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Incorporating an Interdisciplinary Approach to Examine the Relationship Between Physical Capacity, Perceptual Motor Skill, Mental Toughness and Match Performance in Australian Football

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Incorporating an Interdisciplinary Approach to Examine the Relationship Between Physical Capacity, Perceptual Motor Skill, Mental Toughness and Match Performance in Australian Football

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Doctor of Philosophy

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Author's Declaration

I declare that this thesis is my own account of my research and contains as its main content, work which has not previously been submitted for a degree at any tertiary education institution.

Ben Piggott

May 2020

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List of Abbreviations

AF	Australian football
AFL	Australian Football League
GEE	Generalised estimating equations
ICC	Intra-class correlation coefficients
LMM	Linear mixed model
M	Mean
MT	Mental toughness
MTC	Mental toughness coach
MTI	Mental Toughness Index
QIC	Quasi likelihood under independence model criterion
RTD	Representative task design
SSG	Small-sided games
SD	Standard deviation
WAFL	West Australian Football League
WAAFL	West Australian Amateur Football League

Summary of Research

Performance in sports involves a combination of components such as physiological, psychological and perceptual-cognitive-motor. Yet, despite a call in the literature dating back more than 20 years for an interdisciplinary approach, the majority of studies in sports science have used a monodisciplinary approach focusing on one component to understand sport performance. Accordingly, the primary aim of this thesis was to investigate the value of an interdisciplinary approach to understand match performance using Australian Football (AF) as the exemplar sport. The secondary aim of this thesis was to quantify individual differences in performance and representative task design (RTD) of tests used in the interdisciplinary approach. This aim relates to a more recent call in the literature to determine how individuals perform and whether tests used to measure performance represent match contexts. Therefore, through these aims, this thesis has theoretical and practical implications for athlete assessment and development in a variety of sports.

This thesis is comprised of four studies and an overview of how these studies are related is shown in *Figure A*. The first study (chapter two) involved a systematic review to identify the extent of interdisciplinary research conducted within the field of sports science (i.e., within talent identification, talent selection and competition performance domains). Thirty-six studies met the selection criteria out of an initial search that yielded 23,806 articles. Twenty-five studies were categorised as interdisciplinary and eleven categorised as multidisciplinary. The secondary purpose of the review was to critique the level of performance analysis and RTD of performance tests in the studies. The review concluded that sports science research is beginning to fulfil the call for interdisciplinary research, however, there is a lack of interdisciplinary research in the competition performance domain, especially in team sports. Further, the review found that future interdisciplinary research needs to consider individual analyses and RTD of tests to progress sports science knowledge. Therefore, study two and three were aimed at developing performance tests in different sub-disciplines of sports science. These performance tests were incorporated into study four, which used an interdisciplinary approach and considered individual analyses, as well as RTD.

Study two (chapter three) focused upon the sub-discipline of Motor Control to determine if small-sided games (SSG), which have a high level of RTD, could discriminate perceptual-cognitive-motor skill in AF players. Higher skilled and lesser skilled players participated in three SSG of three minutes duration. Each disposal (handball or kick) was scored for decision-making and motor skill execution and the scores were combined for a total score. Higher skilled players scored significantly higher than lower skilled players on total score and decision-making, however, the execution score was not significantly different between groups. In addition, mean total score of higher skilled players significantly predicted a component of match performance, that of disposal efficiency. This study demonstrated that coaches could easily implement SSG to discriminate perceptual-cognitive-motor skill performance in skilled players, which is a predictor of match performance.

The third study (chapter four) focused on the Sports Psychology sub-discipline and extended research on mental toughness (MT) and sports performance. This study investigated whether skilled AF players would perform better under a high-pressure scenario within a SSG where the changed ratio of defenders to attackers increased the level of pressure. Higher and lower skilled players were recruited and coaches rated participants' MT using the Mental Toughness Index (MTI); this was known as Mental Toughness Coach (MTC). Additionally, participants competed in SSG with varied attacker to defender ratios in the game in order to create low and high-pressure scenarios. Decision-making, motor skill execution and a combined total were measured. MTC rating was higher for the higher skilled players. Total scores obtained by the higher skilled players was significantly superior to lower skilled players in high and low-pressure scenarios. A 'pressure differential score' (calculated to determine whether participants maintained performance across increased challenge), indicated a significant decrease in performance (total score) from low to high pressure scenarios for lower skilled, but not for higher skilled players. Furthermore, MTC scores were predictive of players' performance within the high-pressure scenario total scores. Findings suggest higher levels of MT may contribute to maintaining performance across increased challenge of pressure within SSG.

The fourth study (chapter five) compared monodisciplinary and interdisciplinary approaches to predict match performance in AF. Semi-professional players' disposal efficiency and number of coaches' votes received across a competitive season were used as measures of match performance. Performance test measures relevant to AF from different sports science sub-disciplines were included; Exercise Physiology (3 x 1 km trial), Motor Control (SSG test, validated in study two) and Sports Psychology (MTC test, validated in study three). Univariate monodisciplinary models indicated that all tests predicted the match performance measure of disposal efficiency, but only the SSG predicted the match performance measure of coaches' vote. A multivariate interdisciplinary model indicated that SSG and MTC tests predicted disposal efficiency with a better model fit than the corresponding univariate (monodisciplinary) model. The interdisciplinary model formulated an equation that could identify individual differences in disposal efficiency. In addition, the interdisciplinary model showed that the higher representative SSG test contributed a greater magnitude to the prediction of competition performance, than the lower representative MTC rating.

Overall, this thesis demonstrates that an interdisciplinary approach can provide a more comprehensive understanding of sport performance, individual differences, and representative tasks in AF. The thesis also provides a template for future interdisciplinary competition performance, but also talent identification and training research in sport science.

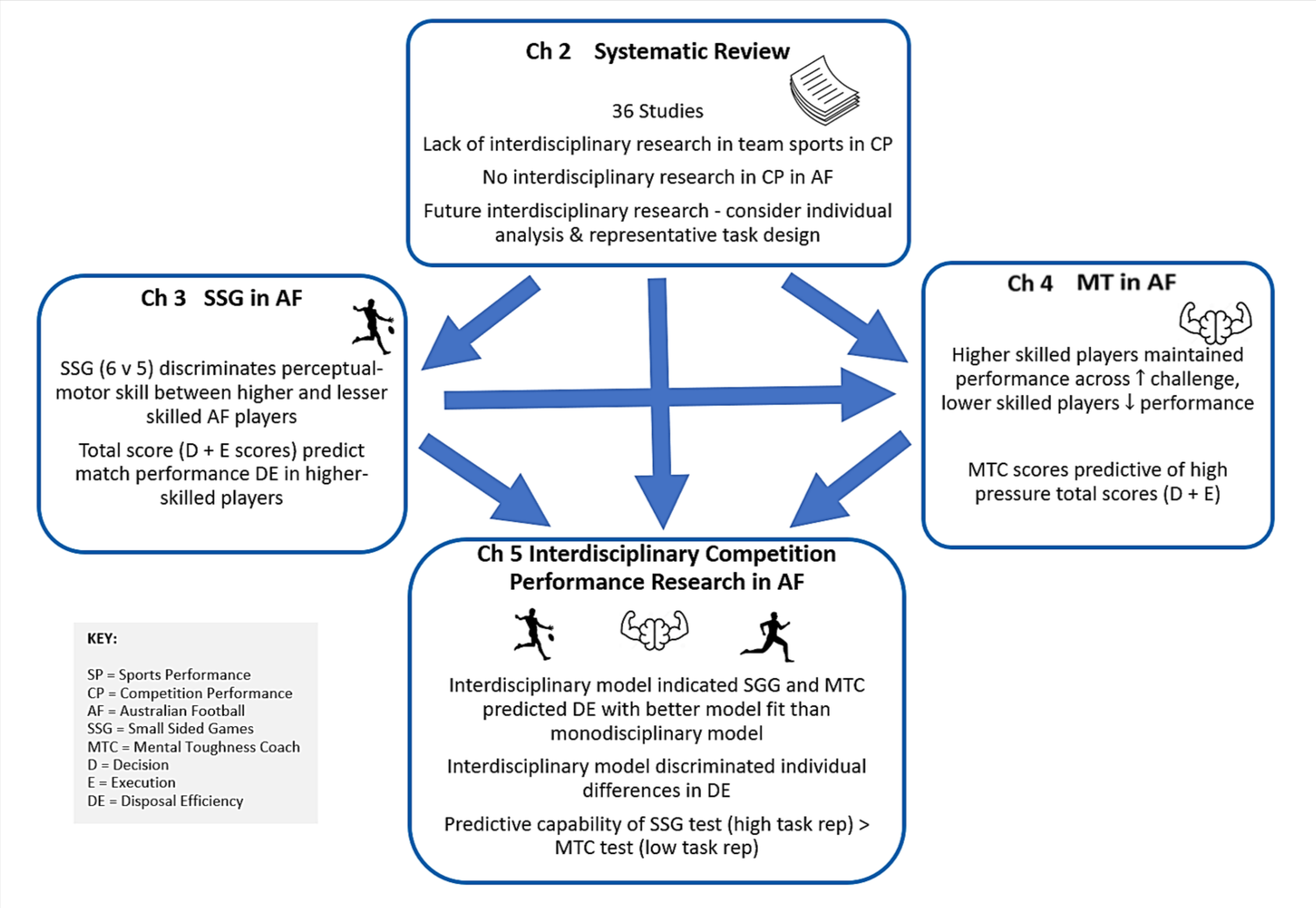

Figure A Thesis summary showing relationship of chapters

Publications by the Candidate

Piggott, B., Müller, S., Chivers, P., Papaluca, C., & Hoyne, G. (2019). Is sports science answering the call for interdisciplinary research? A systematic review. *European Journal of Sport Science. 19*(3): 267- 286. doi:10.1080/17461391.2018.1508506

Piggott, B., Müller, S., Chivers, P., Cripps, A., & Hoyne, G. (2019). Small-sided games can discriminate perceptual-cognitive-motor capability and predict disposal efficiency in match performance of skilled Australian footballers. *Journal of Sports Sciences. 37*(10): 1139-1145. doi:10.1080/02640414.2018.1545522

Piggott, B., Müller, S., Chivers, P., Burgin, M., & Hoyne, G. (2019). Coach rating combined with small-sided games provides further insight into mental toughness in sport. *Frontiers in Psychology.* 10, 1552. doi:10.3389/fpsyg.2019.01552

Piggott, B., Müller, S., Chivers, P., Cripps, A., & Hoyne, G. (2020). Interdisciplinary sport research can better predict competition performance, identify individual differences & quantify task representation. *Frontiers in Sports and Active Living, 2*(14). doi: 10.3389/fspor.2020.00014

Presentations by the Candidate

Piggott, B. (2020*). Benefits of an interdisciplinary approach to research: An example from Australian football.* Symposium on Developing Athletes through Sport Psychology and Skill Learning at Murdoch University, Murdoch, Australia.

Piggott, B. & Müller, S., (2020*). Benefits of an interdisciplinary approach to talent development.* Invited presentation to West Coast Eagles Coaching Staff, West Coast Football Club, Lathlain, Australia.

Piggott, B. (2019). *Interdisciplinary practice: An example from Australian football* Symposium on Skill Learning at Murdoch University, Murdoch, Australia.

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I have had a very rewarding PhD experience. Reflecting on why this was the case, I realise it stems from the great people I worked with along the way and the support that I had from my family.

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To Sean, I have learnt so much from you and I would like to thank you for all the time, effort and expertise you have provided as part of this journey. I have learnt what it takes to undertake quality sports science research that has applied and theoretical value. Hopefully, we can continue collaborating in the years ahead. Above all, I value the friendship that has developed from working together.

To Paola, you have been such a constant source of inspiration and encouragement throughout my PhD and I thank you for this. Again, I have learnt so much from you in regards to the research process, particularly from your expertise in statistics. I found our weekly meetings very valuable and incredibly helpful in keeping me on track with the project.

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Chapter 1 Introduction

1.1 Introduction

Sport performance is a complex field of study involving interactions of multiple components such as the physical, mental and skill capabilities of players (Cardinale, 2017). Whether the performance is in an individual or team sport, athletes such as Ashley Barty (tennis) and Cristiano Ronaldo (soccer), require these components to work in synchrony to produce a performance, superior to their opponent(s). Moreover, these components of human performance are required to function at a superior level under high pressure situations encountered during competition. Despite acknowledgment of the intricate interaction of components for superior performance, sports science research that is performance oriented has traditionally used a monodisciplinary approach focused upon understanding isolated function of components (Glazier, 2017). Understandably, the call for a more integrated approach to sports science research that emerged over 25 years ago (Burwitz, Moore, & Wilkinson, 1994), has become emphatic in recent times (Buekers et al., 2016; Cardinale, 2017; Glazier, 2017).

Understanding the different levels of integration in sports science research is essential to conceptualise what is known about sport performance. Monodisciplinary research refers to research that focuses on measures that are related to a single sports science sub-discipline. For example, this would include independent research that would focus on Exercise Physiology, Motor Control, Biomechanics, Sports Psychology, or Functional Anatomy. Multidisciplinary research is characterised by researchers from different sub-disciplines working independently of each other, investigating a shared problem or research question (Freedson, 2009). In regards to interdisciplinary research, specialists from the different sub-disciplines work collaboratively integrating ideas and combining methods to investigate a problem and generate solutions (Freedson, 2009). A visual representation to help represent the difference between multidisciplinary and interdisciplinary research is presented in *Figure 1.1*.

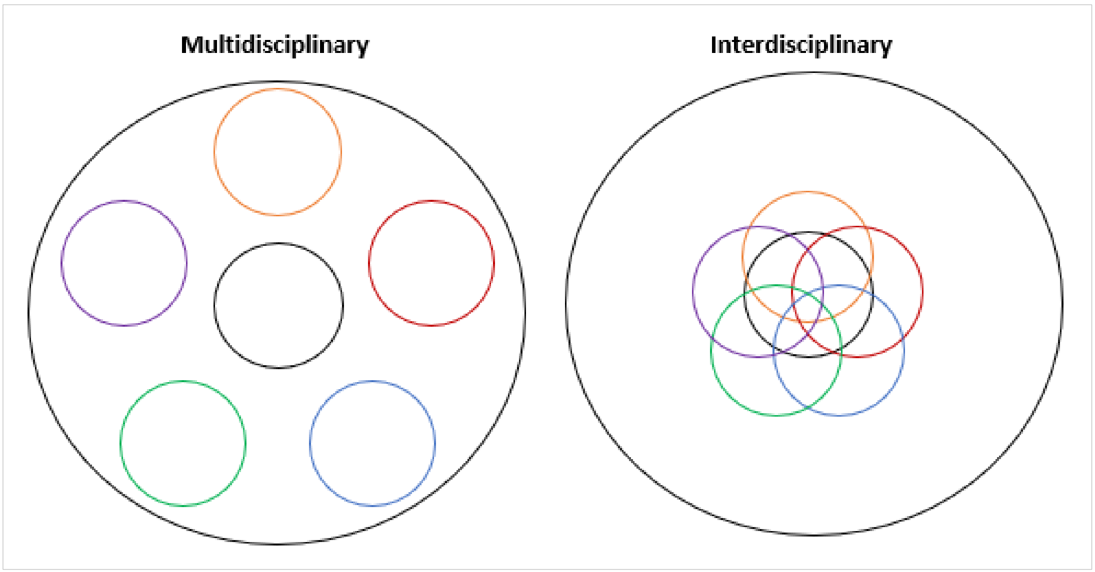

Figure 1.1 The difference between multidisciplinary and interdisciplinary research. The circles represent the sub-disciplines in human movement science (Adapted from Abernethy et al., (2013) pg. 8).

There are powerful examples of where an interdisciplinary approach to sport performance has resulted in superior performance. Recently, Eliud Kipchoge ran a sub two-hour marathon. This was achieved through an interdisciplinary approach to sport performance. First, Nike developed a mechanically more efficient running shoe (Quealy & Katz, 2019). Second, during the race, pacesetters were strategically positioned during the marathon to create a slip stream airflow around Kipchoge that could reduce drag. Third, during the race, Kipchoge was periodically given energy sources (gels and fluid). Therefore, if the sport community wants to continue to see this type of amazing feat, coaches and sports scientists must continue to work together to improve their athletes using an interdisciplinary approach.

Justification for the use of an interdisciplinary approach in sports science research is based on the fact that improvement in athletic performance is rarely achieved by focusing solely on one sports science sub-discipline (Sands, 2017). Accordingly, by constraining research in this way, although it may provide certain practical implications to improve performance, when viewed from another sub-discipline it may seem contrary to achieve enhanced performance outcomes (Balagué, Torrents, Hristovski, & Kelso, 2017). An example to illustate this point, presented by Burwitz et al. (1994), is a debate regarding the use of a helmet in boxing. A biomechanist recommended the use of a helmet to reduce injury, alongside a sport psychologist who argued that a helmet may actually lead to increased risk-taking and lead to other injuries (e.g. concussion, broken jaw). Alternatively, an exercise phsyiologist suggested the protective helmet may impair thermoregulation, which could be detrimental to overall performance. Adopting a suitable theoretical framework can guide investigation in the young field of sports science to move away from a specialisation focus towards a more integrated (and less conflicting) approach to examine performance ‘problems’ (Balagué et al., 2017). As explained through the Kipchoge and boxing examples, an interdisciplinary approach (or team) working together, underpinned by a theoretical framework, can be more successful in achieving performance goals.

The theoretical framework for this thesis is based on constraints theory (Higgins, 1977; Newell, 1986), which forms part of information processing and ecological dynamics theories. Constraints theory predicts that intricate interaction between characteristics of the organism (or individual), their immediate environment and the task, determines performance of the skill goal. A schematic overview of this theory is depicted in *Figure 1.2*.

