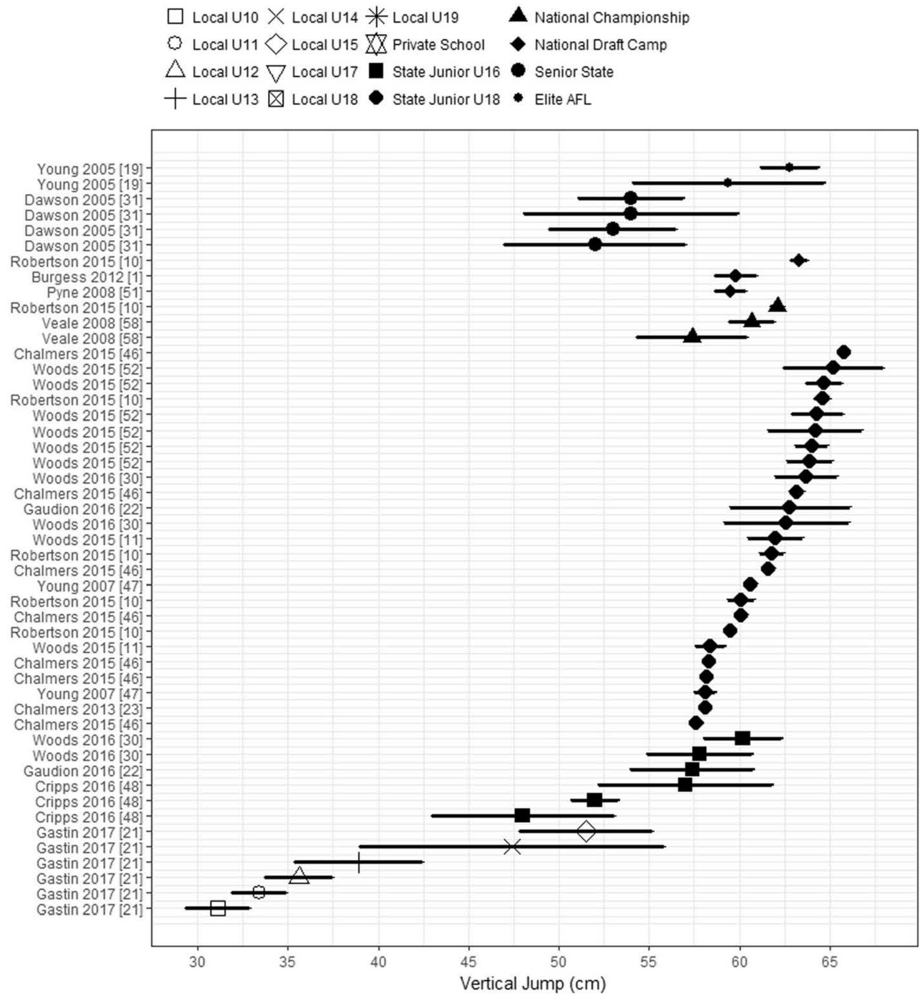


**Fig. 5** Mean and CIs of reported countermovement jump height across the AFL participation pathway levels. Values are ordered by position in AFL participation pathway, then by sample size reported for each group. All players' levels are shown in the legend for consistency though not all levels may have data on the charted performance measure. AFL Australian Football League, U Under

U10 (31 cm), Local U11 (33 cm), Local U12 (36 cm), Local U13 (39 cm), Local U14 (47 cm), and Local U15 (52 cm). Overlap in jump means and CIs between each level within the local participation pathway was observed; therefore, similarities in jump performance are assumed between these players.

The highest mean jump height was observed for the State Junior U18 level (range 58–66 cm). The most overlap observed in reported means and CIs was noted in the State Junior U16 (range 48–60 cm), National Championship (range 57–62 cm), National Draft Camp (range 60–63 cm), Senior State (range 52–54 cm), and Elite AFL (range 59–63 cm). Both the National Draft Camp and State Junior U16 groups appeared to have one outlying study (Robertson, Woods and Gastin [10], and Cripps, Hopper and Joyce [48]). When these outliers were removed, the jump mean was 60 cm for National Draft Camp and range 48–52 cm for State Junior U16s. Multiple studies across the AFL talent pathway levels had overlapping CIs, with jump performance observed to be similar among these levels.

No overlap in reported means and CIs was evident for jump height performance between the Local U10s, U11s, and U12s, when compared with all other levels along the AFL participation pathway. High variability in mean jump heights was noted within the Elite AFL, State Senior, State Junior U16s, and Local U10 to U15s as these levels were observed to exhibit the largest CIs.

Another reported measure was the running vertical jump (RVJ) off the left and right foot, with five of the 27 studies reporting running jump performance (see Table 1). Of these, one reported running RVJ scores for State Junior U16s, five for State Junior U18s, one for National Draft Camp, and one for National Championship level players. No running RVJ measures were reported for Elite and Senior State players. As such, no comparison

**Table 1** Jump performance measures reported for level of AFL participation pathway. Measures represented as mean ± standard deviation

| Study | AFL pathway level | Sample (*n*) | Running vertical jump right (cm) | Running vertical jump left (cm) |
|---|---|---|---|---|
| Robertson et al. [10] | National Draft Camp | 229 | 72 ± 9 | 78 ± 9 |
| Robertson et al. [10] | National Championship | 219 | 71 ± 9 | 76 ± 8 |
| Chalmers and Magarey [46] | State Junior U18 | 247 | 67 ± 8 | 71 ± 8 |
| | | 219 | 67 ± 8 | 70 ± 8 |
| | | 240 | 66 ± 9 | 10 ± 8 |
| | | 240 | 69 ± 8 | 72 ± 8 |
| | | 220 | 69 ± 8 | 73 ± 8 |
| | | 248 | 71 ± 8 | 75 ± 8 |
| | | 300 | 74 ± 8 | 78 ± 8 |
| Chalmers et al. [23] | State Junior U18 | 382 | 66 ± 8 | 71 ± 8 |
| Woods et al. [52] | State Junior U18 | 212 | 72 ± 10 | 79 ± 11 |
| | | | 73 ± 8 | 78 ± 8 |
| | | | 75 ± 9 | 79 ± 9 |
| | | | 71 ± 10 | 77 ± 9 |
| | | | 73 ± 9 | 78 ± 9 |
| | | | 73 ± 9 | 78 ± 9 |
| Robertson et al. [10] | State Junior U18 | 3708 | 67 ± 9 | 72 ± 9 |
| | State Junior U18 | 115 | 70 ± 8 | 74 ± 8 |
| | State Junior U18 | 219 | 73 ± 9 | 79 ± 9 |
| | State Junior U18 | 115 | 71 ± 8 | 75 ± 8 |
| Gaudion et al. [22] | State Junior U18 | 37 | 73 ± 9 | 75 ± 8 |
| Gaudion et al. [22] | State Junior U16 | 40 | 66 ± 6 | 71 ± 6 |

*AFL* Australian Football League, *U* Under

across the entire AFL participation pathway was conducted. The highest running jump score for the right foot was State Junior U18s (mean range 66–75 cm), and for the left (mean range 70–79 cm). The lowest mean scores were recorded for State Junior U16s (right foot 66 cm, left foot 71 cm), with National Draft Camp (right foot 72 cm, left foot 78 cm), and National Championship (right foot 71 cm, left foot 76 cm) players not differing from State Junior U18s. When comparing jump scores for the left and right legs; left leg jumps were higher than those of the right leg for all levels. This trend was found across the State Junior U16s (+ 6 cm), State Junior U18s (+ 4 cm), National Championship (+ 4 cm), and National Draft Camp (+ 6 cm) levels (see Table 1).

### Aerobic

Only 11 articles reviewed reported measures of aerobic fitness using the 20-m MSFT shuttles, with none reporting 20-m MSFT shuttles for Elite and Senior State levels. Mean 20-m MSFT performance was only published for AF players involved in local participation and talent pathway levels (see Fig. 6). Two groups reported the mean number of shuttles achieved for National Draft Camp (range 13.20–13.50 shuttles) and National Championship (12.90 shuttles), seven groups reported for State Junior U18 (range 11.90–13.30 shuttles), two reported State Junior U16 (range 11.08–12.60 shuttles), and four reporting local participation levels' (Local U10 to U19) player scores (range 6.10–12.02 shuttles).

A linear trend was observed (Fig. 6) for 20-m MSFT shuttles in local participation levels, with performance increasing approximately 1 shuttle per age group from U11s (mean range 6.10–6.40 shuttles) to U17s (mean 11.40 shuttles). This trend plateaued as players entered the AFL talent pathway levels. The U10 level (mean 6.40 shuttles) performed slightly better in the 20-MSFT when compared to U11s, despite being a level lower in the local participation pathway. The highest mean 20-m MSFT shuttle reached was observed for the National Draft Camp group (range 13.20–13.50 shuttles). The State Junior U16 (range 11.08–12.60 shuttles), State Junior U18 (range 11.90–13.30 shuttles), National Championship (12.90 shuttles), and National Draft Camp remained consistent in 20-m MSFT test scores range when comparing between these talent pathway levels. Overlap in reported means and CIs for these levels was evident; however, only 8 out of 17 (47%) of the State Junior U18 groups exhibited overlapping CIs with the national level groups. As such, the 20-m MSFT scores between these talent levels were considered to be most similar. No overlap in reported means and CIs were found between the National Championship and National Draft Camp levels, and all other levels reported within the local participation pathway (mean shuttle range 6.10–12.02 shuttles), with the exception of Local U19s (mean 10.70 shuttles). The greatest variability in 20-m MSFT scores was observed within the Local U15 group (range 8.70–11.30 shuttles) and State Junior U16s when compared to all levels across both the entire local participation and talent pathways.

### Strength

Compared to other physical performance measures, reported strength measures across the AFL participation levels were limited. Bench press was the most reported measure, followed by bench pull and back squat (see Table 2). One group reported mean bench pull 1RM measures for Elite AFL (mean 99 kg), one for Senior State (86 kg), and one for State Junior U18s (78 kg). The differences between mean pull strength for Elite and State Junior U18s 1RM was 21 kg with a 13 kg difference between Elite and Senior State players. Mean bench pull 1RM was 8 kg heavier for Senior State than for State Junior U18s. Bench press 1RM was reported for

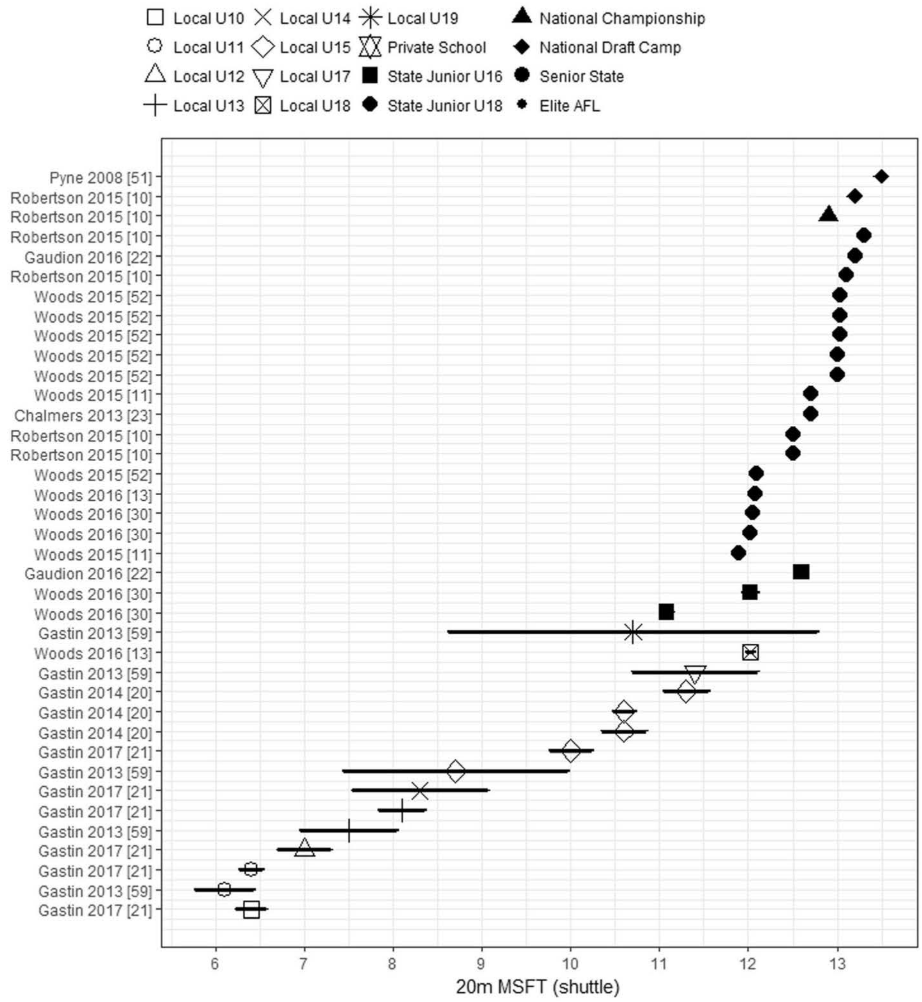


**Fig. 6** Mean and CIs of 20-m MSFT shuttles reached by levels across the local participation and talent pathways. Values are ordered by position in AFL participation pathway, then by sample size reported for each group. All players' levels are shown in the legend for consistency though not all levels may have data on the charted performance measure. AFL Australian Football League, MSFT multi-stage fitness test, U Under

State Junior U18s (mean 88 kg) and Senior State (mean 97 kg) by one group, with two groups reporting Elite AFL 1RM (mean range 103–114 kg). State Junior U18s bench-pressed 9 kg less than State Senior and a further 21 kg less than Elite AFL players, with State Senior pressing 12 kg less than Elite. A comparison of lower body strength across AFL participation pathway levels was not possible as only two groups reported back squat 1RM for elite players, with no performance measures reported for Senior State or levels within the local participation and talent pathways.

## Repeat sprint ability

Studies assessing repeat sprint ability were limited, with only two articles of the 27 reporting repeated sprint times in AF players (see Table 3). The only tests reported across the AFL participation pathway were the 6 × 20 m sprint on 30 s (2 studies), the 6 × 30 m sprint on 20 s (3 studies), and the 6 × 40 m sprint on 15-s test protocols (2 studies). Reported 6 × 20 m sprint times were not different between Elite AFL and Senior State groups, with no studies reporting times for talent or local participation levels. Two groups reported mean total sprint time (s) for 6 × 20 m sprints on 30 s for Elite and Senior State players (range 17.99–19.08 s), with no substantial difference observed. Repeat sprint times were reported for Elite and National Draft Camp level players for the 6 × 30 m sprints on 20 s, with National Draft Camp players' mean total sprint time approximately 0.50 s slower than that of elite players. Two groups reported measures for Elite and Senior State players using the 6 × 40 m sprints on 15 s, with total sprint time similar between these levels (mean range 32.40–37.00 s).

## Movement quality

Movement quality was measured using three different assessments: the Athletic Abilities Assessment (AAA) (1

**Table 2** Reported strength performance measures reported for level of AFL participation pathway. Measures represented as mean ± standard deviation

| Study | AFL pathway level | Sample (*n*) | Bench press (kg) | Bench pull (kg) |
|---|---|---|---|---|
| Bilsborough et al. [25] | Elite AFL | 19 | 109 ± 13.3 | 98.6 ± 5.2 |
| | | 27 | 114 ± 7.2 | 98.5 ± 10.3 |
| Hrysomallis and Buttifant [72] | Elite AFL | 20 | 108.3 ± 13.3 | |
| | | | 102.8 ± 14.0 | |
| | | | 113.8 ± 10.5 | |
| Bilsborough et al. [25] | Senior State | 22 | 96.5 ± 16.6 | 85.8 ± 9.2 |
| Bilsborough et al. [25] | State Junior U18 | 21 | 87.9 ± 12.7 | 77.8 ± 9.6 |

*AFL* Australian Football League, *U* Under

study), a modified AAA (2 studies), and the Functional Movement Screen (FMS) (1 study) (Table 4). Four groups reported movement ability across the AFL participation pathway, with one group reporting for Elite AFL, three for State Junior U18, one for State Junior U16, and one for Local U18 levels, with no other levels reported. The AAA and modified AAA tests use the same movement assessment criteria, with the exception of the chin-up and total AAA score. The scores for the overhead squat, double lunge, single-leg Romanian deadlift, and push-up were compared across multiple AFL participation pathway levels. Elite AFL players performed better on all AAA and modified AAA exercises (mean score ranges: overhead squat 6–9, double lunge 7–9, single-leg Romanian deadlift 6–9, and push-up 8–9). No substantial differences were noted between State Junior U18s, State Junior U16s, and Local U18s for all exercises in the modified AAA (mean score ranges: overhead squat 3–9, double lunge 3–7, single-leg Romanian deadlift 3–7, and push-up 4–9). State Junior U16 and Local U18 scored approximately 1–2 points lower on all modified AAA exercises than Elite AFL players. The AAA was only reported for Elite AFL and State Junior U18 players, with Elite AFL reported to score slightly higher for the chin-up (6–9 points) and total AAA score (45–63 points) than State U18s (chin-up 4–6; total AAA score 37–47). Comparisons of the AAA performance across the AFL participation pathway were not possible as no other AFL levels were reported. Only one group reported the FMS, with State Junior U18s the only level reported. The mean range for the FMS score was 10.9–15.5 out of a possible 21, with no comparison between AFL levels conducted.

**Table 3** Repeat sprint performance measures reported for level of AFL participation pathway. Measures represented as mean ± standard deviation

| Study | AFL pathway level | Sample (*n*) | Repeat sprint ability (s) |
|---|---|---|---|
| Aughey [39] | Elite AFL | 35 | 6 × 20 m sprint on 30 s |
| | | | 18.25 ± 0.26 |
| Elias et al. [77] | Elite AFL | 14 | 6 × 20 m sprint on 30 s |
| | | | 18.53 ± 0.38 |
| | | | 18.62 ± 0.46 |
| | | | 18.63 ± 0.45 |
| Gastin et al. [15] | Elite AFL | 25 | 6 × 40 m on 15 s |
| | | | 35.56 ± 0.91 |
| Gastin et al. [16] | Elite AFL | 69 | 6 × 40 m on 15 s |
| | | | 35.6 ± 1.4 |
| Le Rossignol et al. [49] | Elite AFL | 20 | 6 × 30 m |
| | | | 25.26 ± 0.55 |
| | | | 25.92 ± 0.80 |
| Aughey [39] | Senior State | 35 | 6 × 20 m sprint on 30 s |
| | | | 18.27 ± 0.27 |
| Gastin et al. [16] | Senior State | 69 | 6 × 40 m on 15 s |
| | | | 35.6 ± 1.4 |
| Pyne et al. [51] | National Draft Camp | 60 | 6 × 30 m on 20 s |
| | | | 25.83 ± 0.6 |
| Gaudion et al. [22] | State Junior U18 | 37 | 6 × 30 m on 20 s |
| | | | 26.89 ± 0.98 |
| Gaudion et al. [22] | State Junior U16 | 40 | 6 × 30 m on 20 s |
| | | | 27.64 ± 0.81 |

*AFL* Australian Football League, *U* Under

## Discussion

The overarching aim of this review was to (i) conduct a systematic review of physical test performances measures reported for AF players and (ii) establish differences in physical performance across the AFL participation pathway to inform talent selection, recruitment, and fitness program design. The literature search yielded a relatively small number of articles assessing physical performance measures that used consistent testing methods across multiple studies. Moreover, a large number of articles reporting physical tests in AF players were excluded as testing protocols were not consistent across multiple levels of the AFL local participation and talent pathways. Physical testing of AF players is of particular interest in the identification of talented AF players; however, inconsistency in test protocols is a challenge for researchers and the football community in understanding what is required physically of players as they transition from local to elite competition.

As expected, the fastest reported 20-m sprint time in this review was by the Elite AF players [18, 49, 50]; however, the differences in sprint time between Elite and National Junior players were minimal [1, 9–11, 14, 51]. Junior local level players were consistently slower than Junior National and Elite AFL respectively [10, 11, 21, 23, 46, 47, 52]. This finding is supported by those of Papaiakovou et al. [53] and Dupler et al. [54], where more physically mature

**Table 4** Movement ability measures reported for level of AFL participation pathway. Measures represented as mean ± standard deviation

| Study | AFL pathway level | Sample (n) | Overhead squat (score/9) | Double lunge (score/9) | Single leg Romanian deadlift (score/9) | Push up (score/9) | Chin up (score/9) | Total AAA (score/63) | FMS (score/21) |
|---|---|---|---|---|---|---|---|---|---|
| Woods et al. [38] | Elite AFL | n = 20 | 7.5 ± 1.3 | Left 7.8 ± 0.9<br>Right 7.7 ± 1.0 | Left 7.5 ± 1.5<br>Right 7.3 ± 1.4 | 9.0 ± 0.0 | 7.8 ± 1.6 | 53.2 ± 8.5 | |
| Woods et al. [38] | Elite AFL | n = 14 | 7.5 ± 1.6 | Left 8.0 ± 1.2<br>Right 8.1 ± 1.1 | Left 7.8 ± 1.02<br>Right 7.8 ± 1.2 | 8.7 ± 0.8 | 8.9 ± 0.2 | 55.7 ± 7.4 | |
| Woods et al. [38] | State Junior U18 | n = 13 | 7.0 ± 1.5 | Left 5.8 ± 1.2<br>Right 5.9 ± 1.1 | Left 5.3 ± 1.9<br>Right 5.0 ± 1.2 | 7.6 ± 0.9 | 4.7 ± 1.0 | 41.6 ± 5.1 | |
| Woods et al. [37] | State Junior U18 | n = 25 | 5.2 ± 1.7 | Left 5.5 ± 1.0<br>Right 5.7 ± 0.9 | Left 4.8 ± 1.1<br>Right 4.8 ± 1.1 | 6.3 ± 0.9 | | | |
| Gaudion et al. [22] | State Junior U18 | n = 37 | 5.1 ± 1.2 | Left 5.8 ± 1.0<br>Right 5.7 ± 0.9 | Left 4.1 ± 1.4<br>Right 4.2 ± 1.4 | 5.5 ± 1.1 | | | |
| Chalmers et al. [36] | State Junior U18 | n = 237 | | | | | | | 13.2 ± 2.3 |
| Gaudion et al. [22] | State Junior U16 | n = 40 | 5.4 ± 1.1 | Left 5.6 ± 1.0<br>Right 5.7 ± 0.9 | Left 3.8 ± 1.3<br>Right 3.8 ± 1.1 | 4.9 ± 1.2 | | | |
| Woods et al. [37] | Local U18 | n = 25 | 4.0 ± 0.5 | Left 4.4 ± 1.4<br>Right 4.6 ± 1.1 | Left 4.1 ± 1.2<br>Right 4.2 ± 1.1 | 6.1 ± 0.8 | | | |