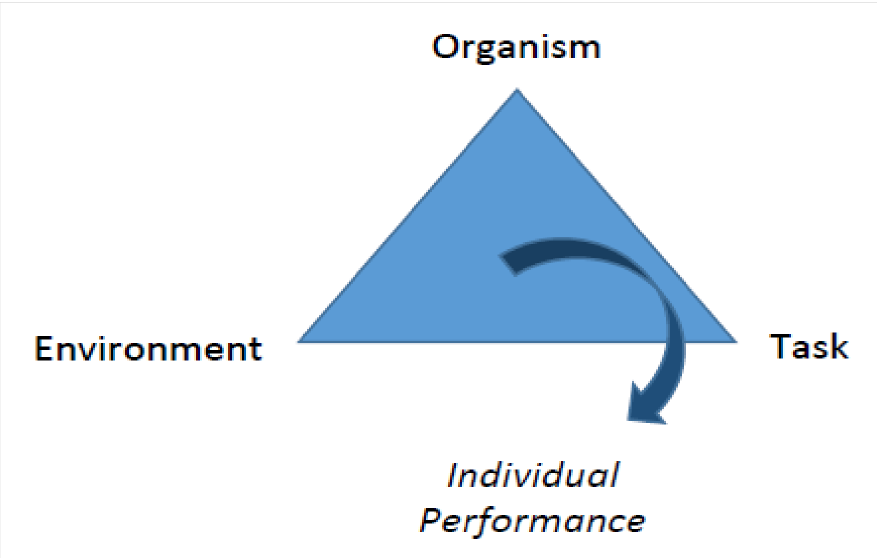

Figure 1.2 Model of interacting constraints which highlights how the interaction between the player, the task and the environment all contribute to the individual performance (adapted from Newell, 1986).

A constraint(s) can be a facilitator or inhibitor to performance (Higgins, 1977; Newell, 1986). An example of constraints theory applied to a sporting context can include an AF player who has possession of the ball with a defender approaching. The player has a choice of two team mates to pass to, one twenty metres away and another forty metres away; both are unmarked and could receive the ball via a pass by foot.

Alternatively, the player may choose to 'take on' the approaching defender and use evasion skills to beat the tackle. The organism (the player) has constraints that include perceptual-cognitive-motor, physiological and psychological component capabilities. Here, the individual's motor skill execution in terms of evading the defender and kicking the ball, decision making capability in terms of whether to take on the defender or pass the ball, level of fatigue and psychological state, together can facilitate or impede performance. The environment is the physical context constraint within which a game of AF is played such as weather conditions (i.e., dry, wet, windy) and size of the playing field. The task constraints include factors such as competition level of the game (i.e., level, age, gender), the 'state' of the game (i.e., current score, time remaining), approaching defender (i.e., slow, fast, size, skill in tackling), and team tactics (i.e., safest option, take risks). Collectively, it is the interactions between the player's component capabilities, and integration with the task within the environment that contributes to the overall individual (and team) match performance.

Constraints and ecological-dynamics theories propose that there is tight coupling between the performer and the environment, which is important to consider when trying to investigate sport performance (Davids & Araújo, 2010). This has several implications for design of experiments to understand sport performance. First, performance in sports is related to interacting performer (individual), environment and task constraints (Davids, Araújo, Hristovski, Passos, & Chow, 2012). Second, design of experimental tasks needs to take into consideration the context to which the findings are to be generalised, which in sport, is the competition setting. This is known as RTD (Araujo & Davids, 2015). Third, performance is individualised, so experimental design needs to be able to understand player performance at the individual level (Müller et al., 2019). Accordingly, performance in sport is viewed as emergent from interacting individual, task, and environmental constraints (Davids et al., 2012). It is important, however, to point out here that cognitive skills such as decision-making, developed through practice and experience are also crucial to guide action responses in sport performance (Christensen & Bicknell, 2019; Christensen, Sutton, & McIlwain, 2016). Based upon these theoretical perspectives, a monodisciplinary approach that investigates sport performance through understanding of isolated human performance components is less able to provide a complete account of performance in sport. Therefore, constraints theory provides an appropriate framework to guide interdisciplinary sport performance research.

1.2 Overview of Australian football

This thesis used AF as an exemplar sport to explore an interdisiplinary approach to sport performance. It is therefore appropriate to provide a brief overview of the game. AF is an invasion sport where two teams (18 players per team on field at one time) compete on an oval field and attempt to outscore their opponent by kicking goals when in possession of the ball. When a team is not in possesion of the ball their aim is to reduce the number of goals that the opposing team scores. Attacking team players progress the ball towards goal by running, kicking or handballing the ball, whilst defending teams attempt to prevent this through tackling or intercepting the ball. It is a fast-paced intermittent contact sport (Gray & Jenkins, 2010) with a unique mix of physical, technical, mental and tactical skills (Young & Pryor, 2007). At the elite level, the game of AF has expanded into a National competition known as the AFL with competitions for both men and women. There are numerous levels below the professional AFL including the state-based semi-professional competitions (e.g. West Australian Football League (WAFL)), and non-professional competitions (often referred to as country league, community leagues or amateurs).

1.3 Thesis aims

The primary aim of this thesis was to investigate the value of an interdisciplinary approach in understanding match performance, using AF as an exemplar sport. The secondary aim of this thesis was to quantify individual differences in performance and RTD of tests used in the interdisciplinary approach. This latter aim relates to a more recent call in the literature to determine how individuals perform and whether tests used to measure performance represent match contexts. Therefore, this thesis has theoretical and applied implications for athlete assessment and development in a variety of sports.

1.4 Significance of thesis

This thesis provides a significant contribution to research and provides important implications for sports coaches and high performance staff. Firstly, chapter two’s systematic review quantifies the amount of inter and multidisciplinary research that has been conducted in the sports performance domain, for the first time in the field of sports science. In addition, the review identifies the sports involved in inter and multidisciplinary research, identifies and rates the level of task representation for each performance test, and identities whether the analysis of the data was at the group or individual level.

Chapter three outlines how the development of a SSG in AF is able to discriminate between skill levels and also predict a component of match performance in regards to average disposal efficiency across the competitive season. This was original research in the field of AF, as well as generalisation to other team sports. The SSG can be easily implemented by coaches to target development of decision making and technical or both component skills.

Chapter four is significant as it advances Sport Psychology research in the topic of MT. It does this specifically by providing evidence to show that higher skilled players reported higher levels of MTC than lower skilled players, and that higher skilled players are also able to maintain their performance under challenging conditions, whereas lower skilled players’ performance declines. In addition, chapter four reports that a significant predictive relationship exists between MTC rating of athletes and *in-situ* performance in the higher-pressure scenario; it provides support for the theory that higher levels of MT correspond with higher levels of performance.

Chapter five identifies the value in conducting interdisciplinary research in the competition performance domain. It does this by providing evidence, from both monodisciplinary and interdisciplinary statistical models, regarding predictive performance outcomes, RTD and individual differences. Therefore, it can be argued that this thesis significantly advances the field of sports science research across different sub-disciplines. The thesis also provides a template for future interdisciplinary research in competition performance that has direct translation to coaching, as well as athlete talent identification and preparation for competition.

1.5 Structure of thesis

This thesis is structured as follows:

- Chapter 1 presents a general introduction to interdisciplinary research in sports science
- Chapter 2 presents a review of relevant literature in the form of a systematic review manuscript which has been published in the European Journal of Sports Science (2019)
- Chapter 3 reports experimental research conducted in manuscript format which has been published in Journal of Sports Sciences (2019)
- Chapter 4 reports experimental work conducted in manuscript format which has been published in Frontiers of Psychology (2019)
- Chapter 5 reports experimental research conducted in manuscript format which has been published in Frontiers in Sports and Active Living (2020)
- Chapter 6 discusses conclusions and suggestions for future research resulting from the experimental work carried out within the thesis.

Due to the structure of this thesis by publication there is unavoidable repetition of content and references in some places, however, an effort has been made to keep this to a minimum. Some acronyms have been adapted from journal specific requirements to improve readability and consistency of thesis. Furthermore, a full reference list is provided at the end of the thesis rather than at end of individual chapters.

Chapter 2 Is Sports Science Answering the Call for Interdisciplinary Research? A Systematic Review

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Is sports science answering the call for interdisciplinary research? A systematic review

Ben Piggott, Sean Müller, Paola Chivers, Carmen Papaluca & Gerard Hoyne

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Research synthesis

The aim of chapter two was to systematically review the sports science literature (within talent identification, talent selection and competition performance domains) to ascertain the extent of interdisciplinary research undertaken in this field. The secondary aim of this chapter was to critique the level of performance analysis and RTD of performance tests used within the identified studies. This review identified the sports and competition domains where interdisciplinary research has been completed and the sub-disciplines that were involved. This chapter also identifies the gaps in the field where interdisciplinary research has not been undertaken; these gaps are the focus of subsequent chapters three, four and five.

Article information

Title

Is sports science answering the call for interdisciplinary research? A systematic review

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Reference

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Abstract

Sports science research is traditionally monodisciplinary despite calls for an interdisciplinary focus. The primary purpose of this systematic review was to identify studies on talent identification, talent selection and competition performance to determine whether interdisciplinary research is being conducted. Thirty six studies met the selection criteria. These studies were critiqued relative to sport, skill level, sport science sub-disciplines included, and whether the research was multidisciplinary or interdisciplinary. The secondary purpose of the review was to critique the level of analysis and level of RTD in performance tests used in the studies. Twenty five studies were categorised as interdisciplinary, with 11 categorised as multidisciplinary. Thirteen sports were represented with soccer the most frequent followed by field hockey, AF, handball and rugby league. Thirty two studies completed their analysis at a group level and four at an individual level. A total of 337 performance tests were rated for RTD with 64 categorised as low, 123 as medium and 150 as high. The results pertaining to interdisciplinary studies and individual analyses are discussed in relation to constraints theory, which predicts that interacting variables can explain sport performance. Sports science research is beginning to fulfil the call for interdisciplinary research. Future research, however, needs to consider individual analyses and RTD of tests to progress sports science knowledge.

Keywords

Sports science, interdisciplinary research, multidisciplinary research, constraints theory, individual differences, RTD.

2.1 Introduction

Sports performance is complex to study because elite athletic skill during competition is comprised of maximal operation of interacting variables including physiological fitness, psychological preparedness, physical development and perceptual-cognitive-motor skill (Buekers et al., 2016). For example, in a game of soccer or AF, a midfielder repeatedly sprints whilst reading the play in order to decide upon which teammate to execute a precision pass of the ball to try and score a goal for their team. Simultaneously, the player can be required to fend off a tackle to retain possession of the ball. Therefore, the integration of knowledge from different sub-disciplines of sports science is of great importance to guide our understanding of elite sports performance. Furthermore, an integrated approach could be applied to areas such as talent identification, selection, and development of athletes across different levels of the skill continuum (Buekers et al., 2016).

Despite sports performance involving multiple interacting components, the trend for sports science research has been overwhelmingly monodisciplinary in nature, confined within one sub-discipline (Glazier, 2017). Burwitz et al. (1994) first called for a more integrated approach to understand sport performance over 20 years ago and this has become more emphatic in recent years (Cardinale, 2017). This is because an integrated approach provides a better profile of the strengths and limitations of each athlete, which can then be targeted with specific intervention programs to attempt to improve success in competition and prolong longevity of a career (Buekers et al., 2016). In addition, sport science practitioners who work with athletes report that the necessary scientific information to improve athlete performance rarely resides in one sports science sub-discipline (Sands, 2017). Moreover, coaches believe that findings from sports science research that integrates different sub-disciplines could inform the structure of individualised assessment and training programs to improve individual athletic performance (Williams & Kendall, 2007).

Multidisciplinary research will approach a scientific question from a sub-discipline specific viewpoint (Glazier, 2017). In this context, the research could involve scientists from different sub-discipline areas working independently of each other, but collectively their research outcomes could provide a solution to the problem being investigated (Freedson, 2009). An example of multidisciplinary research would be a group of researchers who assess a squad of elite soccer players. This could involve the individual athletes being taken through a series of assessments. An exercise physiologist could measure the aerobic capacity using a shuttle run; a skill acquisition specialist could measure perceptual-cognitive-motor skill through a sports-specific perceptual-cognitive-motor test and a sport psychologist could measure MT through a survey. The researchers could publish their data independently, but the cost benefit for the head coach is they could identify the key outcomes from the different sub-disciplines and use this information to guide the development of athletes to improve performance.

Interdisciplinary research is more integrative and involves the interaction of specialists across sub-disciplines working together to generate new knowledge in a more holistic approach to understand sport performance (Freedson, 2009). Accordingly, interdisciplinary research would combine the technical expertise of the researchers, for example, an exercise physiologist, skill acquisition specialist, and sport psychologist to understand how athletes perform sports skills under psychological and physiological stresses as would occur in the game setting. The point of difference here is that the scientists work collaboratively to address the specific research question.

Constraints theory (Higgins, 1977; Newell, 1986), which forms part of the ecological-dynamics theory (Davids, Handford, & Williams, 1994), is a valuable framework which supports interdisciplinary research because it helps explain how integrated variables influence achievement of the task goal (Ibáñez-Gijón et al., 2017). Constraints theory predicts that the immediate environment, task and individual constraints shape how one perceives to guide action in order to achieve the skill goal (Newell, 1986). More specifically, Ibáñez-Gijón et al. (2017) outline that constraints can be conceptualised as interacting ecological and execution scales. The ecological scale refers to the tight linkage between the organism and its environment to achieve the task goal, such that perception and action work in synchrony. The execution scale refers to the use of different degrees of freedom through a variety of coordination patterns to achieve the same task goal. An example of constraints is demonstrated in the last minute of a basketball game where the team in possession of the ball is ahead in score (immediate environment), with the point guard (individual athlete) of the winning team required to dribble the ball up the court, ensuring their team maintains possession for as long as possible to ensure the opposition team has less time to score or cause a turnover in order to score (task). Therefore, constraints involving the ecological scale provides perceptual information of the task and environment to which the execution scale can use a variety of coordination patterns to maintain possession of the ball.

Although constraints theory identifies the importance of the organism (individual), researchers in sports science have often used group comparison design. Groups of participants who can differ in characteristics such as age, skill level, gender, undertake performance tests or training programs and the results are compared. For example, research involving the Ghent youth soccer project aimed to determine the relationships between physical and performance characteristics and level of skill in players (Vaeyens et al., 2006). Results were presented at the group level with participants being categorised by skill level (elite, sub-elite and non-elite) and age (under 13, 14, and 15), with the conclusion drawn that characteristics that discriminate youth soccer players vary according to age. Such research is useful if the aim is to identify the characteristics which discriminate between groups and ages. An emerging approach of late in sports science research involves individual difference comparisons on performance tests (Phillips, Davids, Renshaw, & Portus, 2010). Investigation of individual differences in sports science is particularly relevant as constraints theory predicts that an individual's goal-directed actions will be determined by the environment and the task. Therefore, an individual level of analysis can provide information of individualised solutions and/or deficiencies to achieve the task goal at either the ecological or execution scales (Ibáñez-Gijón et al., 2017). In turn, this can be highly beneficial to practitioners who attempt to design individualised training programs for athletes (Davids, Araujo, Seifert, & Orth, 2015).

Importantly, it has been argued that interdisciplinary research should investigate how individuals exploit constraints to achieve the task goal (Ibáñez-Gijón et al., 2017), and that the tasks undertaken in the research should be representative of the game setting (Buekers et al., 2016). RTD states that properties of performance tests (constraints) should represent the properties (constraints) of the performance environment to which the results are to be generalised (Vilar, Araújo, Davids, & Renshaw, 2012). For example, in regards to the sub-discipline of Motor Control, perceptual-cognitive-motor tests should be structured to ensure that some or all of the perceptual information sampled from the real-world game setting are avaliable to guide action (Pinder, Davids, Renshaw, & Araújo, 2011b). Furthermore, the perceptual-cognitive-motor test should allow the participant to link motor responses or couple action to relevant sensory information in order to guide the execution of a motor-skill action like they would within the competition setting. For example, SSG have been used in soccer as a perceptual-cognitive-motor test to identify talented players (Fenner, Iga, & Unnithan, 2016). This test would be considered to have a high level of task representation as perceptual information like the game setting is available which can be used to guide motor-skill action typical of a soccer game. Accordingly, RTD is vital to ensure that the test(s) used include constraints reflective of the competition setting in order to provide an accurate understanding of how the ecological and execution scales function to achieve goal-directed behaviour in sports.

To summarize, an interdisciplinary approach encompassing multiple sub-disciplines of sports science can provide a more comprehensive understanding of sport performance. More recently, a scale-based theoretical framework (Ibáñez-Gijón et al., 2017), couched within ecological-dynamics theory, outlined that sport performance is best understood by investigation of interacting individual constraints, incorporating perception and execution scales, in tasks that are representative of the competition setting.

The primary purpose of this systematic review was to determine the extent of published research in the sports sciences that could be defined as either multidsciplinary or interdiscplinary in its approach. We focused on research papers that had integrated three, four or five sub-disciplines of sports science as this should more accurately reflect the complex interaction of variables that impact on sports performance such as physiological fitness, psychological preparedness, physical development, perceptual-cognitive-motor skill (Glazier, 2017). The secondary purpose of this review was to critique the level of analysis (group or individual) and the level of RTD (low, medium or high) of the performance tests used within the reviewed studies. Sport scientists' and practitioners' request that sport science research should incorporate more interdisciplinary research is based on the assumption that currently, this approach is limited (Glazier, 2017; Williams & Ward, 2017). The significance of this review is that these opinions and assumptions will be addressed by providing evidence, previously not presented, regarding the extent to which interdisciplinary research has been undertaken in sport science.

2.2 Method

2.2.1 Search strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2015), was followed for the initial identification stage of this review using three electronic databases (Academic Search Premier, SportDiscus and PubMed) between January 1994 and April 2018. The following search terms were included: "multidisciplinary", "multidimensional", "interdisciplinary" "game performance", "match performance", "talent development", "sport performance", "Biomechanics", "Exercise Physiology", "Motor Control", "Sport Psychology", "Exercise Psychology". To ensure a thorough search was conducted, these terms were entered separately and in Boolean combination in each database. In addition, searches through reference lists were also conducted to ensure all possible articles were identified.