*AAA* Athletic Ability Assessment, *AFL* Australian Football League, *FMS* Functional Movement Screen, *U* Under

players between the ages of 14 and 18 years were faster than less mature athletes [53, 54]. Previous studies have reported that 20-m sprint time is purportedly a discriminating factor between drafted and non-drafted players when combined with their 20-m MSFT score [9]. Additionally, 20-m sprint performance is associated with match outcomes across junior state level competitions and players' subsequent selection into higher AF competitions [9, 30, 47]. However, only one group in this review reported 20-m sprint time for Senior State, with their sprint times slower than junior national and state level players, despite the higher competition ranking within the AFL participation pathway [33]. Furthermore, few differences in 20-m sprint performance across the state junior and national levels of the AFL talent pathway were observed in this review. This outcome is supported by previous work showing that sprint time did not contribute to predicting whether a state junior player may be selected for a junior national team [11]. It appears that the 20-m sprint time may not be a discriminating physical characteristic between junior talent levels; however, it may contribute to player selection from local participation in the talent pathway, or junior talent levels into elite AF competition.

The AFL planned agility run course is 21.8 m in length including one 180° and four 90° turns for assessing a player's ability to change direction at AFL talent identification camps [1, 9, 12, 55]. Junior and adult AF players' agility scores were similar across the AFL participation pathway. This is comparable to previous literature, as the AFL planned agility test did not discriminate between drafted and non-drafted AF players, unless players also performed better in the 20-m MSFT and 20-m sprint [9]. Moreover, it has not been shown to be related with career success of players as a stand-alone measure [1]. AFL planned agility time across the 1999–2004 AFL drafts was largely unchanged, despite increases in AF match speeds and improvements in other combine tests (height and 20-m sprint) [14]. However, small- and medium-sized players were slightly faster (effect size (ES) = 0.64–1.11) than taller players or ruckmen. The ability of the AFL planned agility test to identify talented AF players within a positional group is questionable, but it should be useful in discriminating between different positional groups. Shoe surface friction may have influenced the variability in the AFL planned agility tests, with less friction possibly causing a player to slip during a COD test, decreasing their performance [56]. Of the studies reported in this review, only seven [10–12, 22, 46, 47, 52] of the 13 disclosed the surface used to assess player COD, with all using indoor, wooden surfaces. However, when conducting large-scale fitness testing, it is not feasible to supply footwear to players to control for surface friction [57]. As such, surface friction and footwear is a consideration when analysing any COD testing.

The VJ was the second most commonly assessed physical measure reported. However, visually there was greater spread in VJ results within the Elite and Senior State levels when compared across the AFL participation pathway. Studies by Pyne et al. [9] and Burgess, Naughton, and Hopkins [1] reported that VJ performance did not impact on a player's success within elite AFL competition. Relative VJ scores can be counterintuitive, as lower jump scores were reported for players that were drafted to an AFL team, debuted in the elite competition, played more elite level games, and had greater career potential and value [9]. This data may support the variation in VJ performance in the Senior State group, as the training and development of adult AF players may be focused on other physical and skill attributes, and not on their jumping ability.

Inconsistency in VJ performance was also evident across the junior talent pathway, with the greatest disparity in VJ scores in National Draft Camp players [58], and for State U16s players [22, 52]. This variability in results may be caused by differences in the physical maturity levels of the players tested, with ages ranging between 16 and 18 years. Players may be at different pubertal stages, with Gastin et al. [59] reporting AF players within this age group spanned across the fourth and fifth pubertal stages of development (outlined by Duke et al. [60]). Similar differences in VJ performance were also noted by Jones et al. [61], who reported that jump performance increased with biological maturity in males ($r = 0.56$). While VJ performance may not contribute directly to a player's success in the elite AFL completion, it may enhance the success of a player's selection and transition across the AFL talent pathway. Several groups reported that VJ performance was higher in elite junior AF players (state and national levels) than non-selected players [11, 13, 30, 34, 47]. However, other groups reported that VJ does not significantly contribute to the success of players' progression through the AFL talent pathway [9, 10]. The similarity between the VJ scores in this review supports the mixed findings indicating that the VJ is not a highly reliable tool for talent identification of AF players.

This review only reported running endurance performance measures of aerobic capacity, with the 20-m MSFT considered a proxy test for measuring aerobic capacity of individuals [62, 63]. As expected, a gradual increase in 20-m MSFT scores occurred as players progressed along the AFL participation pathway. This increase in aerobic performance was also reported by two groups [20, 59], who found a significant increase in 20-m MSFT with player maturity. Furthermore, large positive correlations ($r = 0.65$) were observed between the biological maturity of junior AF players and 20-m MSFT score [59]. This trend is not restricted to AF players, with similar increases reported across general population males of the same ages [61, 64]. Substantial differences in 20-m MSFT scores were not observed between National Championship, State Junior U18s, State Junior U16s, and Senior State players. This outcome contradicts previous observations showing 20-m MSFT scores contributed significantly to differences between junior national and junior state level players [11] and subsequent draft success of players [10]. While no studies reported shuttle levels achieved for Elite AFL players, predicted maximal oxygen uptake ($VO_{2max}$) ($58.0 \pm 3.2$ mL kg$^{-1}$ min$^{-1}$) from the 20-m MSFT had small associations with career progression of Elite AFL players [9]. Furthermore, Elite AFL player's $VO_{2max}$ range between 51 and 68 mL kg$^{-1}$ min$^{-1}$ [39, 65] when measured using a laboratory-based $VO_{2max}$ treadmill test, with these measures providing a guideline as to the estimated $VO_{2max}$ capacity of Elite AFL players. When comparing local participation level players to players within the talent pathway, there was a larger variability in 20-m MSFT shuttle scores for Local U15 players [59]. The standard deviation of test scores was 3 shuttles for U15, which is almost twofold higher than those of the other groups across the talent pathway levels. This observation is explained partly by variations in biological maturity [59] and pubertal stages [60] of players competing in this age group.

Lower body strength is an underlying physical characteristic that affects force generation, thus influencing both injury prevention and power production in team sport athletes' [33, 66–69]. Unfortunately, only one group [66] reported Elite AFL 1RM back squat and one [33] reported Senior State 1RM front squat as measures of lower body strength. No 1RM strength measures in any lower body exercise were reported for junior and developing AF players. The absence of strength testing literature may relate to concerns regarding the safety and reliability of 1RM testing in inexperienced athletes; however, the 1RM back squat is a reliable measure provided to players who have had 6–12 months of familiarisation with the exercise [70, 71]. Tackling and fending off opponents during AF game play require upper body strength [25, 72]; however, the upper body strength literature was also limited. A gradual increase in bench press and bench pull measures was noted as players progress through the AFL participation pathway. This trend is likely a result of long-term adaptations to specific resistance training [25, 73], in combination with physical maturation of players [74–76]. Clearly, strength development is important in AF players; however, further research is required to profile lower and upper body strength of AF players across the entire local and junior talent pathways.

Repeat sprint ability is considered to be one of the more critical aspects in AFL performance, as the game requires players to repeatedly chase defensively and sprint to create space offensively [8, 15, 49]. Unfortunately, comparisons of repeat sprint ability between AFL participation pathway levels are not possible given inconsistencies across test protocols. One group found repeat sprint ability using the 6 × 30 m sprints on 20 s protocol was a discriminating performance measure between selected and non-selected elite AF player [49]. This protocol is currently used as a test in the annual AFL Draft Combine [51], yet no other studies have determined the relationship between performance in this test, and a players' likelihood of being drafted.

Another two repeat sprint protocols, the 6 × 20 m sprint on 30 s and the 6 × 40 m sprint on 15 s, have been used in the literature [15, 16, 39, 77]. Of these, Aughey [39] and Elias et al. [77] only reported 6 × 20 m sprint results as a profiling tool for Elite and Senior State level players, with no analysis conducted on repeat sprint testing as a talent discriminating factor. Similarly, the 6 × 40 m sprint protocol reported by Gastin et al. [15] and Gastin et al. [16] was assessed in relation to its influence on injury risks of Elite AFL players, predicting match performance. Neither study evaluated this repeat sprint test as a tool for talent identification. Furthermore, Gastin et al. [15] noted that 6 × 40 m sprint protocol was not significantly associated with match performance in elite AF players. It appears the repeat sprint test may not be a reliable tool for assessing whether a player will become a successful AF player. Future research should focus on reporting repeated sprint measures using uniform protocols across the AFL participation pathway levels to allow for meaningful comparisons between groups. This is essential as repeated sprint testing is currently included in the annual AFL National Draft Combine physical testing battery to identify elite AF players.

Movement quality is an underpinning quality of sporting performance, with AF players requiring strong foundation movements such as squats, lunges, pushing, pulling, and bracing to be successful in competition [38, 78, 79]. Movement quality is measured using an objectively assessed criterion to determine if dysfunctional patterns are present [78, 79]. Three movement assessments (AAA, modified AAA, and FMS) were reported for AFL players within the Elite AFL, State Junior U18, State Junior U16, and Local U18 levels [22, 36–38]. The AAA and modified AAA allowed movement comparisons across the abovementioned levels for the following exercises: overhead squat, double lunge, single-leg Romanian deadlift, and push-up. Furthermore, the AAA or modified AAA has been used as a talent identification tool across Elite AFL, State Junior U18, State Junior U16, and Local U18 levels, with junior talent players (State Junior U18 and State Junior U16) exhibiting lesser movement ability than Elite AFL [22, 37, 38]. Woods et al. [37] did find significant differences in AAA scores between State Junior U18 and Local U18 players for the overhead squat, double lunge (both legs), and single-leg Romanian deadlift (right leg). Additionally, a significant effect between State Junior U18 and State Junior U16 levels for the single-leg Romanian deadlift (left leg) (ES = 0.24, $p < 0.05$) and push-up (ES = 0.52, $p < 0.05$) was noted [22]. However, no substantial differences were observed between levels in the junior talent pathway when scores were pooled in this review. The FMS is another movement screening reported by Chalmers et al. [36]; however, this group only examined the association between the FMS and injury risk in State Junior U18 level. Players with observed asymmetrical movements were more likely to sustain an injury during an AF season [36]. Targeting asymmetry in junior players may reduce injury risk and improve athletic performance and development potential as players transition through the AFL participation pathways [36, 37]. While movement ability was found to be similar within the AFL talent pathway, the differences observed between Elite AFL and talent pathway players highlight the importance of developing junior players' movement ability.