2.2.2 Eligibility criteria

Only research articles published between January 1994 and April 2018 and written in English were included in this review. The year 1994 was used as a starting point as this corresponded with the first call for such research (Burwitz et al., 1994). The article had to integrate knowledge and testing measures from three or more recognised sub-disciplines of sports science (Abernethy et al., 2013) including Functional Anatomy, Exercise Physiology, Motor Control, Biomechanics and Sport and Exercise Psychology. The research article had to be in the area of sport performance, which for the purposes of this paper, included talent identification, talent selection and competition performance. Finally, the article had to be a primary research article and not a review.

2.2.3 Classification of integration

For each article identified in the review, a classification was given as to whether the research was multidisciplinary or interdisciplinary. The basis for this classification was the previously mentioned definitions which focused on the level of integration (Freedson, 2009). For the article to be classified as interdisciplinary, there had to be an integration of knowledge and results from performance tests across three or more sub-disciplines of sports science. To ascertain whether integration occurred, two of the researchers reviewed the identified articles independently of each other. If methods were used in the analysis that integrated information from the different sub-disciplines (e.g., step wise regressions, predictions equations, modelling) then the article was classified as interdisciplinary. If this did not occur, then the article was classified as multidisciplinary.

2.2.4 Classification of analysis

A classification was given as to whether the analysis was at the group or individual level. To ascertain whether a group or individual analysis was conducted, again two of the researchers reviewed identified articles independently of each other. If the article compared results across performance tests at the group level (e.g., elite and non-elite, selected and not selected, under 18 and 16 years of age, male and female) then a "group" classification was given. If the article compared results across performance tests to investigate individual differences, then an "individual" classification was given. For example, Müller, Gurisik, Hecimovich, Harbaugh, and Vallence (2016) found that a short term temporal occlusion anticipatory training intervention had individualised benefits to *in-situ* performance of field hockey goalkeepers. Therefore, if correlational methods were used to report relationships between performance tests and competition performance and this was the only statistical method used, the article was classified as "group" as this does not allow differences at individual level to be investigated.

2.2.5 Rating of representative task design

A rating of RTD was given for each performance test identified in the review. Functional Anatomy tests were not given a rating as they are considered measurements (e.g., height, weight, skinfolds) and there is no opportunity in this sub-discipline for the participant to engage the sensorimotor system in a goal-directed task. A rating scale was developed and applied by the researchers as follows:

Low representative task design: Perceptual information that occurs in the competition environment may or may not be presented to the participant in the performance test. Opportunity is not provided to couple action to available perceptual information like in the competition environment.

Medium representative task design: Perceptual information that occurs in the competition environment is presented to the participant in the performance test.

Opportunity is provided to couple action to incomplete or later occurring perceptual information.

High representative task design: Perceptual information that occurs in the competition environment is presented to the participant in the performance test. Opportunity is provided to couple action to the available perceptual information like in the competition environment.

2.3 Results

A summary of the systematic search and selection process is provided in the PRISMA flow diagram (*Figure 2.1*).

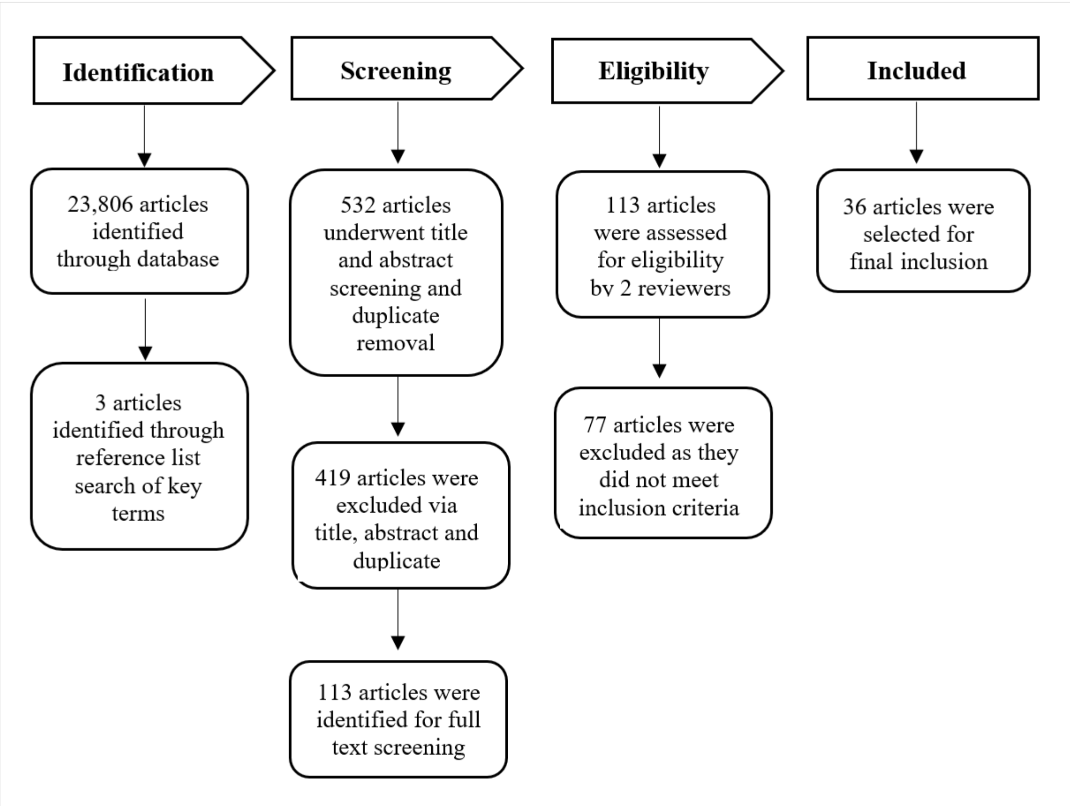

Figure 2.1 Flow diagram for the article selection process used in this systematic review

A total of 113 articles were identified in the original search with 23,806 selected via screening using the set criteria. After the eligibility criteria was applied, 36 articles were considered to integrate multiple sub-disciplines and thus, were included in this review. *Table 2.1* outlines the authors, and year of publication, sport, skill level, domain of sport performance, sub-disciplines included within each study, level of integration and the level of analysis.

Table 2.1

Sub-Disciplines, Level of Integration and Level of Analysis in Identified Articles Organised by Sport (n=36)

Study and Category	**Sport and skill level** *(as reported)*	**Number, Age Range and Mean Age (years) of Participants** *(reported if available)*	**Sub-Disciplines of Human Movement Science** **FA**	**EP**	**MC**	**B**	**SEP**	**Level of Integration of Sub-Disciplines**	**Group or Individual Analysis**
Talent Identification									
Woods, Raynor, Bruce, McDonald, and Robertson (2016)	AF SE	n = 84 17-18 17.5	✔	✔	✔			Inter	G
Cripps, Hopper, and Joyce (2016)	AF SE	n = 94 15-16 15.7	✔	✔	✔			Inter	G
Carvalho, Gonçalves, Collins, and Paes (2018)	Basketball SE & NE	n=58 9.5-15.5 13.1	✔	✔			✔	Inter	G
Elferink-Gemser, Visscher, Lemmink, and Mulder (2007)	Field Hockey SE & NE	n =65 12-16 14.2	✔	✔	✔		✔	Multi	G
Keogh, Weber, and Dalton (2003)	Field Hockey SE & NE	n=74 19-21 19.9	✔	✔	✔			Multi	G
Elferink-Gemser, Visscher, Lemmink, and Mulder (2004)	Field Hockey E & SE	n=126 11-16 13.9	✔	✔	✔		✔	Inter	G

Study and Category	Sport and skill level *(as reported)*	Number, Age Range and Mean Age (years) of Participants *(reported if available)*	Sub-Disciplines of Human Movement Science					Level of Integration of Sub-Disciplines	Group or Individual Analysis
			FA	**EP**	**MC**	**B**	**SEP**		
Nieuwenhuis, Spamer, and Rossum (2002)	Field Hockey SE & NE	n= 52 14-15	✓	✓	✓		✓	Inter	G
Pion, Lenoir, Vandorpe, and Segers (2015)	Gymnastics SE & NE	n = 243 6-9 7.7	✓	✓	✓			Inter	G
Vandorpe et al. (2011)	Gymnastics SE & NE	n=168 6-8	✓	✓	✓			Inter	G
Matthys et al. (2013)	Handball E, SE & NE	n=94 13-17	✓	✓	✓			Inter	G
Matthys et al. (2011)	Handball E, SE & NE	n=428 12-17	✓	✓	✓		✓	Inter	G
Höner, Leyhr, and Kelava (2017)	Soccer SE	n=14,178 11-12 11.32	✓	✓	✓			Inter	G
Figueiredo, Coelho e Silva, and Malina (2011)	Soccer NE	n = 143 11-14	✓	✓	✓			Inter	G
Hoare and Warr (2000)	Soccer NE	n = 17 15 – 19	✓	✓	✓			Multi	G
Reilly, Williams, Nevill, and Franks (2000)	Soccer E & SE	n = 31 15-16	✓	✓	✓		✓	Inter	G

Study and Category	Sport and skill level *(as reported)*	Number, Age Range and Mean Age (years) of Participants *(reported if available)*	Sub-Disciplines of Human Movement Science FA	EP	MC	B	SEP	Level of Integration of Sub-Disciplines	Group or Individual Analysis
Talent Selection									
Cripps, Joyce, Woods, and Hopper (2017)	AF SE & NE	n=50 15-16 15.6	✔	✔	✔			Inter	G
Tribolet, Bennett, Watsford, and Fransen (2018)	AF SE	n=277 12-15	✔	✔	✔			Multi	G
Torres-Unda et al. (2013)	Basketball SE & NE	n = 62 13-14	✔	✔	✔			Multi	G
Bartolomei et al. (2018)	Field Hockey SE & NE	n=30 25.4	✔	✔	✔			Multi	G
Massuca, Fragoso, and Teles (2014)	Handball E & SE	n=193 23.6	✔	✔	✔		✔	Inter	G
Tredrea, Dascombe, Sanctuary, and Scanlan (2017)	Rugby League NE & SE	n=160 15-18	✔	✔			✔	Inter	G
Gabbett, Jenkins, and Abernethy (2011b)	Rugby League E & SE	n=86 23.3	✔	✔	✔			Inter	G
Huijgen, Elferink-Gemser, Lemmink, and Visscher (2014)	Soccer SE & NE	n=113 16-18	✔	✔	✔		✔	Inter	G

Study and Category	Sport and skill level *(as reported)*	Number, Age Range and Mean Age (years) of Participants *(reported if available)*	Sub-Disciplines of Human Movement Science					Level of Integration of Sub-Disciplines	Group or Individual Analysis
			FA	**EP**	**MC**	**B**	**SEP**		
Vandendriessche et al. (2012)	Soccer E	n = 78 15-16 15.2	✔	✔	✔			Multi	G
Coelho e Silva et al. (2010)	Soccer SE & NE	n = 128 13-14	✔	✔	✔		✔	Inter	G
Figueiredo, Gonçalves, Coelho e Silva, and Malina (2009)	Soccer NE	n=159 11-14.9	✔	✔	✔		✔	Multi	G
Vaeyens et al. (2006)	Soccer E, SE & NE	n = 232 10-14 12.2	✔	✔	✔			Inter	G
Rikberg and Raudsepp (2011)	Volleyball E & SE	n = 65 16-17 16.7	✔	✔	✔		✔	Inter	G
Gabbett, Georgieff, and Domrow (2007)	Volleyball SE & NE	n = 28 15.5	✔	✔	✔			Inter	G
Falk, Lidor, Lander, and Lang (2004)	Water Polo E & SE	n = 24 14-15	✔	✔	✔		✔	Multi	G

Study and Category	Sport and skill level *(as reported)*	Number, Age Range and Mean Age (years) of Participants *(reported if available)*	Sub-Disciplines of Human Movement Science FA	EP	MC	B	SEP	Level of Integration of Sub-Disciplines	Group or Individual Analysis
Competition Performance									
Gómez-Molina et al. (2017)	Marathon Running NE	n=78 31.5	✔	✔		✔		Inter	I
Novak, Bennett, Fransen, and Dascombe (2018a)	Mountain Biking SE	n=12 32.2	✔	✔	✔			Inter	I
Novak, Bennett, Fransen, and Dascombe (2018b)	Mountain Biking NE	n=8 36.8	✔	✔	✔			Inter	I
Barrett and Manning (2004)	Rowing E	n = 15 26	✔	✔		✔		Multi	G
Gabbett et al. (2011a)	Rugby League E	n = 58 23.8	✔	✔	✔			Multi	G
Morais, Silva, Marinho, Lopes, and Barbosa (2017)	Swimming SE	n=91 11.6	✔		✔	✔		Inter	I

FA=Functional Anatomy, EP=Exercise Physiology, B=Biomechanics, Motor Control=Motor Control, SEP=Sport & Exercise Psychology, Multi=multidisciplinary, Inter =interdisciplinary, I=individual, G=group E=elite (highest level e.g. national representative or national competition) SE=sub-elite (level below elite e.g. state/regional representative) NE=non-elite (club level), tick = included, ARF=Australian Rules football

2.3.1 Level of integration and analysis

Of the 36 articles, 69% (25/36) were rated as interdisciplinary in design with the remaining 31% (11/36) rated as multidisciplinary. In regards to the level of analysis, 89% (32/36) analysed their results at the group level, whilst 11% (4/36) completed analysis at the individual level.

2.3.2 Sports and sub-discipline involvement

There were 13 different sports represented in the identified articles. Soccer was the sport that was most represented in integrated research 25% (9/36), followed by field hockey 14% (5/36) and AF 11% (4/36). Three of the 13 represented sports were individual, eight were team sports and two could be classified as both individual and team (gymnastics and rowing). The proportion of articles in each sports performance domain were: talent identification 42% (15/36), talent selection 42% (15/36) and competition performance 17% (6/36). The most highly represented sub-disciplines of research within the 36 articles was Functional Anatomy with 100% (36/36) followed by Exercise Physiology 97% (35/36), Motor Control 89% (32/36) and Sport and Exercise Psychology 36% (13/36). Biomechanics was the least represented with 8% (3/36).

2.3.3 Rating of task representation of performance tests

A total of 337 performance tests (excluding Functional Anatomy) were used across the 36 articles. The performance tests used in the identified articles and the ratings given for RTD are shown in *Table 2.2*. Overall, 19% (64/337) of performance tests rated as low, 36% (123/337) as medium and 45% (150/337) as high in regards to the level of RTD. The percenatge of tests in each sub-discipline which had a high rating of RTD, was 65% in Exercise Physiology, 18% in Motor Control, and 100% in Biomechanics. Sport and Exercise Psychology had no test(s) reporting high rating of representative design.

Table 2.2

Sub-Disciplines Tests, Ratings of Representative Task Design and Main Findings in Identified Articles Organised by Sport (n=36)

Study and Category	Exercise Physiology Tests	R	Motor Control Tests	R	Biomechanics Tests	R	Sport & Exercise Psychology Tests	R	Main Findings
Talent Identification									
Woods, Raynor, Bruce, McDonald, et al. (2016) AF	DVJ MSFT	H H	AF kicking test AF handball test Decision making *(video based)*	M M L					Handballing accuracy on non-dominant side, decision making score and DVJ non-dominant leg take off displayed largest ES btn talent identified and non-identified players.
Cripps et al. (2016) AF	VJ DVJ Sprint (20m) MSFT	M H H H	AFL kicking test AFL handball test	M M					ES comparisons revealed very large to moderate effects btn maturation groups for anthropometric measures, sprint, VJ & DVJ. Small to moderate effects btn groups for coaches' perception of skill.
Carvalho et al. (2018) Basketball	Line drill run YYIR1	H H					WOFO DPMQ	L L	Sig variation for body size, line drill run, YY1R1, and aspects of WOFO and DPMQ (mastery and will to excel) for players of differing maturity levels.
Elferink-Gemser et al. (2007) Field Hockey	Peak shuttle sprint Repeat shuttle sprint Slalom sprint Interval endurance	H H H H	Peak shuttle dribble Dribble repeat shuttle Slalom dribble Tactics in sport questionnaire	M M M L			PSIS		E players performed better than SE players on technical and tactical tests. Female E scored better than SE on interval endurance and aspects of PSIS (motivation and confidence).
Keogh et al. (2003) Field Hockey	Sprint (10,40m) RSA (10,40m) MSFT VJ Hand grip strength Agility (Illinois)	H H H M L H	Agility (Illinois) dribble Shooting accuracy Pushing speed	M M M					Sprinting, % body fat, agility, dribbling control, aerobic and muscular power, and shooting accuracy can discriminate btn female players of varying standards.

Study and Category	Exercise Physiology Tests	R	Motor Control Tests	R	Biomechanics Tests	R	Sport & Exercise Psychology Tests	R	Main Findings
Elferink-Gemser et al. (2004) Field Hockey	Peak shuttle sprint	H	Peak shuttle dribble	M			PSIS	L	E youth scored better than SE players on technical (dribble performance in peak and repeated shuttle run), tactical (general tactics; tactics for possession and non-possession of ball) and psychological variables of PSIS (motivation)
	Repeat shuttle sprint	H	Dribble repeat shuttle	M					
			Slalom dribble	M					
	Slalom sprint	H	Tactics in sport questionnaire	L					
	Interval endurance	H							
Elferink-Gemser et al. (2004) Field Hockey	Peak shuttle sprint	H	Peak shuttle dribble	M			PSIS	L	E youth scored better than SE players on technical (dribble performance in peak and repeated shuttle run), tactical (general tactics; tactics for possession and non-possession of ball) and psychological variables of PSIS (motivation)
	Repeat shuttle sprint	H	Dribble repeat shuttle	M					
			Slalom dribble	M					
	Slalom sprint	H	Tactics in sport questionnaire	L					
	Interval endurance	H							
Nieuwenhuis et al. (2002) Field Hockey	MSFT	H	Agility dribble	M			CSAI-2	L	Successful players performed sig better than less successful players in regard to frontal thigh skinfold, MSFT, 40m sprint, agility dribble, metre stick test, slalom dribble, push for accuracy air, and each subscale of AMSSE (motivation)
	VJ	M	Metre stick test	M			AMSSE	L	
	Multi-level sit ups	L	Push for accuracy ground	M					
	Sit and reach	L	Hit for accuracy stationary ball	M					
	Sprint (40m)	H	Hit for accuracy rolling ball	M					
	Agility (505)	H	Push for accuracy air	M					
			Slalom dribble	M					
			Reverse stick pass for accuracy	M					
			Hit for distance and accuracy	M					

Study and Category	Exercise Physiology Tests	R	Motor Control Tests	R	Biomechanics Tests	R	Sport & Exercise Psychology Tests	R	Main Findings
Pion et al. (2015) Gymnastics	Sit and reach Sprint (40m) CMJ Knee push ups Sit ups Rope skipping (60 secs)	H H H H M M	Motor coordination skills (KTK): KTK balance beam KTK jumping sideways KTK moving sideways KTK hopping for height Basic locomotion motor skills *(running backwards, skipping, hopping, shuffle pass, cross steps, bouncing, jumping jacks, tuck jumps, giant jumps)*	 H H H H H					Gymnasts with score in best quartile of basic motor skills, shoulder strength, leg strength and three gross motor coordination items had sign ↑ chance of survival in program.
Vandorpe et al. (2011) Gymnastics	Sit and reach Sprint (20m) CMJ Knee push ups Sit ups Rope skipping (60 secs) Leg lifts Rope climbing	H H H M M M M M	Motor coordination skills *(KTK)*: KTK balance beam KTK jumping sideways KTK moving sideways KTK hopping for height Basic locomotion skills *(running backwards, skipping, hopping, shuffle pass, cross steps, bouncing, jumping jacks, tuck jumps, giant jumps)*	 H H H H H					E potential gymnasts outperformed SE gymnasts on all physical and coordinative variables. Discriminant analysis revealed motor coordination is most important in discriminating btn young female E and SE gymnasts.

Study and Category	Exercise Physiology Tests	R	Motor Control Tests	R	Biomechanics Tests	R	Sport & Exercise Psychology Tests	R	Main Findings
Matthys et al. (2013) Handball	Sit and reach YYIR1 CMJ Five jump test Sit ups Hand grip Cross hopping Shuttle run Handball shuttle run Sprint (5, 10, 20, 30m)	L H M M L L M H H H	Slalom dribbling	M					E players performed sig better than SE on YYIR1, shuttle run, cross hoping, handball shuttle run, slalom dribbling, and 30m sprint. YYIR1 and coordination with and without the ball were most discriminating factors btn playing levels.
Matthys et al. (2011) Handball	Sit and reach YYIR1 CMJ Five jump test Sit ups Hand grip Cross hopping Shuttle run Handball shuttle run Sprint (5, 10, 20, 30m)	L H M M L L M H H H	Slalom dribbling	M			TEOSQ	L	E players had sig greater aerobic capacity, strength and power (U14: CMJ, sit ups, handgrip U16: CMJ, five jump test) and speed and agility than SE when maturation was controlled for. E and SE did not differ in TEOSQ.
Vandendriessche et al. (2012)	Sprint (20m) Agility	H H	Slalom dribbling Ball control Shooting	M M M					Empirical evidence provided on relevance of speed related and technical skills with results demonstrating that motor predictors prognostic validity over 9 years period.

Study and Category	Exercise Physiology Tests	R	Motor Control Tests	R	Biomechanics Tests	R	Sport & Exercise Psychology Tests	R	Main Findings
Höner et al. (2017)									
Soccer									
Figueiredo et al.	YYIETL1	H	Ball control	M					Except for the CMJ, predictors of
(2011)	Sprint	H	Dribbling	M					functional capacities and soccer skills
Soccer	Agility	H	Shooting accuracy	M					differed btn age groups.
	CMJ	M	Passing	M					
Hoare and Warr	VJ	M	Juggling	M					It is possible to select potential E
(2000)	Sprint (5,10,20m)	H	Dribbling	M					female soccer players based on
Soccer	Agility (505)	H	Passing & receiving	M					anthropometric, physiological and skill
	MSFT	H	Agility with ball	M					attributes.
			SSG *(3v3, 6v6)*	H					
Reilly et al.	Sprints	H	Shooting	M			TEQOSQ	L	Most discriminating measures btn E
(2000)	(5,15,25,30m)		Slalom dribble	M			CSAI-2	L	and SE groups were agility, sprint time,
Soccer	MSFT	H	Anticipation test	L					aspects of TEQOSQ (ego orientation)
	VJ	M	*(video based)*						and anticipation test. E players were sig
	Agility	H							leaner, possessed more aerobic power
									and were more tolerant of fatigue. E
									players were better at dribbling but not
									shooting.

Study and Category	Exercise Physiology Tests	R	Motor Control Tests	R	Biomechanics Tests	R	Sport & Exercise Psychology Tests	R	Main Findings
Talent Selection									
Cripps et al. (2017) AF	VJ DVJ Sprint (20m) MSFT	M H H H	AFL Kicking test AFL Handball test	M M					Talent identified players at U16 level are likely to be more biologically more mature than non-talented players. Further differences btn groups were evident in measures of standing and sitting height, DVJ non-dominant foot and handball test scores. Strongest measures to define player status were standing height, DVJ non-dominant foot and handball test scores.
Tribolet et al. (2018) AF	Agility (T test) SBJ Knee Push Ups	H M L	Kick technique Kick game Marking Handballing *Coach rank of above Motor coordination skills *(KTK):* KTK balance beam KTK jumping sideways KTK moving sideways	M H M M L L L					There were sig age related differences for anthropometry, fitness and coach skill ratings. Selected players were more mature, taller, heavier, more explosive, faster at changing directions and had superior kick technique and marking results.
Torres-Unda et al. (2013) Basketball	Endurance test Sprint (20m) CMJ-S	H H H	Slalom dribble test Point average score in games	M L					E players are taller, heavier and high higher muscle percentage that non-E players. E players perform better in jump, endurance, sprint and slalom dribble test.

Study and Category	Exercise Physiology Tests	R	Motor Control Tests	R	Biomechanics Tests	R	Sport & Exercise Psychology Tests	R	Main Findings
Bartolomei et al. (2018) Field Hockey	Hand grip CMJ Sprint (30m) MSFT Agility (slalom)	L M H H H	Pushing speed Shooting accuracy Dribble test	M M M					Division 1 players when compared to Division 2 players had lower % body fat and performed 14.5% better on shooting accuracy. There were no sig differences between groups for shooting speed, slalom agility and performance dribble.
Massuca et al. (2014) Handball	Sprint (30m) Grip strength SJ CMJ Sit ups YYIE2	H L M M L H	Handball skill test: (coach rank on): Pass and reception Shooting 1 v 1 actions Create and occupy space Tactical skills Reactive ability	 M M M M M M			TEOSQ BVLQ	L L	E players scored better on all fitness tests (sprint 30m, grip strength, SJ, CMJ, sit ups, YYIE2) as well as handball specific tests (pass and reception, shooting, 1 v 1 actions, create and occupy space, tactical skills, reactive ability) than SE players. No statistically sig results btn E and SE players for TEOSQ.
Tredrea et al. (2017) Rugby League	CMJ Sprint (10,40m) Push ups Chin Ups MSFT	M H M M M					MTQ48		Sprint (10m), Vo2 max and body mass sig predicted selection in U16 players whilst push-ups, sprint (10m), body mass and chronological age sig predicted selection in U18 players.
Gabbett et al. (2011b) Rugby League	Sprint (10,40m) Agility (505) VJ RSA (20m) MSFT	H H M H H	Tackling (1v1) Draw and pass (2v1) *(single condition)* Draw and pass (2v1) *(dual task)* Reactive agility Pattern recall and prediction *(video)*	H H H M L					Selected players were older, more experienced, leaner, had faster 10m and 40m sprint times, had superior VJ, MSFT, tackling proficiency, and dual task draw and pass ability than non-selected players. Skinfold thickness and dual-task draw and pass proficiency were only variables that contributed sig to discriminant analysis of selected and non-selected players.

Study and Category	Exercise Physiology Tests	R	Motor Control Tests	R	Biomechanics Tests	R	Sport & Exercise Psychology Tests	R	Main Findings
Huijgen et al. (2014) Soccer	Peak shuttle sprint Repeated shuttle sprint Slalom sprint ISRT	H H H H	Peak shuttle dribble Repeated shuttle dribble Slalom dribble TACSIS	M M M L			TEOSQ PSIS - Youth	L L	Selected players performed sig better than non-selected players in peak and repeated shuttle sprint, peak and repeated shuttle dribble, and aspects of TACSIS (positioning and deciding). Discriminant function analysis showed the combination of peak dribbling, aspects of TACSIS (positioning and deciding) and peak sprinting classified 69% of talented players correctly.
Vandendriessche et al. (2012) Soccer	Hand grip Sit and reach SBJ VJ T test Sprint (5,10,20,30m)	L L M M H H	U Gent dribbling KTK balance beam KTK jumping sideways KTK moving sideways KTK hopping for height	M L L L L					More mature players possessed higher morphological measures and outperformed later maturing peers on all fitness tests except sit and reach and sprint 5m. Soccer specific (U Gent dribbling) and non-specific (KTK tests) motor coordination tests did not differentiate btn maturity levels.
Coelho e Silva et al. (2010) Soccer	SJ CMJ Agility RSA YYIE1	M M H H H	Ball control with body Dribbling speed Shooting accuracy Wall pass	M M M M			TEOSQ		Compared to non-selected players, selected players had an ↑ maturity status, were heavier, taller, performed better in explosive power, repeated sprints, ball control and were more ego oriented (aspect of TEOSQ). Selection of players was associated with advanced skeletal maturity, ego orientation, years training in sport, muscular power, agility and speed.

Study and Category	Exercise Physiology Tests	R	Motor Control Tests	R	Biomechanics Tests	R	Sport & Exercise Psychology Tests	R	Main Findings
Figueiredo et al. (2009) Soccer	YYIETL1 Sprint Agility CMJ	H H H M	Ball control Dribbling Shooting accuracy Passing	M M M M			TEOSQ	L	E players were older chronologically and skeletally, larger in body size and performed better in functional capacities and three skill tests that club players and dropouts. Baseline TEOSQ did not differ among dropouts and club and elite players at follow up.
Vaeyens et al. (2006) Soccer	Sit and reach SBJ VJ Hand grip strength BAH Abdominal strength Abdominal endurance Sprint (30m) Shuttle sprint Agility ESHR STR	L M M L L L L H H H H H	Slalom dribble Lob pass Shooting accuracy Juggling	M M M M					E players scored better than SE players on strength, flexibility, sprint, aerobic endurance, anaerobic capacity and several technical skills.
Rikberg and Raudsepp (2011) Volleyball	Sit ups Agility (Illinois) VJ	L H H	Volleyball skill test *(coach rank on):* Passing Setting Serving Spiking Game intelligence (coach observe in game) Decision making *(video)*	 M M M M H L			AGQ-S SPPC SEBS	L L L	Selected players scored better than non-selected players in VJ, passing, spiking, game intelligence characteristics, and reported higher mastery approach goals (AGQ-S), perceived sport competence (SPPC), and enjoyment of sport (SEBS). Most discriminating variables were game intelligence, mastery approach goals, perceived sport competence and passing technique.

Study and Category	Exercise Physiology Tests	R	Motor Control Tests	R	Biomechanics Tests	R	Sport & Exercise Psychology Tests	R	Main Findings
Gabbett et al. (2007) Volleyball	VJ Spike jump OH med ball throw Sprint (5,10m) Agility (T-test) MSFT	H H M H H H	Spike accuracy Spike technique Serving accuracy Serving technique Setting accuracy Setting technique Passing accuracy Passing technique *Accuracy involved hitting specified target and technique involved coach rank of skill whilst performing accuracy test	M M M M M M M M					Discriminant analysis showed that passing technique and serving technique were the only significant variables to distinguish btn successful and unsuccessful talent identified players.
Falk et al. (2004) Water Polo	Swimming ability: Freestyle 400m Freestyle 200m Freestyle 100m Freestyle 400m Freestyle 50m Breast-stroke 50m Butterfly 100m VJ in water	 H H H H H H H H	Ball dribble Goal throw Distance throw Game intelligence *(coach observe in game)*	M M M H					Players who made final selection (after 2 years in program) were superior on the majority of swim tasks, dribbling and game intelligence and this superiority was maintained for the 2 years period.
Competition Performance									
Gómez-Molina et al. (2017) Half- Marathon Running	Vo2 Max HR Max RCT% Vo2 Max Peak speed RCT speed *Measures taken during incremental run test	H H H H H			Min contact time Max step rate Max step length RCT contact time RCT step rate RCT step length *Measures taken during incremental run test	H H H H H H			Performance was predicted by a model which included peak speed, RCT speed and years of running experience.

Study and Category	Exercise Physiology Tests	R	Motor Control Tests	R	Biomechanics Tests	R	Sport & Exercise Psychology Tests	R	Main Findings
Novak et al. (2018a) Mountain Biking	Grip strength Vo2 Max MAP PPA peak PPA mean * Measures taken during incremental cycle test	L H H H H	Decision making test *(video based)*	L					Performance was predicted using a model which included Vo2 Max relative to total cycling mass, maximal mean power across 5 and 30 s peak left hand grip strength and response time for correct decisions in the decision making test.
Novak et al. (2018b) Mountain Biking	Grip strength Vo2 Max MAP PPA peak PPA mean * Measures taken during incremental cycle test	L H H H H	Decision making test *(video based)*	L					Performance was predicted using a model which included Vo2 Max rel to total cycling mass, max power output sustained over 60 s rel to total cycling mass, peak left hand grip strength, and two-line decision making score.
Barrett and Manning (2004) Rowing	Peak strength Forward flexion Low back flexion Hamstring flexion Planter flexion 2 km ergo time *Peak strength taken during 2km ergo time	H L L L L H			Kinematic variables (taken during race. E.g. trunk angle at catch)	H			Individual variables that had highest significant correlations with 2km race time were 2 km ergo time, mass, height, oar length and peak strength.

Study and Category	Exercise Physiology Tests	R	Motor Control Tests	R	Biomechanics Tests	R	Sport & Exercise Psychology Tests	R	Main Findings
Gabbett et al. (2011a) Rugby League	Sprint (10,40m) Max velocity Agility (505) VJ RSA Prolonged high intensity intermittent running	H H H M H H	Tackling (1v1) Draw and pass (2v1) *(single condition)* Draw and pass (2v1) *(dual task)* Reactive agility Pattern recall and prediction *(video)*	H H H M L					Line break assists was sig associated with greater playing experience, dual-task draw and pass proficiency, reactive agility, pattern recall and prediction ability. Faster speed (40m) was sig associated with a higher number of tries scored. Greater age and playing experience, better lower body muscular power, and faster 10 m and 40 m speed were sig associated with the number of tackle attempts, tackles completed and proportion of missed tackles.
Morais et al. (2017) Swimming	Swim velocity * Measures taken during 25m maximal swim	H	Stoke frequency Stroke length * Measures taken during 25m maximal swim	H H	Intra-cyclic velocity Propelling efficiency Stroke index * Measures taken during 25m maximal swim	H H H			Performance over 3 seasons was predicted using a model including age, arm span, stroke length and propelling efficiency.

EP= Exercise Physiology, MC=Motor Control, B=Biomechanics, SEP=Sport & Exercise Psychology, R = Rating, H=High, M=Medium, L=Low, KTK=Korperkoordinationstest fur Kinder, COD=Change of Direction, VJ=Vertical Jump, DVJ=Dynamic Vertical Jump, RSA=Repeat Sprint Ability, HIR=High Intensity Running, MFST=Multi-Stage Fitness Test, TEQOSQ=Task and Ego Orientation in Sport Questionnaire, CSAI-2= Competitive State Anxiety Inventory-2, SBJ=Standing Broad Jump, BAH=Bent Arm Hang, ESHR=Endurance Shuttle Run, STR=Shuttle Tempo Run, 20m pro run=20metre progressive run, YYIE1=Yo-Yo Intermittent Endurance Level 1, YYIETL1=Yo-Yo intermittent endurance level 2, YYIR1=Yo-Yo Intermittent Recovery Level 1, CMJ=Counter Movement Jump, CMJ-S= Counter Movement Jump with Arm Swing, SSG=Small sided games, PSIS=Psychological Skills Inventory for Sports, AMSSE=Achievement Motivations Scale for Sporting Environments, SJ=Squat jump, TEOSQ=Task and Ego Achievement Goal Orientations, AGQ-S=Achievement Goals Questionnaire for Sport, SPPC=Self-Perception Profile for Children (athletic subscale used only), SEBS=Satisfaction/Enjoyment/Boredom in Sport (enjoyment subscale used only), AF=Australian Football, Australian Football League, WOFO=The Work and Family Orientation Questionnaire, DPMQ=Deliberate Practice Motivation Questionnaire, BVLQ=Biosocial Variables and Lifestyle Questionnaire, MTQ48=Mental Toughness Questionnaire 48, ISRT=Interval Shuttle Run Test, TACSIS=Tactical Skills Inventory for Sport, OH=Overhead, RCT=Respiratory Compensation Threshold, MAP=Maximal Aerobic Power, PPA=Peak Power Assessment, E=Elite, SE=Sub-elite, btn=between, rel=relative, ES=Effect Size, sig=Significantly

2.4 Discussion

This systematic review set out to determine whether we were answering the call for interdisciplinary research in the field of sports science. The primary purpose of this systematic review was to identify and critique sports science research articles that integrated multiple sub-disciplines in the domains of talent identification, talent selection, and competition performance. The secondary purpose of this review was to critique the level of analysis and RTD of the assessments presented in the research articles. The majority of the articles that met the inclusion criteria were classified as interdisciplinary, indicating that sport science is responding to the call of Burwitz et al. (1994) for more interdisciplinary research.