The 20-m sprint [18, 49, 50], VJ [19], and 6 × 30 m repeated sprint tests [49] were the only AFL Draft Combine tests reported for Elite AFL players. No elite level data were noted for the AFL planned agility, RVJ, or 20-m MSFT, in spite of these physical performance measures forming the physical component of talent identification [9–14]. The limited number of studies reporting Elite AFL players may suggest that elite clubs place less value on physical performance measures as talent identification tools, or they do not release results of these tests to preserve any competitive advantage. Other studies reported that jump performance [1, 9], 20-m MSFT [9], and AFL planned agility time [1, 14] had small to trivial associations with career progression of Elite AFL players unless combined with performances in other physical tests. Furthermore, repeat sprint [15, 16, 39, 77] and strength [25, 72] tests were reported mainly for Elite AFL players, indicating that elite clubs place more value on developing these physical characteristics in players than on other qualities assessed through the AFL Draft Combine test battery. Physical performance tests were not consistent across the entire AFL participation pathway; as such, a testing battery that can provide valuable insight into physical differences across the AFL participation pathway is required.

## Conclusions

The physical tests reported in this review are currently used to assess physical characteristics of players and their subsequent progress through the AFL participation pathway. Elite AFL data was only reported for the 20-m sprint and VJ, with no other physical test results available. Elite AFL players had the fastest reported means for 20-m sprint time, with local level players the slowest. All other sprint performances were similar across the talent levels (State U16s–Elite AFL), as mean and CIs in sprint time overlapped with each other. For VJ performance, the State U18s had, counterintuitively, greater jump heights than senior level players. The lowest jumps were reported for Local U10s; however, reported means and CIs for VJ heights overlapped across the AFL talent pathway, and thus, VJ performances were largely similar. AFL planned agility times were only available in the talent pathway, with mean performance times similar across all groups. The 20-m MSFT mean scores were only reported from Local U10s to National Draft Camp, with similarities in performance between the AFL levels. Furthermore, a linear improvement was evident within the local participation pathway for 20-m MSFT performance

(1 shuttle per level) as players progressed through the levels. This trend was plateaued when players entered the talent pathway. Finally, players forming the talent pathway performed better in all physical tests than local participation players. However, when assessing levels within the talent pathway, players across different levels tended to exhibit similar mean test scores for each physical test. Physical tests will more effectively discriminate levels of competition between local participation AFL players but are less useful within the AFL talent pathway.

**Acknowledgements**
Not applicable

**Availability of data and materials**
Not applicable.

**Authors' contributions**
Furthermore, all authors met the requirements for authorship in this journal and provided significant contributions to this article. All authors read and approved the final manuscript.

**Funding**
No sources of funding were used to assist in the preparation of this article.

**Authors' information**
Not applicable.

**Ethics approval and consent to participate**
All studies included in this systematic review reported that the ethics approval was obtained from an appropriate ethics committee.

**Consent for publication**
All studies included in this systematic review reported that consent was obtained from all participants regarding their participation and publication of data.

**Competing interests**
Jade Haycraft, Stephanie Kovalchik, David Pyne, and Sam Robertson declare that they have no conflicts of interest relevant to the content of this review. However, David Pyne and Sam Robertson were authors/co-authors of the eight articles included in the analysis.

## Publisher's Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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Received: 14 July 2017 Accepted: 5 November 2017
Published online: 19 December 2017

**References**

1. Burgess D, Naughton G, Hopkins W. Draft-camp predictors of subsequent career success in the Australian Football League. J Sci Med Sport. 2012; doi:10.1016/j.jsams.2012.01.006.
2. Coutts AJ, Quinn J, Hocking J, et al. Match running performance in elite Australian rules football. J Sci Med Sport. 2010; doi:10.1016/j.jsams.2009.09.004.
3. Dawson B, Hopkinson R, Appleby B, et al. Player movement patterns and game activities in the Australian Football League. J Sci Med Sport. 2004; doi:10.1016/S1440-2440(04)80023-9.
4. Wisbey B, Montgomery PG, Pyne DB, et al. Quantifying movement demands of AFL football using GPS tracking. J Sci Med Sport. 2010; doi:10.1016/j.jsams.2009.09.002.
5. Veale JP, Pearce AJ, Carlson JS. Player movement patterns in an elite junior Australian rules football team: an exploratory study. J Sports Sci Med. 2007;6(2):254–60.
6. Boyd LJ, Ball K, Aughey RJ. Quantifying external load in Australian football matches and training using accelerometers. Int J Sports Physiol Perform. 2013;8(1):44–51.
7. Hiscock D, Dawson B, Heasman J, et al. Game movements and player performance in the Australian Football League. Int J Perform Anal Sport. 2012;12(3):531–45.
8. Gray AJ, Jenkins DG. Match analysis and the physiological demands of Australian football. Sports Med. 2010; doi:10.2165/11531400-000000000-00000.
9. Pyne DB, Gardner AS, Sheehan K, et al. Fitness testing and career progression in AFL football. J Sci Med Sport. 2005; doi:10.1016/S1440-2440(05)80043-X.
10. Robertson S, Woods C, Gastin P. Predicting higher selection in elite junior Australian rules football: the influence of physical performance and anthropometric attributes. J Sci Med Sport. 2015; doi:10.1016/j.jsams.2014.07.019.
11. Woods CTE, Raynor AJ, Bruce L, et al. Predicting playing status in junior Australian football using physical and anthropometric parameters. J Sci Med Sport. 2015; doi:10.1016/j.jsams.2014.02.006.
12. Young W, Rogers N. Effects of small-sided game and change-of-direction training on reactive agility and change-of-direction speed. J Sports Sci. 2014; doi:10.1080/02640414.2013.823230.
13. Woods CT, Raynor AJ, Bruce L, et al. The application of a multi-dimensional assessment approach to talent identification in Australian football. J Sports Sci. 2016; doi:10.1080/02640414.2016.1142668.
14. Pyne DB, Gardner AS, Sheehan K, et al. Positional differences in fitness and anthropometric characteristics in Australian football. J Sci Med Sport. 2006; doi:10.1016/j.jsams.2005.10.001.
15. Gastin PB, Fahmer B, Meyer D, et al. Influence of physical fitness, age, experience, and weekly training load on match performance in elite Australian football. J Strength Cond Res. 2013; doi:10.1519/JSC.0b013e318267925f.
16. Gastin PB, Meyer D, Huntsman E, et al. Increase in injury risk with low body mass and aerobic-running fitness in elite Australian football. Int J Sports Physiol Perform. 2015; doi:10.1123/ijspp.2014-0257.
17. Young W, Cormack S, Crichton M. Which jump variables should be used to assess explosive leg muscle function? Int J Sports Physiol Perform. 2011;6(1):51–7.
18. Young W, Russell A, Burge P, et al. The use of sprint tests for assessment of speed qualities of elite Australian rules footballers. Int J Sports Physiol Perform. 2008;3(2):199–206.
19. Young WB, Newton RU, Doyle TLA, et al. Physiological and anthropometric characteristics of starters and non-starters and playing positions in elite Australian rules football: a case study. J Sci Med Sport. 2005; doi:10.1016/S1440-2440(05)80044-1.
20. Gastin PB, Bennett G. Late maturers at a performance disadvantage to their more mature peers in junior Australian football. J Sports Sci. 2014; doi:10.1080/02640414.2013.843016.
21. Gastin PB, Tangalos C, Torres L, et al. Match running performance and skill execution improves with age but not the number of disposals in young Australian footballers. J Sports Sci. 2017; doi:10.1080/02640414.2016.1271137.
22. Gaudion S, Kenji D, Sinclair W, et al. Identifying the physical fitness, anthropometric and athletic movement qualities discriminant of developmental level in elite junior Australian football: implications for the development of talent. J Strength Cond Res. 2017; doi:10.1519/JSC.0000000000001682.
23. Chalmers S, Magarey ME, Esterman A, et al. The relationship between pre-season fitness testing and injury in elite junior Australian football players. J Sci Med Sport. 2013; doi:10.1016/j.jsams.2012.09.005.
24. Young W, Farrow D, Pyne D, et al. Validity and reliability of agility tests in junior Australian football players. J Strength Cond Res. 2011; doi:10.1519/JSC.0b013e318215fa1c.
25. Bilsborough JC, Greenway KG, Opar DA, et al. Comparison of anthropometry, upper-body strength, and lower-body power characteristics in different levels of Australian football players. J Strength Cond Res. 2015; doi:10.1519/JSC.0000000000000682.
26. Buchheit M, Racinais S, Bilsborough J, et al. Adding heat to the live-high train-low altitude model: a practical insight from professional football. Br J Sports Med. 2013; doi:10.1136/bjsports-2013-092559.
27. Caia J, Doyle TLA, Benson AC. A cross-sectional lower-body power profile of elite and subelite Australian football players. J Strength Cond Res. 2013; doi:10.1519/JSC.0b013e3182815743.