There are several possible reasons why the field of sports science has progressed towards interdisciplinary research. First, there simply may be improved collaborations between researchers from the different sub-disciplines of sports science. For example, researchers with expertise in Functional Anatomy, Exercise Physiology and Motor Control have combined to incorporate sub-discipline knowledge to better understand sport performance (Gabbett, Jenkins, & Abernethy, 2011a), Second, progressive evidence across monodisciplinary to interdisciplinary studies have reported better prediction of the intended outcome. For example, Woods, Raynor, Bruce, and McDonald (2016) created a video decision making test for AF players (Motor Control sub-discipline), which was able to discriminate decision-making performance between talent identified and non-talent identified players. Thereafter, the test was incorporated into an interdisciplinary study which included measures from Functional Anatomy, Exercise Physiology and Motor Control (technical skill) to provide a more comprehensive discriminator and stronger predictor of talent (Woods et al., 2016). It is likely that these combined tests provide a stronger prediction because they incorporate a combination of constraints that are representative of talent and performance in the competition setting. Third, sports science researchers may have developed a better understanding of advanced statistical analyses to deal with multiple sub-discipline measures (such as linear regression modelling, step-wise discrimination analysis and receiver operating curves) (see Gabbett, Jenkins, & Abernethy, 2011b; Woods et al., 2016)). Utilisation of more complex statistical analyses allows sports science researchers to integrate knowledge and variables from the different sub-disciplines, including their interactions, to generate a more holistic understanding of the complex interplay between sub-discipline knowledge to create new knowledge of athlete performance.

The move towards interdisciplinary sports science research will provide a better understanding of how individual, task and immediate environmental constraints interact (Higgins, 1977; Newell, 1986) to explain sport performance. This is because a constraints approach has the capability, as argued by Ibáñez-Gijón et al. (2017), to inform how the perception scale (e.g., decision-making) interacts with the execution scale (e.g., coordination) to achieve the goal of the designated sport skill. Here, a critical point to determine the more consistent adoption of an interdisciplinary approach is to consider how these scales are captured in terms of individualised constraints and representative tasks that encapsulate interacting constraints.

In relation to individualised comparisons, the finding in this review that the majority of the articles completed their analysis at the group level, is not entirely surprising. This is likely because the traditional approach to sampling, experimental design and statistical analyses are focused upon larger group-based differences or correlational relationships, which are deemed to be generalisable to a broader population. Accordingly, the domains of talent identification and talent selection lend themselves to group study designs because they include relatively larger samples such as 'talent identified and non-talent identified' (Woods et al., 2016), 'elite and sub-elite' (Elferink-Gemser, Visscher, Lemmink, & Mulder, 2004, 2007) and 'successful and less successful' (Nieuwenhuis, Spamer, & Russom., 2002) participants. In recent times, however, sport science research has incorporated understanding of attainment of expertise in sport (Baker & Farrow, 2015). Expertise research has moved towards the investigation of individual differences as this approach allows the study of variables that constitute an exceptional test batsman or footballer or soccer player to be unravelled from others, rather than being masked by group scores (Phillips et al., 2010). As the field of sport expertise continues to grow, it is reasonable to expect that there will be more research conducted at the individual level. This is because expert performers can achieve the task goals in different ways and to levels of success; so analysing their individual differences will also be useful for coaches (Davids et al., 2015). Therefore, developing protocols that explore skill differences among individuals is needed to understand individualised constraints to sport performance.

In regards to RTD, the review identified a range from low to high representative design tasks across the sub-disciplines. For example, in the decision-making test used in the performance prediction study for mountain bikers, participants had to watch a video of an experienced mountain biker riding trails and then choose the fastest line option as quickly as possible by touching an arrow (Novak, Bennett, Fransen, & Dascombe, 2018a). This test was rated as a low level of RTD as it was video based and did not require participants to couple action to available perceptual information as in the competition environment. Despite this, the decision-making test was found to contribute significantly to a model which was able to predict overall time-trial performance (within 2% accuracy), along with VO_2 Max relative to total cycling mass, maximal mean power across five and 30 s and peak left hand grip strength (Novak et al., 2018a). Accordingly, low representative design tests can still be valuable as long as they, for example, represent the perceptual information (constraint) used in the competition setting. Alternatively, all Biomechanics tests were rated as high in RTD. For example, Morais, Silva, Marinho, Lopes, & Barbosa (2017) calculated 'propelling efficiency' from swimming kinematic data when participants performed three maximal 25m time trials with analysis showing that propelling efficiency was part of a model that was able to predict performance along with age, arm span and stroke length. In contrast, there were no Sport and Exercise Psychology tests rated as having a high level of RTD and this is because all the tests in the identified studies relied solely on survey methodology. Again, it is not our contention that the Sport and Exercise Psychology survey tests are not valuable, in fact some could discriminate between groups such as Task and Ego Achievement Goal Orientations Questionnaire (Coelho e Silva et al., 2010), but there appears to be scope to expand these measures to incorporate *in-situ* sport-specific representative tests that may provide new insights into psychological skills. This approach is now beginning to gain momentum in the Sport Psychology literature (see Bell, Hardy, & Beattie, 2013).

It is not surprising that soccer features most prominently in terms of integrated sports science research. The majority of professional soccer clubs and national associations run youth academies in order to identify talent which is a priority for such organisations, as focusing resources on developing a talented pool of future athletes from a young age can equate to a more effective financial investment (Fenner et al., 2016). These soccer academies and other similar programs then become the focus of integrated research as the clubs attempt to develop those young players who had been identified as future elite players through a talent identifcation program.

The proliferation of talent academies that attempt to identify and develop future elite players across all sports is one logical reason why the majority of integrated sports science research occurs in the talent identification domain. An effective talent identifcation program increases the likelihood of success and can generate significant finiancial rewards. It is not uncommon to see millions of dollars invested in evidence-based strategies in order to gain a competitive advantage (Hogan & Norton, 2000). These progams can become the focus of research by sports scientists and can result in large-scale studies that undertake a battery of multidisciplinary tests. A challenge for talent academies is to ensure the tests involved in these studies are representative of the performance demands of the sport (Johnston, Wattie, Schorer, & Baker, 2018).

In contrast, the least amount of integrated research occurred in the competition performance domain. One possible reason for this is that for competition performance research to occur, sports scientists need to be able to measure the individual performance of an athlete in a competition environment. This can be relatively easy in sports such as swimming, running and cycling, as time can be used as a valid measure, but it is more challenging in team sports. For example, how does a rugby league coach measure the performance of an individual player in a game? Gabbett et al. (2011a) measured performance in rugby league by coding game-specific events in both attack and defence from video replays and included items such as runs, line breaks, tries, try assists, tackle breaks, dominant tackles, ineffective tackles and tackling efficiency. Access to such competition performance data generally occurs at only the professional levels of sport where games are broadcast on television or sports scientists are hired to independently film and code the match performance which are time intensive and hence, a possible reason for the lack of integrated research in competition performance. Furthermore, such applied research can be limited in sample size, due to their being a relatively smaller number of professional athletes in a team, compared to those talent identification programs that attempt to select potential athletes from a larger group. The value of such highly representative smaller samples in high-performance sport may not be fully appreciated, which can lead to less published research (Cardinale, 2017).

Functional Anatomy and Exercise Physiology were the most commonly occurring sub-disciplines included within integrated sports science research. Body composition and anthropometric assessments are classified as Functional Anatomy and these are standard practice for coaches and athletes (Ratamess, 2012). Previous literature which reviewed sports science research also concluded that Exercise Physiology was a dominant research sub-discipline (Williams & Kendall, 2006). The lack of representation from Biomechanics in integrated sports science research could be due to feasibility, as research in this sub-discipline often relies on expensive and non-portable equipment which can restrict data collection to laboratory based investigations rather than field settings. Feasibility of research methods is an important consideration for engaging athlete and coach compliance (Robertson, Burnett, & Cochrane, 2014). Feasibilty of Biomechanical tests was overcome in one article identified in the review, by using video capture and motion analysis during a competition event (Barrett & Manning, 2004). Improved portability of testing equipment and the development of non-invasive wearable sensors will increase the opportunity to conduct Biomechanics research in field (*in-situ*) or competition settings (Williams & Kendall, 2006), as well as integrate Biomechanics into sports science research.

In summary, this systematic review of 36 published articles has provided evidence that the field of sports science is beginning to undertake integrated research that combines multiple sub-disciplines. The majority of this research was classified as interdisciplinary incorporating knowledge, methods and measures from three or more sub-disciplines to better understand sport performance. Talent identification is the domain where there is the most prolific integrated sports science research, followed by the talent selection and competition performance domains. Group analysis was used in all talent selection and talent identification studies, whereas individual analysis was more common in competition performance studies. Levels of RTD varied from low to high in the performance tests used in the articles identified, however, close to half of all performance tests were considered to have a high level of RTD. When undertaking future interdisciplinary sports science research, individual differences and RTD need to be carefully considered.

Chapter 3 Small-Sided Games Can Discriminate Perceptual-Cognitive-Motor Capability and Predict Disposal Efficiency in Match Performance of Skilled Australian Footballers

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Small-sided games can discriminate perceptual-cognitive-motor capability and predict disposal efficiency in match performance of skilled Australian footballers

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Research synthesis

The previous chapter highlighted the void of interdisciplinary research in the sport of AF within the competition performance domain. Furthermore, there was an absence of a performance test in the Motor Control sub-discipline in AF across all sport performance domains, that could offer high level RTD, and which was effective in measuring perceptual-cognitive-motor capability. Chapter three addresses these gaps in the literature by creating a performance test for AF based on SSG which can also predict a component of match performance.

Article information

Title

Small-sided games can discriminate perceptual-cognitive-motor capability and predict disposal efficiency in match performance of skilled Australian footballers

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Abstract

This study determined if SSG could discriminate perceptual-cognitive-motor skill in Australian Footballers. Higher skilled WAFL (*n* = 17) and lesser skilled Amateur (*n* = 23) players were recruited. Participants played three SSG of three minutes. Each disposal was scored for decision-making and motor skill execution, with these scores combined for a total score. Mann-Whitney U tests indicated significantly superior mean decision-making by higher skilled (*M* = 2.9, *SD* = 0.02) over lesser skilled (*M* = 2.7, *SD* = 0.04) (*p* = .012) players. Execution score was not significantly different between groups. Linear mixed model analysis found higher skilled players (*M* = 5.3, *SD* = 0.08) scored significantly higher than lower skilled players (*M* = 4.9, *SD* = 0.13) on total score (*p* =.009). Large effect sizes were found for decision-making and total score relative to games and position played in WAFL players. High agreement of scoring was observed for an elite (inter-rater) and a novice (intra-rater) coaches. Linear mixed model analysis indicated mean total scores of WAFL players significantly predicted disposal efficiency in match performance (*p* = .011). SSG can be easily implemented to identify talented players and assess perceptual-cognitive-motor skill.

Keywords

RTD, decision-making, motor skill execution, SSG, sports-specific assessment

3.1 Introduction

AF is a dynamic invasion sport, where players move the ball toward the attacking end by running, kicking or handballing with the end aim to kick a goal (Cripps, Hopper, & Joyce, 2015). Because of the fast paced and dynamic nature of AF, professional teams invest significant time and financial resources to identify skilful players (Cripps, Hopper, Joyce, & Veale, 2015); superior decision-making (Berry, Abernethy, & Côté, 2008) and accurate execution to achieve the skill goal (Parrington, MacMahon, & Ball, 2015) are key components of skilful players. Therefore, development of a test that is highly representative of the game, which can discriminate skilled players, and predict a match performance component, would be valuable for talent identification and athlete development.

Performance in sports such as AF is comprised of two components, 'how' which refers to technique (motor skill execution) and 'what' which refers to decision-making (perceptual–cognitive skill) (Starkes, Cullen, & MacMahon, 2004). Sports-specific tests commonly focus on technical execution to identify talented players and they can be used to guide further skill development in established players (Elferink-Gemser et al., 2004; Gabbett et al., 2011b). For example, the AF skill test kicking component requires the player to turn with ball in possession, run a short distance and kick to one of six stationary target players (Cripps et al., 2015; Woods, Raynor, Bruce, & McDonald, 2015). In the handball component, the player runs to receive the ball and is required to handball at one of six stationary target players (Cripps et al., 2015; Woods et al., 2015). These tests, however, do not incorporate the dynamic nature of AF play to probe combined perceptual-cognitive-motor components of sports-specific skill.

Perceptual-cognitive skill has been predominantly assessed in team sports using video simulation tests to probe decision-making (Berry et al., 2008; Lorains, Ball, & MacMahon, 2013; Woods et al., 2016). Typically, a participant is required to watch video of sports-specific game scenarios and at the conclusion of the footage make a written, verbal or button-press choice of the best option to pass the ball. It has been reported that talent-identified and expert AF players made more accurate decisions compared to non-talent identified and sub-elite AF players, respectively (Lorains et al., 2013; Woods et al., 2016). Accordingly, fine-grained skill group discrimination is possible with video tests, but the focus is more on the perceptual-cognitive component of the skill.

Some researchers argue that RTD needs to be taken into consideration when designing sports-specific tests in order to better capture how perception informs action and to produce more generalisable findings (Vilar et al., 2012). Accordingly, Araujo and Davids (2015) outlined three principles for designing representative sports-specific tests that include; visual-perceptual information (stimuli), action fidelity (coupling of action) and performance achievement. Visual-perceptual information refers to sports-specific stimuli such as the creation of space by a teammate in AF that invites a kick or handball from another teammate in possession of the ball. Action fidelity refers to the capability of the player to perform their skills such as to run, kick and handball like in a game of AF. Performance achievement can vary depending upon the sport; in AF this can relate to the correct decision to pass to a teammate in space and the accurate execution of the pass. Therefore, the challenge exists to design a highly representative test that incorporates decision-making and motor skill execution for AF.

In-situ tests are one way to increase the level of RTD where perceptual information and action fidelity are closely related to the game setting (Müller et al., 2015). SSG can be used as an *in-situ* test, where small teams of players compete against each other, to mimic the dynamic change of player positions under limited space and time to execute perceptual-cognitive-motor skills that mirror the competition setting. For example, Farrow, Pyne, and Gabbett (2008) compared skill demands of open (SSG) and closed (repetition drills) skills in AF. Results indicated that SSG required greater decision-making coupled with skill execution compared to closed skill drills (Farrow et al., 2008). This implies that SSG are more representative of perceptual-cognitive-motor skill required for AF competition. The motor skill execution tests, currently used in AF skills testing, tend to isolate action fidelity from contextualised visual-perceptual information (Davids, Araújo, Correia, & Vilar, 2013). Therefore, use of SSG as a perceptual-cognitive-motor skill test could preserve the tight coupling of critical perceptual information to guide the execution of a motor skill that is more reflective of the competition setting (Pinder et al., 2011b).

The primary purposes of this study were to determine; (i) whether perceptual-cognitive-motor differences (decision, execution and total score) exist between higher and lower skilled AF players during a SSG test, (ii) the reliability of scoring decision-making and motor skill execution in a highly dynamic SSG, and (iii) whether test scores in the SSG predicted disposal efficiency in match performance of AF. A secondary exploratory purpose of this study was to determine whether perceptual-cognitive-motor differences existed within the highly skilled group relative to the number of senior games played and position. We hypothesized that: (a) higher skilled players will achieve significantly higher scores than lower skilled players in decision making, motor skill execution and total score, and (b) scores from higher skilled players would predict disposal efficiency in match performance of AF.

3.2 Method

3.2.1 Participants

A total of 40 male participants were recruited for this study from two WAFL competitions. A higher skilled group (*n* = 17) comprised of one semi-professional WAFL club who participate in the state league. The lower skilled group (*n* = 23) was recruited from two West Australian Amateur Football League (WAAFL) Clubs. A priori power analysis was conducted based on $\alpha = 0.05$, power $(1- \beta) = 0.8$, effect size = 0.15, and two groups (WAFL and Amateur) with a total sample of 351 trials required. The inclusion criteria for the higher skilled group was that participants had to have played at least one senior game at WAFL level within the previous two years. Players from either skill group were excluded if they had an injury at the time of testing which prevented them performing as they would in a typical game situation. The age of the higher skilled group was (Mage = 23.0 years, age range: 20-29) and the lower skilled group was (Mage = 23.9, age range: 19-30). Ethical approval was granted by the Ethics Committee from the University of Notre Dame, Australia (ref: 016050F) and participants provided written informed consent.

3.2.2 Design and procedure

Participants completed the SSG test at the end of their pre-season period. Participants were divided into teams consisting of six attackers versus five defenders (one defender on the bench who could rotate into the team). The higher skilled and lesser skilled participants completed the testing at separate times to ensure that participants in each session were of the same skill level, that is, higher skilled defenders versus higher skilled attackers. Only the attacker participants were assessed and were given the task of maintaining possession of the football for a three minute period (one set) in a 40 m x 40 m grid. The task of keeping possession of the ball is highly representative of competition at the AFL elite level. To this, Woods, Robertson, and Collier (2017) reported that AFL coaches have adopted tactics from other team invasion sports such as field and ice hockey, soccer and basketball where players use possession tactics to maintain control of the game and search for attacking opportunities. A grid size of 40m x 40m was selected, as this size had been previously used to investigate open skills in AF (Farrow et al., 2008). In addition, the grid size allowed for players to execute disposals by foot over short (~25m), medium (~35m) and long (~50m) (diagonal pass) and also by hand over distances less than 15m (shortest legal kick distance), which is highly representative of AFL elite match play (Appleby & Dawson, 2002). Furthermore, the grid size enabled the raters to view the full field when scoring from the video footage; if raters are to be able to assess decision making accurately they need to be able to view all options available to the participant.

Instructions given to participants included:

- Attackers were required to maintain possession by passing the ball by hand or foot as they would in a match.
- Defenders could disrupt the attacker’s possession of the ball by intercepting, spoiling (knocking ball away from opponent during marking contest) and tackling (body check only). A body check involves a defender restraining the attacker with arms and not taking them to ground as they would in game situation. This was done to limit the chance of injury.
- If the attacking team disposed of the ball and it was intercepted or the ball went out of bounds, then the closest player on the attacking team was given the possession of the ball and the test continued.

Each attacking player wore a different coloured vest to enable each pass to be analysed easily from the video record. At the conclusion of the three minute attacking set there was a one minute change over period for the defenders and the attackers to alternate roles. Each participant was required to complete three sets each in attack and defence. The test was umpired by a research assistant with AF knowledge. Each skill group completed the testing in one session which was recorded using a standard 25 Hz video camera (Panasonic SDR-H250, Australia), which was positioned approximately 10 m off the ground, a distance of 20 m from the grid and at the halfway point of one of the grid sidelines.