28. Cormack SJ, Newton RU, McGulgan MR, et al. Reliability of measures obtained during single and repeated countermovement jumps. Int J Sports Physiol Perform. 2008;3(2):131–44.
29. Crow JF, Buttifant D, Kearny SG, et al. Low load exercises targeting the gluteal muscle group acutely enhance explosive power output in elite athletes. J Strength Cond Res. 2012; doi:10.1519/JSC.0b013e318220dfab.
30. Woods CT, Cripps A, Hopper L, et al. A comparison of the physical and anthropometric qualities explanatory of talent in the elite junior Australian football development pathway. J Strength Cond Res. 2016; doi:10.1016/j.jsams.2016.11.002.
31. Dawson B, Gow S, Modra S, et al. Effects of immediate post-game recovery procedures on muscle soreness, power and flexiblity levels over the next 48 hours. J Sci Med Sport. 2005;8(2):210–21.
32. Hart NH, Nimphius S, Spiteri T, et al. Leg strength and lean mass symmetry influences kicking performance in Australian football. J Sports Sci Med. 2014;13(1):157–65.
33. Hori N, Newton RU, Andrews WA, et al. Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? J Strength Cond Res. 2008; doi:10.1519/JSC.0b013e318166052b.
34. Keogh J. The use of physical fitness scores and anthropometric data to predict selection in an elite under 18 Australian rules football team. J Sci Med Sport. 1999;2(2):125–33.
35. Woods MA, Watsford ML, Cavanagh BP, et al. Factors affecting jump performance in professional Australian rules footballers. J Sports Med Phys Fitness. 2015;55(10):1114–21.
36. Chalmers S, Fuller JT, Debenedictis TA, et al. Asymmetry during preseason functional movement screen testing is associated with injury during a junior Australian football season. J Sci Med Sport. 2017;20(7): 653–7. doi:10.1016/j.jsams.2016.12.076.
37. Woods CT, Banyard HG, McKeown I, et al. Discriminating talent identified junior Australian footballers using a fundamental gross athletic movement assessment. J Sport Sci Med. 2016;15(3):548–53.
38. Woods CT, McKeown I, Haff GG, et al. Comparison of athletic movement between elite junior and senior Australian football players. J Sport Sci. 2015; doi:10.1080/02640414.2015.1107185.
39. Aughey RJ. Widening margin in activity profile between elite and sub-elite Australian football: a case study. J Sci Med Sport. 2013; doi:10.1016/j.jsams.2012.10.003.
40. Bellenger CR, Fuller JT, Nelson MJ, et al. Predicting maximal aerobic speed through set distance time-trials. Eur J Appl Physiol. 2015; doi:10.1007/s00421-015-3233-6.
41. Inness MWH, Billaut F, Aughey RJ. Team-sport athletes' improvement of performance on the Yo-Yo Intermittent Recovery Test Level 2, but not of time-trial performance, with intermittent hypoxic training. Int J Sports Physiol Perform. 2016;11(1):15–21.
42. AFL Community. Participation and talent pathways. 2016. http://www.aflcommunityclub.com.au/index.php?id=26. Accessed 10 May 2016.
43. AFL Community. DraftStar. 2017. http://www.aflcommunityclub.com.au/index.php?id=1771. Accessed 11 Nov 2017.
44. Burgess D, Naughton G, Norton K. Quantifying the gap between under 18 and senior AFL football: 2003 and 2009. Int J Sports Physiol Perform. 2012;7(1):53–8.
45. Moher D, Liberati A, Tetzlaff J, et al. Reprint—Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA statement. Phys Ther Sport. 2009;89(9):873–80.
46. Chalmers S, Magarey M. Annual improvement in fitness test performance for elite junior Australian football cohorts. J Sci Med Sport. 2015;19(10):843–7.
47. Young WB, Pryor L. Relationship between pre-season anthropometric and fitness measures and indicators of playing performance in elite junior Australian rules football. J Sci Med Sport. 2007; doi:10.1016/j.jsams.2006.06.003.
48. Cripps AJ, Hopper L, Joyce C. Maturity, physical ability, technical skill and coaches' perception of semi-elite adolescent Australian footballers. Pediatr Exerc Sci. 2016; doi:10.1123/pes.2015-0238.
49. Le Rossignol P, Gabbett TJ, Comerford D, et al. Repeated-sprint ability and team selection in Australian Football League players. Int J Sports Physiol Perform. 2014; doi:10.1123/IJSPP.2013-0005.
50. Johnston R, Watsford M, Pine M, et al. Standardisation of acceleration zones in professional field sport athletes. Int J Sports Sci Coach. 2014; doi:10.1260/1747-9541.9.5.1161.
51. Pyne DB, Saunders PU, Montgomery PG, et al. Relationships between repeated sprint testing, speed, and endurance. J Strength Cond Res. 2008; doi:10.1519/JSC.0b013e318181fe7a.
52. Woods CT, Robertson SJ, Gastin PB. Does relative age distribution influence the physical and anthropometric profiles of drafted under 18 Australian footballers? An investigation between the 2010 and 2013 seasons. Talent Dev Excellence. 2015;7:83–90.
53. Papaiakovou G, Giannakos A, Michailidis C, et al. The effect of chronological age and gender on the development of sprint performance during childhood and puberty. J Strength Cond Res. 2009;23(9):2568–73.
54. Dupler TL, Amonette WE, Coleman AE, et al. Anthropometric and performance differences among high-school football players. J Strength Cond Res. 2010; doi:10.1519/JSC.0b013e3181e4f9ec.
55. Hart NH, Spiteri T, Lockie RG, et al. Detecting deficits in change of direction performance using the preplanned multidirectional Australian Football League agility test. J Strength Cond Res. 2014; doi:10.1519/jsc.0000000000000587.
56. Damm L, Starbuck C, Stocker N, et al. Shoe-surface friction in tennis: influence on plantar pressure and implications for injury. Footwear Sci. 2014; doi:10.1080/19424280.2014.891659.
57. Dos' Santos T, Thomas C, Jones PA, et al. Mechanical determinants of faster change of direction speed performance in male athletes. J Strength Cond Res. 2017; doi:10.1519/JSC.0000000000001535.
58. Veale JP, Pearce AJ, Koehn S, et al. Performance and anthropometric characteristics of prospective elite junior Australian footballers: a case study in one junior team. J Sci Med Sport. 2008; doi:10.1016/j.jsams.2006.12.119.
59. Gastin PB, Bennett G, Cook J. Biological maturity influences running performance in junior Australian football. J Sci Med Sport. 2013; doi:10.1016/j.jsams.2012.05.005.
60. Duke PM, Litt IF, Gross RT. Adolescents' self-assessment of sexual maturation. Pediatrics. 1980;66(6):918–20.
61. Jones MA, Hitchen PJ, Stratton G. The importance of considering biological maturity when assessing physical fitness measures in girls and boys aged 10 to 16 years. Ann Hum Biol. 2000;27(1):57–65.
62. Wagner PD. Determinants of maximal oxygen transport and utilization. Annu Rev Physiol. 1996;58(1):21–50.
63. Aandstad A, Holme I, Berntsen S, et al. Validity and reliability of the 20 meter shuttle run test in military personnel. Mil Med. 2011;176(5):513–8.
64. Beets MW, Pitelli KHA. Comparison of shuttle-run performance between midwestern youth and their national and international counterparts. Pediatr Exerc Sci. 2004;16(2):94–112.
65. Lorenzen C, Williams MD, Turk PS, et al. Relationship between velocity reached at $VO_{2max}$ and time-trial performances in elite Australian rules footballers. Int J Sports Physiol Perform. 2009;4(3):408–11.
66. Nibali ML, Chapman DW, Robergs RA, et al. A rationale for assessing the lower-body power profile in team sport athletes. J Strength Cond Res. 2013; doi:10.1519/JSC.0b013e3182576feb.
67. Wisløff U, Castagna C, Helgerud J, et al. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. Br J Sports Med. 2004;38(3):285–8.
68. Scase E, Cook J, Makdissi M, et al. Teaching landing skills in elite junior Australian football: evaluation of an injury prevention strategy. Br J Sports Med. 2006; doi:10.1136/bjsm.2006.025692.
69. Orchard J, Marsden J, Lord S, et al. Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. Am J Sports Med. 1997;25(1):81–5.
70. Comfort P, McMahon JJ. Reliability of maximal back squat and power clean performances in inexperienced athletes. J Strength Cond Res. 2015;29(11):3089–96.
71. Kraemer W, Fry A, Ratamess N, et al. Strength testing: development and evaluation of methodology. In: Maud P, Foster C, editors. Physiological assessment of human fitness. Champaign: Human Kinetics; 1995. p. 115–38.
72. Hrysomallis C, Buttifant D. Influence of training years on upper-body strength and power changes during the competitive season for professional Australian rules football players. J Sci Med Sport. 2012;15(4):374–8.
73. Baker DG. 10-year changes in upper body strength and power in elite professional rugby league players—the effect of training age, stage, and content. J Strength Cond Res. 2013; doi:10.1519/JSC.0b013e318270fc6b.
74. Philippaerts RM, Vaeyens R, Janssens M, et al. The relationship between peak height velocity and physical performance in youth soccer players. J Sports Sci. 2006;24(3):221–30.
75. Lloyd RS, Oliver JL, Faigenbaum AD, et al. Chronological age vs. biological maturation: implications for exercise programming in youth. J Strength Cond Res. 2014; doi:10.1519/JSC.0000000000000391.

76. Matthys S, Vaeyens R, Coelho-e-Silva M, et al. The contribution of growth and maturation in the functional capacity and skill performance of male adolescent handball players. Int J Sports Med. 2012;33(7):543–9.
77. Elias GP, Varley MC, Wyckelsma VL, et al. Effects of water immersion on posttraining recovery in Australian footballers. Int J Sports Physiol Perform. 2012;7(4):357–66.
78. Cook G, Burton L, Hoogenboom BJ, et al. Functional movement screening: the use of fundamental movements as an assessment of function—part 1. Int J Sports Phys Ther. 2014;9(3):396–409.
79. McKeown I, Taylor-McKeown K, Woods C, et al. Athletic ability assessment: a movement assessment protocol for athletes. Int J Sports Phys Ther. 2014;9(7):862–73.

## C.2. Study II, Chapter 4

Haycraft, J., Kovalchik, S., Pyne, D. B., Larkin, P., & Robertson, S. (2018). The influence of age-policy changes on the relative age effect across the Australian Rules football talent pathway. *Journal of Science and Medicine in Sport*, 21(10), 1106-1111. doi: https://doi.org/10.1016/j.jsams.2018.03.008

Journal of Science and Medicine in Sport 21 (2018) 1106–1111

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

# The influence of age-policy changes on the relative age effect across the Australian Rules football talent pathway

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ARTICLE INFO

*Article history:*
Received 13 December 2017
Received in revised form 12 February 2018
Accepted 14 March 2018
Available online 21 March 2018

*Keywords:*
Talent identification
Development
Recruitment
Selection bias
Team sport
Birth date distribution

ABSTRACT

*Objectives:* To identify the influence of age-policy changes on the relative age effect (RAE) across the Australian Football League (AFL) talent pathway.
*Design:* Retrospective cross-sectional analysis of junior AFL players attending the National Draft (National), State, and State Under 16s (U16) combines between 1999–2016.
*Methods:* Birth-date data was obtained for players attending the AFL State U16 ($n = 663$, age: $15.9 \pm 0.4$ years), State ($n = 803$, age: $19.1 \pm 1.7$ years), National ($n = 1111$, age: $18.3 \pm 0.8$ years) combines. Corresponding aged-matched Australian general population birth rate data was also collected.
*Results:* A chi-squared analysis comparing birth month distributions found all combine groups differed significantly from the general population (Under 16s: $\chi^2 = 62.61$, State: $\chi^2 = 38.83$, National: $\chi^2 = 129.13$, $p < 0.001$). Specifically, Under 16s had greater birth frequencies for months January to March ($\geq 2\%$, $p < 0.05$), with more State players born in January (4.9%, $p < 0.05$). Age-policy changes at the National level reduced birth distribution bias for some months, however the RAE remained for March, June and July (3.9%, 6.1%, 4.3%, $p < 0.05$). State U16s and National players had 2–9% lower birth frequencies for November–December births compared general population.
*Conclusions:* Selection bias exists towards older players is present at the AFL's State U16, and is maintained at State and National level combines. Age-policy changes are only partially successful at addressing the RAE at the National level, with alternative strategies also recommended in order to address the RAE across the AFL talent pathways.



## 1. Introduction

The relative age effect (RAE) is a demographic characteristic where a bias exists towards selecting athletes born earlier in a defined age group year comparative to those born later.[1–3] The prevalence of the RAE has been described in several team sports (i.e., ice hockey, baseball, soccer, and basketball).[4–6] A common environmental constraint in junior sport is the placement of children into annual age-grouped teams to balance competition between players of similar skill and maturity.[7,8] As such, RAE usually occurs in more physically demanding sports, with up to a year of developmental variation in skill and maturity levels arising amongst players within a single age group.[4,7,9] This developmental variation between chronological age and biological maturation is considered an individual constraint amongst players.[3,5,8] The task constraints within the game, player position, and competition level in Australian football (AF) place value on skill, physical strength, speed, and aerobic capacity. As such AF is susceptible to the RAE within talent development pathways, as there is an increased pressure to identify and select talented players into highly competitive junior state and national competitions.[2,8,10] The consequence of the RAE is that talented late-developers may be overlooked at talent selection points, as early developers exhibit the physical and skill characteristics valued by coaches and talent scouts.[2,11,12]

The Australian Football League (AFL) participation pathway is comprised of the local participation pathway and the talent pathway, with many elite level players progressing through the latter.[13,14] The first major AFL talent selection point is the State

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https://doi.org/10.1016/j.jsams.2018.03.008
1440-2440/

U16, with players recruited from the local participation pathway into a representative team consisting of the most talented players from each Australian State.[13] Talented local level players overlooked at the State U16 level may be invited by the AFL to attend the State and National level combines, with subsequent selection into these development squads.[13,14] Elite AF players are usually selected through the annual AFL National Draft, with most players nominated from National junior teams.[13,15]

Specific to this investigation, a selection bias in birth distributions of National junior players drafted into the AFL has been reported, with more players born in the first half of the selection year (60% vs. 40%).[2] Furthermore, 56% of State junior Under 18 (U18) AFL draftees were born in the first half of the year compared to the second half (44%).[16] Contrary to this, a reverse RAE exists for mature aged AF draftees (those drafted over the age of 20), with 63% born in the first half and 37% in the second half.[2] The bias in birth distribution within junior talent levels of the AFL pathway may be attributed to the differences observed in biological maturation between talent selected and non-selected AF players' of similar age.[2,12,17] These differences have also been observed in local level players aged between 11 and 19 years, with biological maturation having strong positive correlations with 20-m sprint time, aerobic capacity, and high-intensity game running.[12,18] As such, the RAE is linked to athlete dropout rates, with players born later in the selection year having a performance disadvantage compared to older players, thus contributing to them being overlooked for representative AF squads.[1,4,18] However, to date no research has assessed the prevalence of the RAE in the AFL's State U16 level, with further analysis required to determine whether RAE exists within this AFL talent pathway level.

Numerous policy changes have been suggested to eliminate or reduce the RAE in individual and team sports, with many involving the modification of age-groupings for competition.[7,19,20] Further policy change recommendations include; grouping players based on their biological maturity,[19,20] shifting selection dates for talent and elite teams,[7,8,20] and allocating uniform numbers based on the relative age of players.[7] Policy modifications specifically targeting the RAE require sporting organisation's to make dramatic changes to their competition structures, with organisation seeking more simple methods to reduce the RAE.[7] As such, it is difficult to implement and test these policy changes within a sporting organisation's talent identification structure, leading to limited research regarding the impact of policy change on reducing the RAE.[7] Some studies have found changing selection dates only shifted the bias to the first month of the new selection year.[10,21] However, selection bias in junior soccer was reduced when numbering players shirts according to their relative age within the team, allowing talent scouts to clearly identify early and late developing players.[7]

The AFL have implemented two changes (in 2003 and 2008, see Table 1) to talent selection policies between 1999 and 2016. These policy changes were specifically aimed at minimising the impact of the RAE on players transitioning through the development pathway. The policies imposed restrictions on the age in which players were invited to attend National Draft camps, and elite club's ability to select players through the AFL's National Draft. However, to date there is no empirical evidence concerning the impact these policy changes had on reducing the RAE.

While there is evidence of the RAE in AF, no studies have analysed the RAE in the modern era (past 17 years) of the AFL's National, State, and State U16 testing combines. The annual combines are physical and skill testing days for talent identification of elite (National) and sub-elite (State) junior players, as well as being the entry point into the AFL's talent pathway (U16s).[15,22,23] The point at which the RAE originates within the AFL talent pathway should be identified to allow more targeted selection interventions that address the RAE. It is unknown whether the distribution of players selected to participate from each year quartile differs between those at the National, State, and U16 combines. Furthermore, it is unclear whether the age-policy changes regarding players invited to the AFL National Draft has affected the RAE at this level. The aim of this study was to (i) determine the prevalence of the RAE across the AFL talent pathway between 1999 and 2016, and (ii) analyse the influence that age-policy changes of National Draft invitees have had on the RAE at the National level.

**Table 1**
AFL National Draft Combine birth month codes based on player invitee age rules and policy changes between 1999 to 2016.

| Draft years | Analysis sub-section | Draft selection rule |
|---|---|---|
| 1999–2003 | Pre-2003 | Players required to turn 17 years by June 30 |
| 2004–2008 | 2004–2008 | Players required to turn 17 years by April 30 |
| 2009 | Post-2009 | New AFL team introduced (Gold Coast Suns, GC) – able to select 12 players turning 17 years by 1st January<br>All other players required to turn 18 years in draft year |
| 2010 | Post-2009 | New AFL team introduced (Greater Western Sydney, GWS) – able to select 12 players turning 17 years by 1st January<br>All other players required to turn 18 years in draft year |
| 2011 | Post-2009 | GC trade rights to 2 players aged 17 years by 1st January<br>All other players required to turn 18 years in draft year |
| 2012 | Post-2009 | GWS trade rights to 2 players aged 17 years by 1st January<br>All other players required to turn 18 years in draft year |
| 2013–Current | Post-2009 | All players turn 18 years in draft year |

## 2. Methods

This study used a retrospective cross-sectional analysis to assess the RAE and impact of the AFL's age-policy changes within the junior National, State, and State U16s combines held between 1999 and 2016. Date of birth (DOB) data was obtained for players attending the AFL National Combine ($n = 1111$, age: $18.3 \pm 0.8$ years), State Combine ($n = 803$, age: $19.1 \pm 1.7$ years), and State U16 Combine ($n = 663$, age: $15.9 \pm 0.4$ years). National player data was available for all years between 1999–2016, with State and State U16 player data only available between 2004–2016 and 2008–2016 respectively. Players were classified by the Combine level they attended (National, State, State U16), then further classified into birth month (1 to 12; starting with January as '1'), and quartile (Q1: January–March, Q2: April–June, Q3: July–September, Q4: October–December) categories.

The frequency of male births by month in the general population was obtained from statistics on monthly live births between 1981 and 2000 reported by the Australian Bureau of Statistics.[24] Birth statistics were calculated for three different periods to match (as close as possible) the birth cohorts for the three combine groups: the AFL National Combine (birth years 1981–1998), the State Combine (birth years 1985–1997), and State U16 Combine (birth years 1992–2000). Ethics approval for this research was obtained by the Victoria University Human Research Ethics Committee.

Changes in age eligibility policies that effects a players' invitation to an AFL National Draft Combine between 1999 and 2016 were accounted for within the analysis. The policy changes imposed by the AFL regarding age of eligible Draft attendees are presented in Table 1. To account for age-related policies imposed on player attendance at the Draft for a given year, three periods were identified between 1999 and 2016. Pre-2003 was considered as between 1999–2003, where players were required to turn 17 years by June 30. The second policy period was determined as the years between 2004–2008, where player eligibility based on birth month was shifted from June to April and players were required to turn 17 years by April 30. Post-2009 was established as the years between 2009–2016, with all eligible players required to turn 18 by December 31st in the year of the draft. Within each period, National Combine players were further divided into 17 and 18-year-old sub-groups for analysis, as eligibility policies differed by birth year. For example, with the pre-2003 only those 17-year-olds born before July could be observed. Since 100% of the 17-year-olds were to fall between January–July, the general population proportions in Q1 and Q2 are normalized to sum to 100% in the pre-2003 comparison. All 17-year-olds were excluded from analysis in Post-2009 as, during these years, the acquisition of 17-year-olds became limited to trades for a select number of teams and were eliminated from 2013 on.

All statistical analyses and figures were conducted and produced using RStudio® statistical computing software version 1.0.136 (RStudio, Boston, Massachusetts). Differences in the Combine and age-matched general population birth month and quartile frequencies were assessed with chi-squared ($\chi^2$) analyses. Comparisons were conducted separately for National (18-year-old players only), State, and State U16 groups. A p-value of $<0.05$ was the criteria for a significant difference in distributions (global difference). To understand the time-periods contributing to global differences, individual proportion tests were undertaken for each birth month and quartile against its general population estimate.[25] When global differences were found in birth distributions, these further analyses were used to interpret where and in what direction the largest differences occurred. Odds ratios (OR) were used as the effect size for the relative age effect and were calculated as the player sample odds against the Australian general population odds for each AFL player level.

For the National Combine group, further chi-squared analysis was conducted to account for the varying eligibility rules for 17 and 18-year-olds (Table 1). In these analyses, separate groups were created for 17 and 18-year-olds for Pre-2003 (18y: n = 211, 17y: n = 104), 2004–2008 (18y: n = 195, 17y: n = 58) and Post-2009 (18y: n = 435, 17y: n = 46) based on the associated age-policy changes for 17 and 18-year-olds in the National Combine sub-group. For the Pre-2003 and 2004–2008 periods, 17 and 18-year-olds in the National Combine sub-group were separated. The birth month of this sub-group was contrasted against the general population, adjusting for any non-eligible months in the 17-year-old group (Pre-2003: July–December; 2004–2008: May–December). Strict cut-off dates with respect to birth month only affected 17-year-olds, as such global redefinition of the month/quartile categories was not undertaken for all birth-year groups. Instead, the general population birth month proportions were adjusted to reflect the truncation due to eligibility rules for all comparisons against the 17-year-old birth-year group. The 18-year-old players were compared against all months in the general population, with no age restrictions placed on this group. This allowed for normalising of the year proportions for the 17-year-olds for all years prior to 2008.

In addition to assessing the players separately by birth-year group, a combined analysis was also performed with the 17 and 18-year-olds for the National players. In these analyses, the combined proportion of players in a given birth month (quartile) and rule period were compared against an adjusted general population comparison, which was equal to the weighted average of the general population comparisons used in the birth-year specific comparisons, with weight equal to the proportion of each birth-year of the player sample and period. A Chi-squared test was performed to determine the overall agreement between the combined player birth month (quartile) distributions against the general population for each period.

## 3. Results

The birth month distribution for the Under 16s player group differed significantly from the distribution in the age-matched general population ($\chi^2 = 62.61$, $p < 0.001$, Fig. 1). The month-by-month comparisons of State U16s birth distributions showed higher representation in the first months of the year and a lower representation in the later months of the when compared with the general population. Also, more players (>2%) were born in January (n = 81, OR: 1.53), February (n = 67, OR: 1.32) and March (n = 75, OR: 1.33) compared to those born in the general population (Fig. 1). Similarly, the months of November (n = 32, OR: 0.59) and December (n = 19, OR: 0.34) had birth month frequencies 3% or less ($p < 0.05$) than the general population (Fig. 1).

Year-quartile distributions differed significantly between the Under 16s and the age-matched general population (Fig. 1; $\chi^2 = 50.80$, $p < 0.001$). Higher frequencies in birth rates were observed for Q1 (8.7%, n = 223, OR: 1.53, $p < 0.05$) and Q2 (3.6%, n = 189, OR: 1.20, $p < 0.05$) (see Fig. 1). Furthermore, the frequencies were less (−9.8%, n = 98, OR: 0.53, $p < 0.05$) for Q4 than the age-matched general population (Fig. 1). There were only trivial differences in birth month distributions for Q3 between the U16s and general populations. Between quartile comparison found differences between all quartiles, the largest observed difference being between Q1 and Q4 (OR: 2.92). However slight decreases in birth distribution occurred between each quartile (Q1vQ2 OR: 1.26, Q1vQ3 OR: 1.72, Q2vQ3 OR: 1.37, Q2vQ4 OR: 2.31, Q3vQ4 OR: 1.69).