The scoring system for the SSG, which was developed through pilot testing in consultation with two experts who had coached at AFL elite level, is outlined in *Table 3.1*. The execution scoring component of the test was based on a scale used in a previous AF skills test and adapted for SSG (Woods et al., 2015). Decision-making was adapted from previous literature (Práxedes, Moreno, Gil-Arias, Claver, & Del Villar, 2018) and scored as follows; (i) if the attacking player was free and had no opposition player directly marking them, this was judged the "most correct decision" in order to pass (3 points), (ii) if the attacking player was marked by a defender (not the most free player), but the distance between attacker and marking defender was enough that a pass was not intercepted, this was judged the "next correct decision" in order to pass (2 points), and (iii) the remainder of the attacking players, all marked by defenders who were close enough and could easily prevent the attacker from maintaining possession, was judged as "incorrect decision" (0 points). It took approximately two hours to complete video analysis of 40 participants for this study.

Table 3.1

Composite Score for Test Trials

Measure	**Rating**
Decision-Making	3 = Most correct decision
	2 = Next correct decision
	0 = Incorrect decision
Execution	3 = Ball reaches target player on full
	2 = Ball reaches target player on full; however the target player had to change direction to ensure this occurs
	1 = Ball reaches target player but not on full
	0 = Ball does not reach target player at all
Total	**Decision Making + Execution Scores**

The reliability of scoring was assessed by inter- and intra-rater reliability. A novice coach scored all trials by viewing the video record of the SSG. Intra-rater reliability was assessed by the same novice coach (two weeks apart) and inter-rater reliability was assessed by an expert AF coach (Level 3) on 129 (25%) of trials using the video record, which were randomly selected.

To explore the relationship between perceptual-cognitive-motor performance in the SSG test and match performance, disposal efficiency (a match statistic) was collected throughout the 2017 WAFL season. Disposal efficiency is one of the match statistics provided by a commercial statistical analytics company (Champion Data, South Bank, Australia) and is defined as the percentage of disposals that are effective. Champion Data statistics report a 99% accuracy rate for match statistics (O'Shaughnessy, 2006) and have been used in previous research involving AF (Mooney et al., 2011; Piggott, McGuigan, & Newton, 2015).

3.2.3 Data analysis

Statistical analysis was performed using IBM SPSS version 24 (IBM SPSS Statistics for Windows. IBM Corp., Armonk, NY, USA). Data was checked for normality using the Shapiro Wilk's test so that the appropriate statistical tests could be employed. Alpha level was set at .05. Cohen's *d* effect sizes were calculated, with 0.2 considered small, 0.5 medium and 0.8 large effects (Cohen, 1998).

Each time an attacking player passed the ball by a kick or handball it was recorded as a trial, with a total of 516 trials completed. The dependent variables were decision, execution and total score. For each participant, a mean score for decision, execution and total score was calculated across all completed trials.

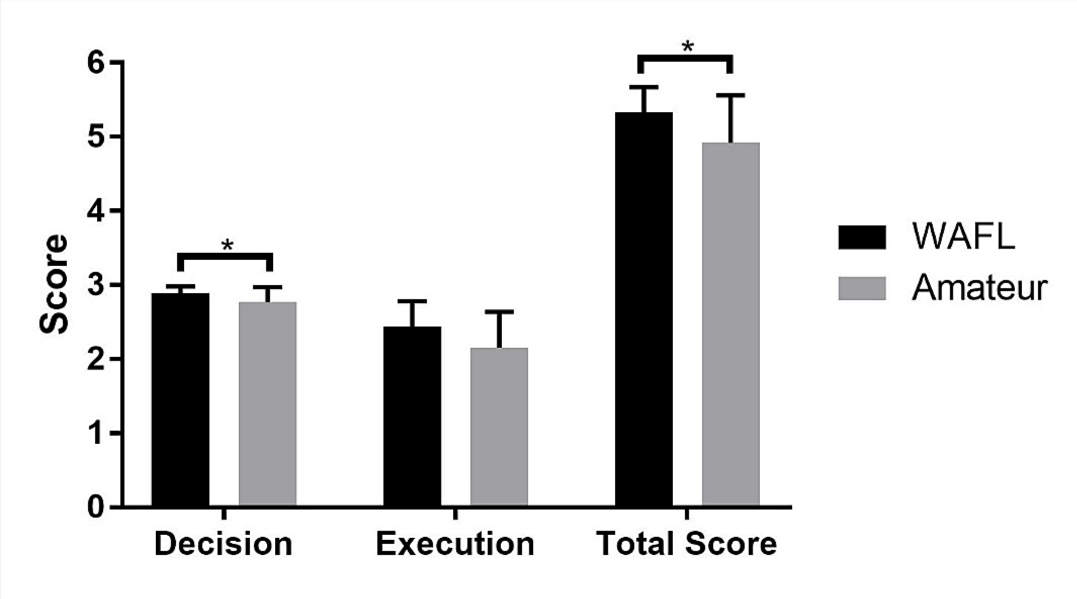
Skill group (higher and lower skilled players) differences for perceptual cognitive-motor outcome measures were examined using a linear mixed model (LMM). LLMs were used as they permit correct modelling of repeated observations (Garson, 2012), controlling for between-subject variability, increasing statistical power and the precision of the estimate, while controlling for any effects over time (e.g., set) (West, Welch, & Galecki, 2007). Residual diagnostics plots of the final reported models were assessed to ensure the LMM assumptions were met. Participants were included as a random effect, with a random slope and intercept, whilst set, skill group (categorical [SPSS factors]) and trial (continuous [SPSS covariate]) were included as fixed effects. First, three LMMs compared skill groups on each of decision, execution and total scores. The LMM models for execution and decision scores were found to violate the assumptions for the LMM, hence, Mann-Whitney U Tests were used to investigate the differences between skill group scores for each decision and execution. The reliability of scoring the SSG test was assessed using inter- and intra-rater reliability which were calculated using two-way mixed intra-class correlation coefficients (ICC) accordingly to (Portney & Watkins, 2009). The following cut-off interpretations were used for ICC values; less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 are indicative of poor, moderate, good, and excellent reliability, respectively. The relationship between total score, number of senior games played and position was investigated using Kruskal-Wallis tests (as LMM violated assumptions). Number of senior games played were grouped into three ranges, 1-25 (n = 9), 26-50 (n = 2), and 50+ (n = 6), whilst position played included, forwards (n = 4), midfield (n = 4), defenders (n = 6), and 'ruck' (n = 3). For only higher skilled players, a LMM was used to explore whether mean total score predicted their disposal efficiency in competition matches (n = 257).

3.3 Results

The higher and lower skilled groups averaged 13.32 (*SD* = 4.40) and 11.95 (*SD* = 3.92) involvements, respectively. The range of involvements for the higher skilled group was 5-23 and the lower skilled group was 5-20.

3.3.1 Group differences

The descriptive data for decision, execution and total score of the SSG test relative to skill groups is shown in *Figure 3.1*. Mann-Whitney U tests reported a significantly higher median score between higher (Decision: *Median* = 2.90, *Range* = 0.30; Total: *Median* = 5.36, *Range* = 1.13) and lower skilled (Decision: *Median* = 2.80, *Range* = 0.73; Total: *Median* = 5.11, *Range* = 1.97) players for decision (p = 0.012, d = 0.26) and total score (p = 0.037, d = 0.30). There was no significant difference between the two groups for execution score (p = 0.90), although higher skilled players still performed at a higher level (d = 0.25).



* Indicates significant difference p <.05 between groups. Error bars represent standard deviation.

Figure 3.1 Mean scores for decision, execution and total score of small-sided games test

The LMM analysis found that the set the trial occurred in and trial number were not significant factors in the test total score model and were removed from the final reported model. The first LMM (*Table 3.2*) found higher skilled players scored significantly higher than lower skilled players on the total score (β = 0.45, p =.009). Kruskal-Wallis tests showed that there was a statistically significant difference in decision scores ($\chi^2$2) = 8.82, p = 0.012, between players with 1-25 games (M = 2.86) and 51+ games (M = 2.98), as well as between players with 26-50 games (M = 2.79) and 51+ games (M = 2.98). Large effect sizes were found between the decision scores of 51+ and 26-50 (d = 2.01), as well as 51+ and 1-25 (d = 2.23) games played. There was no significant difference for total score (p = 0.102) and execution (p = 0.211) relative to games played. However, large effect sizes were found between 51+ and 1-26 games played, for total score (M = 5.56, M = 5.18) (d = 1.25) and execution (M = 2.58, M = 2.31) (d = 0.86). Kruskal-Wallis tests showed no significant differences for decision, execution or total score for position of play. For decision, large effect sizes were found between midfield (M = 2.94) and forward (M = 2.83) (d = 1.02) players, as well as midfield (M = 2.94) and ‘ruck’ (M = 2.85) (d = 1.35) players. For total score, large effect sizes were also found between midfield (M = 5.62) and forward (M = 5.36) (d = 0.85) players, as well as midfield (M = 5.62) and ‘ruck’ (M = 4.97) (d = 3.00) players.

3.3.2 Reliability of test scoring

Inter-rater reliability for decision (*r* = .91, range = 0.88-0.94) and execution (*r* = 0.95, range = 0.94-0.97) indicated excellent levels of agreement. Intra-rater reliability for decision (*r* = 0.90, range = 0.89-0.93) and execution (*r* = 0.95, range = 0.94-0.97) also indicated good and excellent levels of reliability respectively.

3.3.3 Relationship between test and match performance

The second LMM (*Table 3.3*) found that higher skilled players mean total score significantly predicted higher disposal efficiency in competition matches (β = 13.18, p = 0.011).

Table 3.2

Linear Mixed Model Parameter Estimates for Total Score

Parameter	Estimate (β)	SE	*95% CI*	*p*-value
Intercept	4.89	0.11	4.67 – 5.10	<.001*
WAFL[1]	0.45	0.16	0.12 – 0.77	.009*

* Indicates a significant difference p <.05
[1]Comparison group is amateur and parameter estimate is set to zero.
SE = standard error
CI = confidence intervals

Table 3.3

Linear Mixed Model Parameter Estimates for Total Score

Parameter	Estimate (β)	SE	*95% CI*	*p*-value
Intercept	-3.78	24.22	-55.41 – 47.84	.878
Total Score	13.18	4.53	3.53 – 22.82	.011*

* Indicates a significant difference p <.05
SE = standard error
CI = confidence intervals

3.4 Discussion

The primary purpose of this study was to develop a perceptual-cognitive-motor test based upon SSG specifically for AF and determine whether it could discriminate skilled performance, be reliabily scored, and predict a match performance component. The SSG demonstrated fine-grained discrimination between WAFL (higher) and Amateur (lesser) skilled players, and also predicted a component of match performance in the WAFL players. Scoring of the dynamic test was highly reliable. The secondary exploratory purpose of this study was to determine whether games and position of play could discriminate perceptual-cognitive-motor skill within higher skilled players. Collectively, it appears that the AF SSG test can be easily implemented to identify skilful players and to guide coaching intervention to target deficiency in components of perceptual-cognitive-motor skill.

The results demonstrate fine-grained skill level discrimination in relation to the decision-making ('what') component of perceptual-cognitive-motor skill in a highly dynamic test. Fine-grained discrimination of decision-making concurs with previous research which found talent-identified U18 AF players were more accurate at making correct game-based decisions when compared to their non-talent identified peers on a video decision-making test (Woods et al., 2016). Despite the difference in methodologies employed in their study and ours, both video-based and *in-situ* tests appear able to discriminate between skilled players. We believe that the test in our study had a greater level of task representation (players could couple action to sports-specific *in-situ* visual-perceptual information), compared to the video simulation tests, where perception is decoupled from overt action. Alternatively, it could be argued that the highly dynamic nature of visual-perceptual information is appropriately simulated in both video and *in-situ* tests such as they both map onto the perceptual information that occurs in the competition setting (Müller et al., 2015). Therefore, either video simulation or SSG could be used as representative tests to assess decision-making skill in team sports (Araujo & Davids, 2015).

There was no significant difference between higher skilled and lower skilled players in regards to the motor skill execution component of the test. This finding is in contrast with previous research that has found motor skill execution tests can discriminate between skilled players in AF (Woods et al., 2015). Part of the reason for the differing results could be due to the design of the skill tests. The skill tests used in previous research (Cripps et al., 2015; Woods et al., 2015) involved participants disposing of the football to stationary targets after being cued by the experimenter, which can be classified as a closed skill. This is not representative of the competition environment of AF as there is an absence of defenders and the targets are stationary. The motor skill execution component in our study was couched in a more representative open skill task that is like the competition setting, due to the presence of defenders, as well as targets (fellow attackers) who could change position as they would in the competition setting (see Farrow et al., 2008). Accordingly, through increased RTD of skill tests, it appears that it is not necessarily the motor skill execution component that is the limiting factor of expertise in AF, but rather the perceptual-cognitive component. Therefore, a skill test that probes the perceptual-cognitive component is vital for coaches to identify and develop athletes.

One possible reason why higher skilled players' decision-making scores were significantly different to lower skilled players could be related to their exposure to type of training. Typically, coaches at a WAFL club structure training where decision making is a large focus. The majority of coaches at this level have completed higher coaching accreditations (Level 2 and Level 3) and these coaches are encouraged to include decision-making tasks into training (Pill, 2015). In field hockey, another team invasion sport, it has been found that match play and coach-led practice are influential factors in the development of perceptual-cognitive skill (Drake & Breslin, 2017). In addition, WAFL clubs have the resources in terms of video feedback at both the team and individual level, which could be used to review game tactics and decision-making, which may also be used to improve the perceptual-cognitive skill of their players. Further research, however, is required to confirm whether higher qualified coaches design decision-making practice tasks that lead to enhancement of this skill in WAFL players.

An important consideration for using a highly dynamic test based on SSG as a performance test for AF is whether the test can be accurately scored. Inter-rater reliability of scoring our test showed strong agreement between expert and novice coaches and within the novice coach. The previously mentioned AFL motor skill tests reported inter-rater reliability for kicking ($r = 0.96$) and handball ($r = 0.89$) (Cripps et al., 2015). Therefore, even though the SSG test is highly dynamic with several players changing position within the grid continuously across the time allocation for the game, the scoring of the test is reliable and achieves similar results to other tests used in AFL, which are less dynamic.

A crucial finding from this study was that total score on the test for higher skilled players, comprised of deciding who to dispose the ball to and then executing the disposal, also predicted disposal efficiency in match performance. This indicates that the SSG test not only can discriminate between fine-grained skill levels, but has predictive validity. For example, based upon *Table 3.3*, a 1 point increase in total score would result in a 13% increase in match disposal efficiency, although the large confidence intervals should be noted. Previous studies that have employed motor skill execution tests in AF have not reported whether the test scores predict match performance (Cripps et al., 2015; Woods et al., 2015). This could be due to the nature of the samples used in previous studies where match statistics are not readily available; there was no match performance data for the lesser skilled group in our study. Nonetheless, our study provides useful information that the perceptual-cognitive-motor skill components probed and evaluated in SSG can reflect, to a degree, skill capability under match conditions in AF. This is consistent with relationships reported between higher performance on *in-situ* skill tests and match performance in rugby league (Gabbett et al., 2011a). There is also evidence that performance on video simulation decision-making tests is related to match performance (Gabbett et al., 2011a), once again indicating that *in-situ* tests are not the sole representative task predictors of match performance.

The significant differences found in our study between skill levels reflect small effect sizes for decision (d = 0.26) and total score (d = 0.37). A reason for these small differences could be that the actual difference in the skill level between higher (WAFL) and lesser (Amateur) skilled players is small or fine-grained. In comparison to other literature, for example, Lorains et al. (2013) reported no significant difference in decision-making accuracy between elite and sub-elite AF players, but a significant difference between elite and novice players (~22%) on a normal speed video decision-making test. In contrast, Berry et al. (2008) found a moderate to large effect size in the superior decision-making of expert and lesser skilled AF players. In a related manner, the exploratory analysis within the higher skilled group in our study revealed large effect sizes relative to the greater number of games played (50+) and midfield position of play. Breed, Mills, and Spittle (2018) have also reported a difference between highly skilled and skilled AF players (moderate effect size) on a video-based decision-making test. Therefore, considered on balance with the samples in the literature, our SSG test appears to have the sensitivity to detect even small differences in skill levels, as well as differences within a highly skilled group based upon experience. This is highly valuable for coaches to be able to assess players in a highly representative task. Coaches can employ the test with each player receiving a score for decision making, motor skill execution and total score. Coaches can then identify players who score lower relative to the group and need to work on decision making or motor skill execution or a combination of both with drills designed accordingly. Furthermore, coaches could set target scores for players to achieve and the test can be used as a way of measuring development in the players.

A potential limitation of using an *in-situ* test such as SSG is the number of trials per participant can vary. This variation in trial numbers per participant has been argued in the literature as representative of the game situation skill involvements, and can also be due to accessibility to participant time to partake in the test (Müller et al., 2015). The mean number of disposals per player for the higher skilled group in the SSG test of 13.32 (SD = 4.4), compared to 14.38 (SD = 5.05) across the 2017 WAFL season, with a range of involvement being 5-23, compared to a range of 8-28 across the 2017 WAFL season, is favourable. Therefore, the SSG test has comparable player involvement to a game situation in regards to number of involvements.

3.4.1 Practical application and conclusion

Performance tests need to be easily administered within scheduled practice times if they are to be consistently used by athletes, coaches and scientists alike (Robertson et al., 2014). The SSG test for AF has high practical application and feasibility because, (a) players complete a highly game-representative test, (b) it is relatively time efficient (approximately 30 mins to assess 12 players), (c) requires limited equipment (video camera, a set of coloured bibs and a football), and (d) takes two hours for video analysis of the total sample in this study. Coaches may be reluctant to implement skill tests when they do not closely represent the normal game context and when implementation encroaches upon the actual training time. As SSG have high task representation, these tests could also be adopted for use in other sports.