Like the Under 16s there were substantially different patterns of birth month distributions for State Combine players compared with the general population both by month ($\chi^2 = 38.83$, $p < 0.001$, Fig. 1) and quartile (State, $\chi^2 = 22.47$, $p < 0.001$, Fig. 1). The main differences between the State players and general population were found in January (4.9%, n = 106, OR: 1.69, $p < 0.05$) and November (−2.4%, n = 44, OR: 0.67, $p < 0.05$), with no substantial differences in frequency observed for any other month (see Fig. 1). The State level demonstrated similar patterns as the Under 16s group for Q1; with more births in Q1 (7.2%, n = 257, OR: 1.43, $p < 0.05$) than the age-matched general population (Fig. 1). However, the distributions for State level was less consistent across Q2–Q4 (Q2: n = 181, Q3: n = 189, Q4: n = 176), with only trivial differences observed between player birth distributions and the age-matched general population. Comparison between State player birth quartiles found Q1 with substantially more players compared to Q2, Q3 and Q4 (Q1vQ2 OR: 1.58, Q1v Q3 OR: 1.49, Q1v Q4 OR: 1.67). Quartiles Q2–Q4 were all similar in distribution (OR: 0.95–1.12).

The distribution of birth month for 18-year-old National Combine players between 1999 and 2016 was substantially different to the general population both by month ($\chi^2 = 129.13$, $p < 0.001$) and quartile ($\chi^2 = 98.01$, $p < 0.001$) (see Fig. 1). Furthermore, more players were born in March (2.1%, n = 91, OR: 1.26), June (3.0%, n = 94, OR: 1.40), and July (2.2%, n = 90, OR: 1.29), but less in November and December (−6.8% each, November: n = 9, OR: 0.13, December: n = 11, OR: 0.15, $p < 0.05$) than the general population (Fig. 1). Every quartile for the National group was substantially different to the age matched general population. Specifically, quartiles 1, 2 and 3 all had more players born (Q1: 5.5%, n = 255, OR: 1.32, Q2: 4.4%, n = 247, OR: 1.25 and Q3: 4.8%, n = 255, OR: 1.27, $p < 0.05$, Fig. 1) than the general population, with quartile 4 having substantially less National players (−14.7%, n = 83, OR: 1.34, $p < 0.05$) born. Comparing between National player birth quartiles, Q1vQ2 (OR: 1.05), Q1vQ3 (OR: 1.00), and Q2vQ3 (OR: 0.95), were all similar. How-

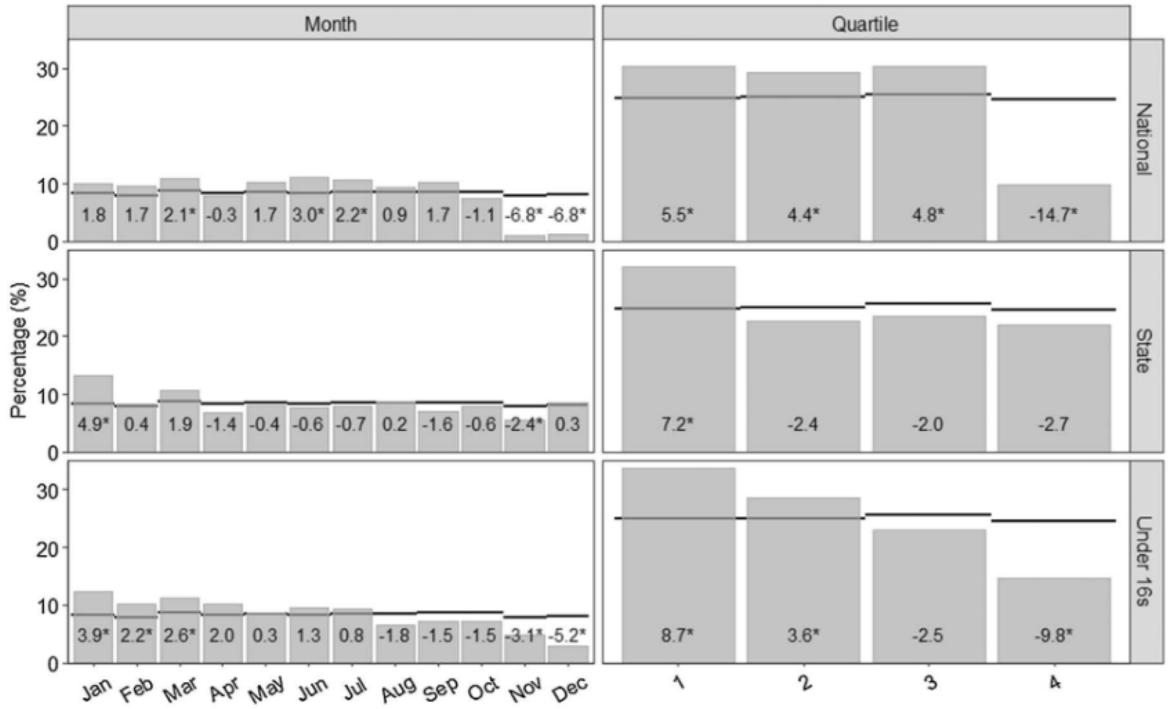


**Fig. 1.** Birth month and quartile distribution of AF players attending the National, State, and State U16 combine tests between 1999 and 2016 compared with the Australian general population birth distribution (black line). Differences in percentage between players born per month and the Australian population is noted within the bars. *P < 0.05.

ever, Q4 had substantially less player than Q1, Q2 and Q3 (Q1vQ4 OR: 3.86, Q2v Q4 OR: 3.68, Q3v Q4 OR: 3.86).

A significant difference between the birth month observed and expected 17 and 18-year-old proportions and the Australian general population for each and age-policy period (Pre-2003: $\chi^2 = 27.10$, 2004–2008: $\chi^2 = 48.23$, Post-2009: $\chi^2 = 69.95$, $p < 0.05$). Similar differences were also found for observed and expected birth quartiles (Pre-2003: $\chi^2 = 14.53$, 2004–2008: $\chi^2 = 29.31$, Post-2009: $\chi^2 = 54.61$, $p < 0.05$). The greatest monthly difference between observed and expected 17 and 18-year-old proportions and the general population for Pre-2003 was in January (2.7%), March (2.1%), November (−4.3%) and December (−4.1%). The greatest monthly differences for 2004–2008 were found in June (4.7%), February (3.6%), July (3.3%), November (−5.4%) and December (−6.3%). Post-2009 was similar with the largest differences observed for January (3.9%), November (−6.7%) and December (−6.5%), when compared to the general population.

Quartile comparisons for each age-policy period also had significant differences between the birth month observed and expected 17 and 18-year-old proportions and the Australian general population (Pre-2003: $\chi^2 = 14.53$, 2004–2008: $\chi^2 = 29.31$, Post-2009: $\chi^2 = 54.61$, $p < 0.05$. For Pre-2003, the largest difference between observed and expected pooled 17 and 18-year-old players and the general population was found in Q1 (4.8%) and Q4 (−8.0%). Between 2004–2008 the greatest observed difference was noted for Q1 (4.9%), Q3 (5.6%), and Q4 (13.1%), and for Post-2009 being Q1 (8.0%) and Q4 (−14.9%) when compared to the general population.

The National combine players birth rate distribution was partially impacted by the age-policy changes imposed by the AFL, as differences in birth distribution were not isolated to the first half of the selection year after the policies were modified. However, within the 18-year-old sub-group (Pre-2003, 2004–2008, and Post-2009), substantial differences remained in age-matched birth month distributions across all three policy periods (Pre-2003: $\chi^2 = 29.74$, 2004–2008: $\chi^2 = 46.18$, Post-2009: $\chi^2 = 70.28$, Fig. 2). Specifically, when compared to the general population, significantly more 18-year-old players were observed to be born in June (6.1%, n = 28) and July (4.3%, n = 25) during the 2004–2008 age-policy restriction, and in March (3.9%, n = 55, $p < 0.05$) of the Post-2009 age restrictions. No other differences in birth distribution between the National 18-year-olds and general population were observed. Furthermore, age-policy changes did not affect player birth distributions for November (Pre-2003: −6.5%, n = 3, 2004–2008: −6.9%, n = 2, and Post-2009: −6.7%, n = 5, $p < 0.05$) or December (Pre-2003: −6.2%, n = 4, 2004–2008: −8.1%, n = 0, and Pre-2009: −6.5%, n = 7, $p < 0.05$), with significantly less players born in these months compared to the general population.

The AFL imposed age-policy changes did not affect birth month distribution for the 17-year-old National players as several months found significant differences between players and the general population. Birth month distributions for the 17-year-old National players found no substantial differences between birth frequencies and the general population for either policy period (Pre-2003: $\chi^2 = 6.53$, 2004–2008: $\chi^2 = 4.17$, Fig. 2). Similarly, no difference was observed for individual month distribution Pre-2003 or 2004–2008 for the 17-year-old group.

## 4. Discussion

The aim of this study was to identify the origins of the RAE, and effect of age-policy interventions on birth month distributions of AFL players selected to attend the National, State and State U16 combines between 1999 and 2016. This study compared player birth month representation with what would be expected in the absence of the RAE. Testing this required comparison of the birth month distribution against the age-matched Australian general population for each given year. For all three levels of the AFL talent pathway, substantially more players were born earlier in the year than the accompanying age-matched Australian birth rates. Despite policy changes implemented by the AFL that modified the age of players invited to participate in the AFL National Draft Combine, the RAE was also evident in both the State and State U16s levels