A further benefit from using a performance test based on a SSG, is that it gives coaches a platform to train and assess new tactics both in attack and defence. An example could be the coach wants to assess perceptual-cognitive-motor skill capability of players when in possession of the ball with a 'zone defence' compared to a 'man-on-man defence'. Alternatively, a coach may set a challenge to the defending team of how many times can they re-possess (gain possession) the ball from the attacking team over a three minute duration. Such a challenge is relevant as the current trend in AF is suggestive of a blended game-style; one that adopts both a possession and re-possession style of play (Woods et al., 2017). Furthermore, manipulations of objectives and rules in SSG by coaches can increase opportunities for common attacking and defensive sub-phases to emerge frequently (Davids et al., 2013).

In conclusion, the SSG test in AF can assist coaches to assess and train players' perceptual-cognitive-motor skills that are reflective of the natural game environment. Accordingly, SSG can be easily implemented to identify talented players, as well as assess and train the perceptual-cognitive-motor skill capability of skilled players.

Chapter 4 Coach Rating Combined with Small-Sided Games Provides Further Insight into Mental Toughness in Sport

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Coach Rating Combined With Small-Sided Games Provides Further Insight Into Mental Toughness in Sport

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Research synthesis

In addition to the paucity of interdisciplinary research in AF within the competition performance domain, chapter two also highlighted there has been no interdisciplinary research in the competition performance domain across any sport that has included a measure from the Sports Psychology sub-discipline. Furthermore, there has been no Sports Psychology measures used in any interdisciplinary research across talent identification or talent selection (in addition to competition performance) within the sport of AF. Chapter four addresses this void in the literature by measuring coach reported MT in a group of AF players and then investigated its relationship with objective measures of performance from SSG tests developed in chapter three.

Article information

Title

Coach rating combined with small-sided games provides further insight into mental toughness in sport

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Reference

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Abstract

Literature indicates that MT contributes to successful performance when faced with challenge. This study used an exemplar sport of AF to investigate whether skilled performance thrived across increased challenge in SSG. Higher (n = 14) and lower (n = 17) skilled Australian footballers were recruited. First, coaches rated participants' MT using the MTI. Second, participants competed in SSG where challenge was manipulated by varying the attacker to defender ratio to create lower and higher pressure scenarios. Decision-making, motor skill execution, and a combined total were measured. MTC rating was higher for higher skilled players. Total score of higher skilled players was significantly superior to lower skilled players in higher and lower pressure scenarios (p = 0.003). A 'pressure differential score', calculated to determine whether participants maintained performance across increased challenge, indicated a significant decrease in performance (total score) from lower to higher pressure scenarios for lower skilled (p = 0.011), but not for higher skilled (p = 0.060) players. Furthermore, MTC scores were predictive of high pressure scenario total scores (p = 0.011). Findings suggest higher levels of MT may contribute to maintain performance across the increased challenge of pressure within SSG. Practitioners can subjectively rate athlete MT and then structure SSG to objectively measure performance under pressure scenarios. This provides an interdisciplinary approach to assess and train psychomotor skill

Keywords

MT, psychomotor skill, pressure scenarios, perceptual-cognitive-motor skill, sports-specific assessment.

4.1 Introduction

In the AFL grand final of 2010, both St Kilda and Collingwood had scored 68 points when the siren sounded for full time; a draw. The rules of the competition stated that the final had to be replayed the following week. In the week preceding the rematch, Collingwood coach, Michael Malthouse, penned a newspaper article titled “Mental toughness will decide premiership” (Malthouse, 2010). Collingwood went on to win the grand final replay by 56 points. They were able to perform to a higher level than their opposition, despite the challenge of having already played in a grand final seven days earlier in front of 90,000 spectators, and the adversity of having fatigued and injured players. According to their coach, the success of Collingwood in the replay of 2010 grand final would suggest that MT played a major role. MT is a concept that indeed warrants further investigation in sports-specific *in-situ* settings.

MT has gained significant interest from the general public, practitioners, and researchers in recent years because it is considered a key factor of superior performance in a variety of domains including sport (Giles et al., 2018). Based upon scientific evidence of MT in a variety of domains such as business, military, education, and sport, the focus has been upon defining the phenomenon and formulation of a theoretical framework from which hypotheses could be tested (Gucciardi, Hanton, Gordon, Mallett, & Temby, 2015). Accordingly, MT has been defined as a personal capacity to produce consistently higher levels of subjective or objective performance, despite everyday challenges, stressors and significant adversities (Gucciardi et al., 2015). Research into MT has also developed and validated several introspective questionnaires in order to measure MT in several domains, and in turn, test and further refine its theoretical framework (Newland, Newton, Finch, Harbke, & Podlog, 2013). Some of these questionnaires include the Mental Toughness Questionnaire-48 (MTQ48) (Clough, Earle, & Sewell, 2002), the Sport Mental Toughness Questionnaire (SMTQ) (Sheard, Golby, & van Wersch, 2009), and the MTI (Gucciardi et al., 2015). Therefore, the vast majority of what is known about MT measurement is based upon introspective survey methodology.

Surveys can provide scientists with valuable information about psychological and emotional states of participants, but there has been a call for incorporation of other methodologies that can provide insight to the link between psychomotor skill capability and MT in athletes (Gucciardi, Gordon, & Dimmock, 2008; Gucciardi & Gordon, 2013; Gucciardi, Mallett, Hanrahan, & Gordon, 2013; Mahoney, Ntoumanis, Mallett, & Gucciardi, 2014). The broader field of Sport Psychology has relied predominantly on introspective surveys and interviews, often undertaken sometime after the competition event. This relies on the athlete having to reflect on their own performance, which can be quite subjective. There is scope, however, to utilise an alternative methodology to better understand the link between psychomotor skill performance and MT in sport. For example, Mahoney, Ntoumanis et al. (2014) recommended that a key starting point for future investigation of MT, is objective measurement of performance under manipulation of lower and higher pressure *in-situ* contexts in sport. This would enable a quantitative assessment of a component prediction of MT theory through varying degrees of pressure that creates increased challenge to performance. This form of assessment places a participant in a game-like pressure context and would help coaches to identify those players who thrive or succumb to the pressure (Mahoney, Ntoumanis et al., 2014). Accordingly, it has been suggested that a characteristic of mentally tough athletes is for their performance to thrive (i.e., performance maintained to a greater degree) when under increased task pressure or challenge (Gucciardi et al., 2008; Jones, Hanton, & Connaughton, 2007).

The importance of MT to superior performance in sport is well recognised among coaches, athletes and sport scientists (Connaughton & Hanton, 2009). Several studies in sport have reported that athletes with higher self-reported scores on MT questionnaires tend to perform better in competition (Cowden, 2016; Drees & Mack, 2012; Mahoney, Gucciardi, Ntoumanis, & Mallett, 2014; Newland et al., 2013). For example, Cowden (2016) reported that amongst professional tennis players, achievement of higher MT scores were correlated with a greater likelihood of winning a national tournament. Drees and Mack (2012) also reported that higher MT scores of high school wrestlers was positively correlated with the season winning percentage. Moreover, Mahoney, Gucciardi et al. (2014) reported a negative relationship such that higher MT scores of adolescent cross-country runners correlated with faster race times. In collegiate basketball players, Newland et al. (2013) reported that MT score partially predicted basketball performance (measured using a metric that combined shot percentage, points, rebounds, assists, steals, turnovers and personal fouls). To our knowledge, there has been no integration of MT survey methodology with systematic manipulation of sports-specific pressure and assessment of perceptual-cognitive-motor skill to further understanding of MT.

SSG have been used with several invasion sports such as soccer, field-hockey and AF to assess the perceptual-cognitive-motor skill of athletes (e.g., see Práxedes et al., 2018). Assessment of the correct decision, such as to pass the ball to a teammate or retain possession of the ball, provides a measure of perceptual-cognitive or decision-making skill (Starkes et al., 2004). Alternatively, assessment of the capability to successfully pass the ball to a teammate provides a measure of motor skill execution (Starkes et al., 2004). Recently, Piggott, Müller, Chivers, Cripps, and Hoyne (2019) designed a sports-specific AF test based upon SSG (six attackers vs. five defenders) in order to assess the perceptual-cognitive-motor skills of Australian footballers. The authors reported that higher skilled players were significantly superior on the total score (decision-making plus execution) compared to lesser skilled Australian footballers. By manipulation of the ratio of defenders to attackers it is possible to increase or decrease pressure in SSG (see Davids et al., 2013), which can then form scenarios to investigate how athletes deal with challenge (as predicted in MT theory) that may affect performance.

This study incorporated existing MT survey methodology with an *in-situ* sports-specific test. AF was used as the exemplar sport skill to further understand the link between MT and psychomotor skill in sport. A sports-specific in-*situ* test for AF was designed based upon SSG that measured participants' decision-making and motor skill execution under higher and lower pressure scenarios. The purpose of this study was to investigate whether: (i) differences existed between higher and lower skilled AF players during pressure scenarios of a SSG test, which provided a proxy to test a component of MT theory that performance in terms of perceptual-cognitive-motor skill would thrive (be maintained) under increased pressure, and (ii) whether MTC scores predicted performance scores in the high pressure scenario. Based upon MT theory and the above literature, it was hypothesized that: (a) higher skilled players will perform signficantly better than lower skilled players in both pressure scenarios, (b) higher skilled, rather than lesser skilled players, would better maintain performance across lower to higher pressure scenarios, and (c) MTC questionnaire scores can predict high pressure scores in SSG.

4.2 Materials and methods

4.2.1 Participants

A total of 31 male participants were recruited for this study. A higher skilled group (n = 14) comprised of one semi-professional WAFL club who participated in the state league. The lower skilled group (n = 17) was recruited from two WAAFL clubs. For a participant to be included in the higher skilled group they had to have played a minimum of one senior WAFL game within the previous two years. The age of the WAFL group was (Mage = 23.0 years, age range: 20-29 years) and the WAAFL group was (Mage = 23.9 years, age range: 19-30 years). Based upon Piggott et al. (2019), a power analysis was conducted using $\alpha = 0.05$, power $(1-\beta) = 0.8$, effect size = 0.15, and two skill groups, which indicated that appropriately 351 trials in total were required. Ethical approval was received from the relevant university committee and participants provided written informed consent.

4.2.2 Materials and procedures

Mental Toughness

All testing was completed at the end of the pre-season training period and before competition games began for the 2017 season. The first component of this study involved coach rating of each participant using the MTI, an eight item scale that when developed displayed strong factor loadings and composite reliabilities were reported to be excellent ($\rho = 0.86\ to\ 0.89$) (Gucciardi et al., 2015). Example items from the scale include *I am able to regulate my focus when performing tasks* and *I am able to execute appropriate skills or knowledge when challenged*. The MTI has been used in previous research with athletes and has been reported to correlate with competition performance (e.g. Gucciardi et al., 2015). The measuring of coach rated MT has also been used in previous research (Bell et al., 2013; Cowden, Fuller, & Anshel, 2014) and is a way of overcoming self-attribution bias that can occur when using self-report. To establish face validity for coach rated MT using the MTI, a panel of expert AFL coaches was consulted and all agreed that the questionnaire was an appropriate measure of assessment. A senior member of each of the teams' coaching staff involved in the study completed the MTC rating for each participant that they coached.

Small-Sided Games

The second component of this study involved both skill groups and relates to item 7 on the MTI: *I am able to execute appropriate skills or knowledge when challenged.* This refers in part to MT theory mentioned earlier and was deemed the easiest to manipulate in terms of pressure contexts in a sports-specific *in-situ* test. For this study, the previous data set from Piggott, Müller, Chivers, Cripps, et al.'s (2019) (2019) was built upon to include another series of SSG involving six attackers versus three defenders. The two series of SSG were termed ‘higher pressure’ (six vs. five) and ‘lower pressure’ (six vs. three), respectively. Both scenarios involved attackers attempting to maintain possession of the ball in a 40 m × 40 m grid using a handpass or kick, whilst defenders tried to spoil or tackle. After a 15 minute warm-up, each skill group completed three sets each in attack and defence. The test was umpired by a research assistant with AF knowledge. Each skill group completed the higher pressure scenario in one session and the lower pressure scenario in another session at least one week apart due to logistics. Each time an attacking player passed the ball by a kick or handball it was recorded as a trial. Decision-making and motor skill execution scores for each disposal (trial), as well as both combined (total score) were coded as objective performance measures. Each session was recorded using a standard 25 Hz video camera (Panasonic SDR-H250, Australia) for later coding (see Piggott, Müller, Chivers, Cripps, et al., (2019) for details of this method).

The scoring system used in both higher and lower pressure scenarios is outlined in *Table 4.1*. In relation to item 7 of the MTI, we reasoned that decision-making score reflects ‘knowledge’, the execution score reflects ‘skills’, and ‘challenge’ reflects the increase in defenders from three to five in the *in-situ* scenarios. The reliability of scoring the scenarios was assessed by inter- and intra-rater reliability. A novice coach scored all trials by viewing the video record of the SSG. Intra-rater reliability was assessed by the same novice coach (two weeks apart) and inter-rater reliability was assessed by an expert AF coach (Level 3) on 136 (14%) randomly selected trials, across both high and low pressure scenarios, using the video record.

Table 4.1

Composite Score for Test Trials

Measure	Rating
Decision-Making	0 = Incorrect decision 2 = Next correct decision 3 = Most correct decision
Execution	0 = Ball does not reach target player at all 1 = Ball reaches target player but not on full 2 = Ball reaches target player on full; however the target player had to change direction to ensure this occurs 3 = Ball reaches target player on full
Total	**Decision Making + Execution Scores**

Note. Adapted from Piggott, B., et al. (2019). "Small-sided games can discriminate perceptual-cognitive-motor capability and predict disposal efficiency in match performance of skilled Australian footballers." Journal of Sports Sciences. p. 3.

Data Analysis

Statistical analysis was performed using IBM SPSS version 24 (IBM SPSS Statistics for Windows. IBM Corp., Armonk, NY, USA). Data was checked for normality using the Shapiro Wilk's test so that the appropriate statistical tests could be employed. Alpha level was set at 0.05.

During the SSG, each time an attacking player passed the ball by a kick or handball it was recorded as a trial, with a total of 980 trials recorded; 423 in the higher pressure scenario and 557 in the lower pressure scenario. The participants' total score for the SSG was the dependent variable, which equalled the sum of the decision and execution scores for each trial with the maximum score achievable being six. Total score had previously been reported to discriminate superior performance of higher and lower skilled Australian footballers (see Piggott, Müller, Chivers, Cripps, et al., (2019))

Inter- and intra-rater reliability of the scoring of the SSG test was assessed using a two-way mixed intra-class correlation coefficients (ICC) according to Portney and Watkins (2009). The cut-off interpretations used for the ICC values were; less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 indicative of poor, moderate, good, and excellent reliability, respectively.

Hypothesis one predicted that higher skilled players will perform significantly better than lower skilled players in both pressure scenarios. To address this hypothesis, repeated measures of trials were examined for between skill group differences for total score on the SSG test, in both higher and lower pressure scenarios, using generalised estimating equations (GEE). GEE use the generalised linear model to estimate more efficient and unbiased regression parameters relative to ordinary least squares regression that accounts for the form of within-subject correlation of responses on dependent variables of many different distributions (Ballinger, 2004). A 2 (skill group) × 2 (pressure scenario) mixed between-within factorial GEE model was used to examine main and interaction effects. Total score was the dependent scale variable in the GEE model. For post-hoc comparisons, a Bonferroni adjustment was applied. Cohen's *d* effect sizes were also calculated, with 0.2 considered small, 0.5 medium and 0.8 large effects (Cohen, 1998).

Hypothesis two predicted that higher skilled, rather than lesser skilled players, would better maintain performance across lower to higher pressure scenarios. To address this hypothesis, a mean of the trials' total score for each participant was calculated for each higher and lower pressure scenarios on the SSG test for both skill groups. A 'pressure differential score' was then calculated by subtracting higher pressure scenario mean total score from lower pressure scenario mean total score. For example, if a participant had a lower pressure mean total score of 5.4 and higher pressure mean total score of 4.6, their pressure differential score would be; 5.4 - 4.6 = 0.8. A pressure differential score closer to zero indicated better sustained performance across lower to higher pressure scenarios; which meant participants were able to maintain perceptual-cognitive-motor skills when challenged. A one-sample t-test was used to compare the mean pressure differential scores to a no-performance-change score of zero for higher and lower skilled players.

Hypothesis three predicted a relationship between MTC questionnaire scores and SSG high pressure scores. To address this hypothesis, a GEE regression model was used to investigate the relationship between MTC and high pressure scenario total score.