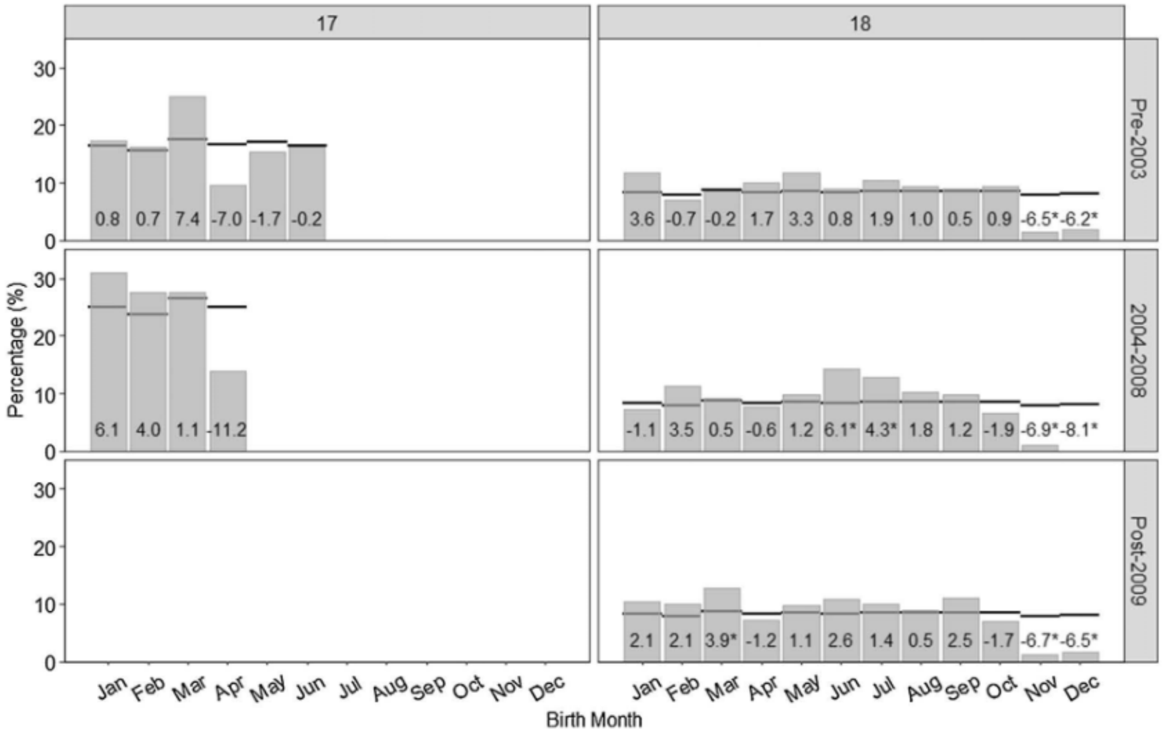


**Fig. 2.** Effect of the implementation of age-policy changes between 1999 and 2016 on birth month distribution of 17 and 18-year-olds attending the AFL National Draft Combine. Monthly player birth rates are compared with the Australian general population (black line), with the percentage differences noted within the bars. *P < 0.05.

prior to reaching National level. It should also be noted that age-policy changes did not influence birth distribution at the National level. These findings have implications for the selection of players into the AFL talent pathway as those born earlier in the selection year are more likely to be chosen than those born later in the selection year. Furthermore, age-policy changes may not have an effect on birth distribution at the National level as the RAE is occurring earlier in the AFL talent pathway.

The birth rate distribution favouring earlier months in the year was observed at the State U16 combine levels. As the State U16 combine is considered one of the first talent selection points of the AFL talent pathway, it is evident that RAE effect is occurring for players aged 15 and 16 years. Like other sports and age brackets, AFL players born earlier in the year are more likely to be selected into a State U16 competition.[3,10,26] This phenomenon is partially explained by variability in biological maturity of players creating differences in anthropometric measures, running fitness, and match running performance in AF players aged 14–16 years.[18] Furthermore, late maturing AF players under 19 years are at a physical disadvantage when compared with their early maturing counterparts.[12,18] Similarly, longitudinal evaluations of anthropometric and physical characteristics of adolescent rugby league players indicated early maturing players were larger and exhibited superior physical performances than late maturing players.[26] A similar scenario in junior AFL may explain the occurrence of RAEs within the State U16s competition, as early maturing athletes are more likely to be selected into the AFL's talent pathway.

The RAE was also observed in the State and National level combines, with birth rate of players in these levels favouring the first quartile of the year. However, when comparing by month, the State level players exhibited a more balanced birth rate distribution than the National and State U16 players, with only January showing a higher birth rate for this level. This difference may be caused by the variability in the age range for players attending the State combine, as older players are able to participate. One study reported that the RAE was reversed in mature age (≥20 years) AFL draftees.[2] Players attending the State combine in this study were approximately 1 year older than those invited to the National combine, therefore the RAE in this level of testing may be confounded by the variable nature of the mature players' attendance.

The age-policy changes imposed by the AFL did influence the birth distribution of the National level players, as substantial differences in birth distribution was not isolated to the first half of the selection year after the policies were modified. However, March, June and July were observed to have a higher player birth rate, with November and December still exhibiting lower birth rates when compared with the general population. This bias was evident when 17 and 18-year-old National players were combined, and when only 18-year-old were grouped for comparison with the expected Australian general population. Delaying player selection has been emphasised as a method of targeting the RAE in team sports such as soccer, rugby, basketball, volleyball and cricket.[1,16,26] Previous work also found that allocating jumper number according to a players age relative to their team has successfully removed the RAE in junior soccer talent selection.[7] Though the policy changes outlined in this study can only be considered partially successful as birth distribution bias was still evident in several months. Furthermore, the RAE was already present at the State U16s level, which may restrict a late-developing player's access to higher-level coaching and athlete development programs, creating a further talent gap between players.[1,6,27] It has also been found that place of birth in conjunction with birth quartile can effect an athletes chance of being selected into a talent development pathway.[6] Unfortunately, the birth location of players in this study was not analysed and may be a limitation. The outcomes in this study demonstrated that whilst policy changes partially addressed the bias in birth distribution at the National level only, the RAE was still evident within the younger talent levels. As such, imposing age-policy restrictions in combination with uniform changes that clearly identify player ages at the local and state competitions, may allow for fewer players to be overlooked for selection into the AFL's talent pathways because of the time of year in which they were born.

## 5. Conclusion

This study determined that birth distribution bias exists for AFL players attending the State U16, State and National Combines across a substantial time period (1999 and 2016). Furthermore, it examined the effect of AFL imposed age-policy changes that specifically address the RAE at the National level. A bias in birth distribution towards the first quartile of the year at the State U16, State and National levels was evident in the AFL talent pathway, with players born earlier in the year more likely to be invited to participate at the annual AFL combines. Changes to age-policy were only partially successful within the National 18-year-old sub-group, as RAE bias was no longer evident in the first half of the selection year. However, the RAE was still observed post-policy change, with more players born in the months of June and July, and no change to number of players born in November and December. The selection bias of players born earlier in the year at State U16s level may have a flow on effect into the higher levels of the talent pathway. Therefore, policy changes regarding age selection rules of players attending the National Draft Combine may not affect the RAE prevalence, as the phenomenon was observed to occur at the State U16s, State and the 17-year-old National sub-group levels. The AFL talent pathway should incorporate selection opportunities for players born later in a given selection year, which balances out the RAE's occurring at the junior level.

## Practical applications

- Recruiters considering talented AFL players across the AFL talent pathway should consider age selection bias when analysing players from junior levels.
- The AFL talent pathway may benefit from creating multiple talent identification points that specifically target players who may have been overlooked due to the month they were born.
- Alternative strategies regarding the relative age of players being selected into AFL talent pathways should be explored to further reduce the prevalence of the RAE in the sport.

## Acknowledgments

The authors would like to thank Paul Sealey and Kevin Sheehan of the Australian Football League for allowing access to the data and their assistance interpreting Australian Football League age-related policy changes. The authors sincerely thank the Australian Football League Research Board for funding this project.

## References

1. Andronikos G, Elumaro AI, Westbury T et al. Relative age effect: implications for effective practice. *J Sports Sci* 2016; 34(12):1124–1131.
2. Coutts AJ, Kempton T, Vaeyens R. Relative age effects in Australian Football League National Draftees. *J Sports Sci* 2014; 32(7):623–628.
3. Simmons C, Paull GC. Season-of-birth bias in association football. *J Sports Sci* 2001; 19(9):677–686.
4. Cobley S, Baker J, Wattie N et al. Annual age-grouping and athlete development. *Sports Med* 2009; 39(3):235–256.
5. Van den Honert R. Evidence of the relative age effect in football in Australia. *J Sports Sci* 2012; 30(13):1365–1374.
6. Finnegan L, Richardson D, Littlewood M et al. The influence of date and place of birth on youth player selection to a National Football Association elite development programme. *Sci Med Football* 2017; 1(1):30–39.
7. Mann DL, van Ginneken PJMA. Age-ordered shirt numbering reduces the selection bias associated with the relative age effect. *J Sports Sci* 2017; 35(8):784–790.
8. Wattie N, Schorer J, Baker J. The relative age effect in sport: a developmental systems model. *Sports Med* 2015; 45(1):83–94.
9. Baxter-Jones AD. Growth and development of young athletes. *Sports Med* 1995; 20(2):59–64.
10. Till K, Cobley S, Wattie N et al. The prevalence, influential factors and mechanisms of relative age effects in UK Rugby League. *Scand J Med Sci Sports* 2010; 20(2):320–329.
11. Woods CT, Raynor AJ, Bruce L et al. Predicting playing status in junior Australian football using physical and anthropometric parameters. *J Sci Med Sport* 2015; 18(2):225–229.
12. Gastin PB, Bennett G, Cook J. Biological maturity influences running performance in junior Australian football. *J Sci Med Sport* 2013; 16(2):140–145.
13. Haycraft JAZ, Kovalchik S, Pyne DB et al. Physical characteristics of players within the Australian Football League participation pathways: a systematic review. *Sports Med Open* 2017; 3(1):46.
14. AFL Development Pathway. Participation and talent pathways. Available at: http://www.aflcommunityclub.com.au/index.php?id=26. Accessed 10 May 2016.
15. Pyne DB, Gardner AS, Sheehan K et al. Fitness testing and career progression in AFL football. *J Sci Med Sport* 2005; 8(3):321–332.
16. Woods CT, Robertson SJ, Gastin PB. Does relative age distribution influence the physical and anthropometric profiles of drafted under 18 Australian footballers? An investigation between the 2010 and 2013 seasons. *Talent Dev Excellence* 2015; 7(1):83–90.
17. Keogh J. The use of physical fitness scores and anthropometric data to predict selection in an elite under 18 Australian rules football team. *J Sci Med Sport* 1999; 2(2):125–133.
18. Gastin PB, Bennett G. Late maturers at a performance disadvantage to their more mature peers in junior Australian football. *J Sports Sci* 2014; 32(6):563–571.
19. Musch J, Grondin S. Unequal competition as an impediment to personal development: a review of the relative age effect in sport. *Dev Rev* 2001; 21(2):147–167.
20. Hurley W. Equitable birthdate categorization systems for organized minor sports competition. *Euro J Oper Res* 2009; 192(1):253–264.
21. Musch J, Hay R. The relative age effect in soccer: cross-cultural evidence for a systematic discrimination against children born late in the competition year. *Sociol Sport J* 1999; 16(1):54–64.
22. Woods CT, Cripps A, Hopper L et al. A comparison of the physical and anthropometric qualities explanatory of talent in the elite junior Australian football development pathway. *J Sci Med Sport* 2016; 20(7):684–688.
23. Woods CT, Raynor JA, Bruce L et al. The use of skill tests to predict status in junior Australian football. *J Sports Sci* 2015; 33(11):1132–1140.
24. Australian Bureau of Statistics Births, by year and month of occurrence, by state. Available at: http://stat.data.abs.gov.au/Index.aspx?DataSetCode=BIRTHS_MONTH_OCCURRENCE. Accessed 30 May 2017.
25. Newcombe RG. Two-sided confidence intervals for the single proportion: comparison of seven methods. *Stat Med* 1998; 17(8):857–872.
26. Till K, Cobley S, O'Hara J et al. Considering maturation status and relative age in the longitudinal evaluation of junior rugby league players. *Scand J Med Sci Sports* 2014; 24(3):569–576.
27. Ford PR, Williams MA. No relative age effect in the birth dates of award-winning athletes in male professional team sports. *Res Q Exerc Sport* 2011; 82(3):570–573.