4.3 Results

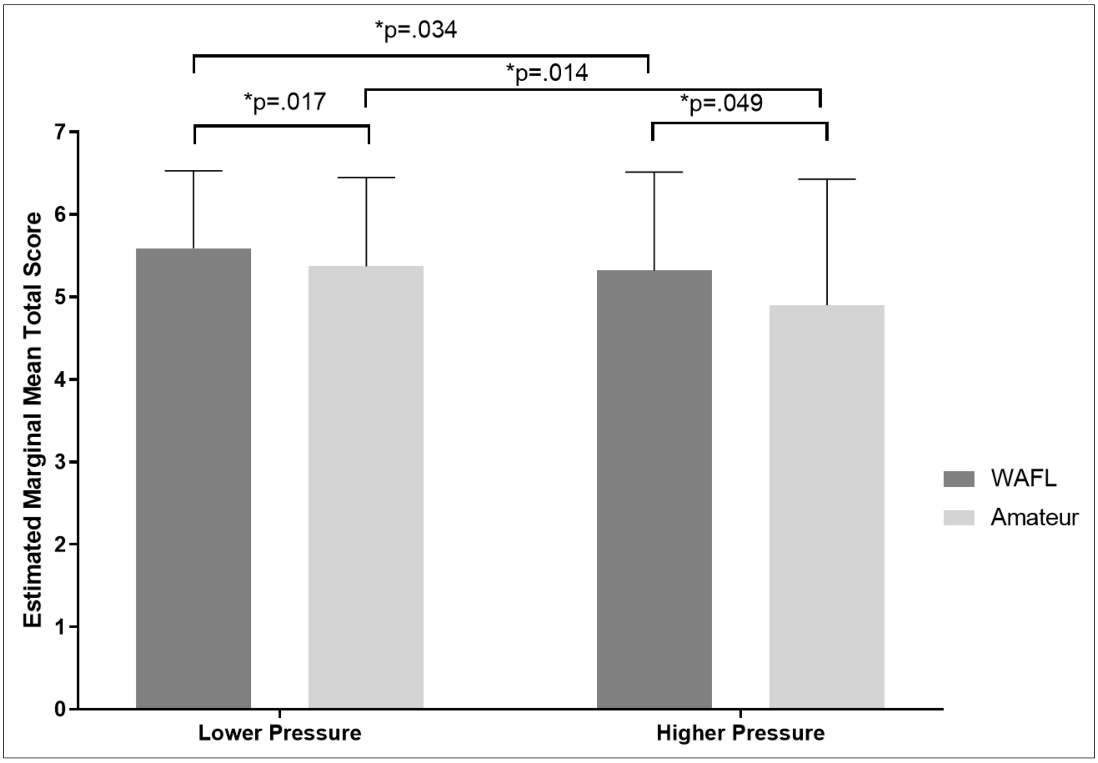
4.3.1 Reliability of SSG test scoring

Inter-rater reliability for decision (*r* = 0.91, range = 0.88 to 0.94) and execution (*r* = 0.98, range = 0.98 to 0.99) indicated excellent levels of agreement. Intra-rater reliability for decision (*r* = 0.86, range = 0.80 to 0.90) and execution (*r* = 0.96, range = 0.95 to 0.97) also indicated good and excellent levels of reliability, respectively.

4.3.2 Skill group differences for SSG

The estimated marginal means derived from the GEE model are presented in *Figure 4.1*. The model indicated significantly superior overall performance by higher skilled players over lower skilled players (β = 0.22, SE = 0.07, *p* = 0.003). In addition, performance under the low pressure scenario was significantly higher than under the high pressure scenario (β = -0.47, SE = 0.15, p = 0.002). The interaction between skill level and pressure was not significant (β = 0.20, SE = 0.18, p = 0.282). However, pairwise comparisons revealed a significantly higher total score by higher skilled players (*M* = 5.32, *SE* = 0.08), over lower skilled players (*M* = 4.90, *SE* = 0.14), under the higher pressure scenario (*p* = 0.049, *d* = 0.31). Pairwise comparisons also revealed a significantly higher total score by higher skilled players (*M* = 5.59, *SE* = 0.05), over lower skilled players (*M* = 5.37, *SE* = 0.06), under the lower pressure scenario (*p* = 0.017, *d* = 0.22). When the total score of higher skilled players was compared across lower (*M* = 5.59, *SE* = 0.05) to higher (*M* = 5.32, *SE* = 0.08) pressure scenarios, a significant difference was found (*p* = 0.034, *d* = 0.12). A significant difference was also found for lower skilled players across lower (*M* = 5.37, *SE* = 0.06) to higher (*M* = 4.90, *SE* = 0.14) pressure scenarios (*p* = 0.014, *d* =0.35).

In relation to performance across scenarios, the pressure differential score indicated that for lower skilled players there was a significant difference compared to a no-performance-change score of zero, *t*(16) = -2.89, *p* = 0.011. This indicates performance decrement for lower skilled players. Conversely, no significant difference was found for pressure differential score for higher skilled players, *t* (13) = -2.06, *p* =.060. This indicates maintenance of performance for highly skilled players. There was a medium effect size (*d* = 0.46) for the pressure differential scores between higher (*M* = 0.22, *SD* = 0.40) and lower (*M* = 0.48, *SD* = 0.68) skilled players.



Note: Pairwise comparisons are depicted * $p < .05$. Error bars represent standard error.

Figure 4.1 Estimated marginal means for total score in small-sided games. Test based on GEE model.

4.3.3 MTC scores and relationship to SSG

The MTC scores for higher and lower skilled groups were (*M* = 43.71, *SD* = 4.41) and (*M* = 42.50, *SD* = 5.37), respectively. There was no significant difference between the two groups for MTC; $t(26) = 0.519$; $d = 0.24$). When examining the relationship between subjective and objective measures, MTC scores were able to predict high pressure scenario total scores ($\beta = 0.04$, SE = .01, $p = 0.011$).

4.4 Discussion

The purpose of this study was to integrate methodologies in order to test a component of MT theory that predicts whether an athlete will thrive under pressure situations and maintain performance. This was done in interlinked components; first, a validated questionnaire was used for coaches MT rating of participants. Second, perceptual-cognitive-motor skill differences between higher and lower skilled AF players were compared across two pressure conditions of a SSG test. Third, the relationships between quantitative and qualitative measures was explored. Fourth, the reliability of scoring the SSG test was checked through inter- and intra-rater reliability.

Skill group differences were found in each pressure scenario, with higher skilled players better able to maintain performance across the pressure scenarios. Furthermore, MTC was predictive of performance under high pressure. Therefore, this study made initial steps to address the call for MT research methodology to be extended and incorporate experimental designs that involve systematic manipulation of pressure contexts within an *in-situ* setting (Mahoney, Ntoumanis et al., 2014).

Both higher and lower pressure scenarios were able to discriminate skill levels, with higher skilled players performing at a superior level than lower skilled players. Previously, MT research in sport has used only survey methodology to attempt to discriminate between skill levels or categories; such as starters and non-starters in basketball (Newland et al., 2013) and team ranking in tennis (Cowden et al., 2014). This study showed that perceptual-cognitive-motor total score in the lower pressure (six vs. three) scenario was also able to discriminate between higher and lower skilled players. This builds upon Piggott, Müller, Chivers, Cripps, et al.'s (2019) study providing further evidence of the capability of SSG to discriminate between closely related skill levels of AF. The design of tasks that involve differing levels of pressure that are highly representative of the competition environment and can discriminate between skill levels provides an important method to test MT theory. Therefore, supporting evidence was provided for hypothesis one.

A unique aspect of this study, was the calculation of the pressure differential score to test a component prediction of MT theory. The theory predicts that mentally tough athletes are able to thrive under pressure (Gucciardi et al., 2008; Jones et al., 2007). The pressure differential score enabled direct investigation of how participants met this challenge by quantification of the degree to which they maintained performance across increased pressure scenarios. Our study showed that higher skilled players could maintain their perceptual-cognitive-motor skill performance across increased pressure scenarios as evidenced by a lower pressure differential score. In contrast, lower skilled players were less able to maintain their perceptual-cognitive-motor skill performance across increased pressure scenarios as evidenced by an increased pressure differential score. Therefore, supporting evidence was provided for hypothesis two. This addressed the call in the literature for an objective measure of MT under manipulation of lower and higher pressure contexts (Mahoney, Ntoumanis et al., 2014).

The findings of this study have also furthered understanding of a subjective measure of MT and its relationship to an objective measure of perceptual-cognitive-motor skill performance. This is important because Gucciardi & Gordon (2013) stated that there was a lack of evidence supporting the link between MT and an objective measure of performance. The significant predictive relationship between coaches' MT rating of athletes and *in-situ* performance in the higher pressure scenario provides support for the theory that higher levels of MT correspond with higher levels of performance. This evidence supports hypothesis three and is consistent with previous studies that have shown a relationship between self-reported MT and competition performance (Cowden, 2016; Drees & Mack, 2012; Mahoney, Gucciardi et al., 2014; Newland et al., 2013). This indicates that either coach or self-report of MT is relevant to motor skill performance, but our study is unique as we have been able to demonstrate through manipulation of the pressure component in which the task is performed, we showed that MTC has predictive capabilities in relation to *in-situ* perceptual-cognitive-motor skill.

4.4.1 Practical implications and limitations

The integration of methods to test theory and evidence presented in this study provides opportunities for practical application in terms of assessment and development of athletes. Accordingly, a multi-method approach to MT could be used (Gucciardi et al., 2013). For example, an AF coach, in consultation with a sport psychologist, could complete the MTI for an athlete as part of their development. The coach could then discuss their responses with the athlete and how they derived each score per item. On item 7 of the MTI (*I am able execute appropriate skills or knowledge when challenged*), the coach may score the athlete three out of seven and could explain that the athlete needs to improve their decision-making and/or skill execution when under pressure situations in competition. The coach would then work with a sport psychologist to design a six week training plan that develops MT. In addition, the coach assisted by a skill acquisition specialist can design a perceptual-cognitive-motor skill training program for a variety of game-specific pressure contexts. Prior to the commencement of the six week training program, the athlete would complete the SSG test and may record a high pressure score of 4.0 and low pressure score 5.4 (pressure differential = 1.4). The athlete and the coach could set a goal for the athlete to achieve a pressure differential of < 1.0 when retested at the completion of the training program. A potential limitation of the study is that when using SSG and *in-situ* methodology, the number of trials per participant can vary. However, Müller et al. (2015) argue that this variation is representative of the game situation. Previously, we have shown using SSG player involvements (trials) is comparable to player involvement (statistics) in competition (Piggott, Müller, Chivers, Cripps, et al., 2019)

4.4.2 Conclusion and future research

Researchers in the domain of MT have called for an extension of methodology beyond traditional surveys often used in sports psychology research. This study used an *in-situ* methodology within AF to create two scenarios; lower pressure and higher pressure SSG scenarios. These two scenarios were able to discriminate between higher and lower skilled players. Also, the pressure differential score showed that the higher skilled players, but not the lower skilled players, could sustain their performance across lower to higher pressure scenarios. This is in line with a component prediction of MT theory. MTC scores were predictive of total scores in the high pressure scenario, indicating a causal relationship between objective and subjective measures of MT. Therefore, through careful manipulation of a SSG task, a prediction of MT theory was tested, which provides support for further application of SSG in field-based sport settings.

Further research is necessary to replicate these findings with other sports, as well as further probe the causal relationship between MT and perceptual-cognitive-motor skill. In relation to the first point, future research could determine the variance that MT scores account for in the SSG task performance. This will help determine how much MT contributes to performance in SSG. In relation to the second point, a psychological skills training program aimed at improving MT could be compared to a perceptual-cognitive-motor skill training program, with their relative benefits assessed using SSG pressure scenarios. A psychological skill intervention has been reported to improve MT and performance in cricket batting (see Bell et al., 2013), but has not specifically been compared to perceptual-cognitive-motor skill training and performance in SSG scenarios. Collectively, fruitful opportunities exist to further understand how MT and perceptual-cognitive-motor skills contribute to performance of sports skills.

Chapter 5 Interdisciplinary Sport Research Can Better Predict Competition Performance, Identify Individual Differences & Quantify Task Representation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Interdisciplinary Sport Research Can Better Predict Competition Performance, Identify Individual Differences, and Quantify Task Representation

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Research synthesis

Chapter five presents an interdisciplinary study in AF in the competition performance domain; a gap previously identified in chapter two. The SSG test developed in chapter three is incorporated with the MTC rating used in chapter four, along with a measure of physical capacity to formulate an interdisciplinary approach to investigate the components which influence performance in competition. This chapter also provides evidence as to why RTD and individual analysis should be a consideration when undertaking interdisciplinary research.

Article information

Title

Interdisciplinary sport research can better predict competition performance, identify individual differences & quantify task representation.

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Abstract

Sport performance consists of interacting individual, task and environmental constraints, but research has used a monodisciplinary, rather than an interdisciplinary approach to understand performance. This study used AF as the exemplar sport to investigate the value of an interdisciplinary approach to understand sport performance. Through this, it was also possible to quantify individual differences and RTD. Fifty-nine semi-professional Australian footballers participated. Based upon accessibility, combinations of these players completed physiological (3 x 1 km trial) and perceptual-cognitive-motor (SSG) tests, with coach rating of psychological skill (MTC). Univariate monodisciplinary models indicated that all tests predicted disposal efficiency; 3 x 1 km trial ($p = 0.047$), SSG ($p = 0.001$) and MTC ($p = 0.035$), but only the SSG predicted coaches' vote ($p = 0.003$). A multivariate interdisciplinary model indicated that SSG and MTC tests predicted disposal efficiency with a better model fit than the corresponding univariate model. The interdisciplinary model formulated an equation that could identify individual differences in disposal efficiency. In addition, the interdisciplinary model showed that the higher representative SSG test contributed a greater magnitude to the prediction of competition performance, than the lower representative MTC rating. Overall, this study demonstrates that a more comprehensive understanding of sport performance, individual differences and representative tasks, can be obtained through an interdisciplinary approach.

Keywords

Interdisciplinary research, individual differences, RTD, sports science, AF.

5.1 Introduction

Sport performance has been frequently studied based upon physical or physiological components such as agility and aerobic capacity (Cardinale, 2017). Coaches and applied scientists, however, believe that competition performance involves an interaction between physiological, psychological, and perceptual-cognitive-motor components (Bonney, Berry, Ball, & Larkin, 2019a; Cardinale, 2017; Zaichkowsky & Peterson, 2018). For example, mid-field players in AF and soccer run approximately 10km per game, whilst attempting to make accurate skill decisions under high-pressure situations. Accordingly, several recent books (Ericsson, Hoffman, Kozbelt, & Williams, 2018; Zaichkowsky & Peterson, 2018) and scientific publications (Cardinale, 2017; Glazier, 2017) have discussed the importance of psychological and perceptual-cognitive-motor components, which need to be considered with physiological components, to provide a more comprehensive understanding of sport performance. This presents an opportunity to extend mechanistic (or theoretical) understanding of sport performance from an interdisciplinary perspective, which has applied implications in terms of identification of strengths and deficiencies of individual athletes for remediation.

Recent reviews of the sports science literature have found that interdisciplinary research continues to be scarce (Buekers et al., 2016; Piggott, Müller, Chivers, Papaluca, et al., 2019). There are several possible reasons for why this is the case. First, sports science researchers may not be aware of suitable theoretical frameworks that can underpin interdisciplinary research questions, experimental design and analyses (Buekers et al., 2016). Second, interdisciplinary research is highly dependent upon the organisation of a team of scientists who have less preference upon a monodisciplinary approach to understand sport performance (Buekers et al., 2016). Third, interdisciplinary research can require greater resources and participant time, which may limit sport performance to be investigated from a monodisciplinary perspective (Buekers et al., 2016). Nonetheless, Buekers et al. (2016) and Piggott, Müller, Chivers, Papaluca, et al. (2019) have presented solutions to these barriers in the form of theoretical frameworks to guide experiment and test design. These authors also mentioned the incentive for researchers to conduct interdisciplinary research, which is its capacity to provide a comprehensive understanding of athletic performance.

A useful framework to underpin interdisciplinary research is constraints theory (Higgins, 1977; Newell, 1986), because it takes into consideration interacting variables that can shape achievement of the motor skill goal. Constraints include interacting components related to the individual, task and immediate environment that can guide achievement of the motor skill goal (Higgins, 1977; Newell, 1986). An example of constraints is demonstrated in the last minute of a rugby game, when the team in possession of the ball is behind by four points (environment). The halfback (individual) of the losing team throws a pass to the winger, the fastest player on their team who has open space in front of him. This gives the halfback an opportunity to score a try (task), whilst avoiding being tackled by an opponent(s), which would result in the team winning the game. In relation to individual constraints; physiological, psychological and perceptual-cognitive-motor components interact with the environment and task constraints to attempt successful achievement of the motor skill goal. Therefore, constraints theory predicts that interacting variables, aligned with an interdisciplinary approach, are crucial to comprehensively understand performance in sport.

Underpinned by constraints theory, it is possible to develop research questions, experimental design and analyses to further understanding of sport performance. AF can be chosen as an exemplar sport because it includes interacting physiological, psychological and perceptual-cognitive-motor individual constraints (Bonney et al., 2019a). A key task constraint of AF competition is effective disposal of the ball to a teammate without being tackled or the pass being intercepted. This refers to the skill (or task) goal in competition, which can be measured using disposal efficiency (Piggott, Müller, Chivers, Cripps, et al., 2019). Disposal efficiency is defined as the percentage of disposals that are effective or hit their intended target and is one of the match statistics provided by a commercial analytics company (Champion Data, South Bank, Australia). Passing the ball in AF occurs under a highly dynamic environmental constraint, because there are multiple players in close proximity to the ball carrier who can tackle from any direction. Therefore, by systematically integrating constraints on the individual, it is possible to determine, as predicted by constraints theory, whether disposal efficiency can be better predicted through a monodisciplinary or interdisciplinary approach. This contributes to theoretical understanding through interacting constraints that may influence sport performance.

Although constraints theory predicts performance based upon the individual, sports science researchers have focused upon group designs, rather than sub-groupings or analyses that can reveal individual differences (Piggott, Müller, Chivers, Papaluca, et al., 2019). The latter analyses have important practical implications, as coaches are interested in the strengths, deficiencies, and development of individual athletes, so that interventions can be tailored to improve individual athlete competition performance. For example, underpinned by constraints theory, Chow, Davids, Button, and Koh (2008) reported individual differences in hip, knee, and ankle joint coordination when novices learned to chip kick a soccer ball to targets of varying distance and size. This study demonstrated that more than one coordination pattern can be used to learn a skill. In another example, Piggott, Müller, Chivers, Cripps, et al. (2019) used a sub-grouping analysis relative to games played and position of play within skilled Australian footballers. They reported superior decision-making in SSG's relative to increased exposure to competition and playing in the mid-field position. This study demonstrated that task experience and position of play can influence decision-making capability. Accordingly, it has been suggested that in order for sport performance research to best guide athlete preparation, individual or sub-groups analyses are necessary to better elucidate interaction with task and environment constraints (Woods, McKeown, Shuttleworth, Davids, & Robertson, 2019).

Design of tests or selection of measurement instruments is also an important consideration for interdisciplinary research to best capture interacting constraints of sport performance. This refers to RTD, which includes properties of the test or measurement instrument and their generalisation to the intended context (Araujo & Davids, 2015), which in sport is the competition setting. It has been argued that properties (constraints) of a test such as perceptual information and action responses need to be sampled from the competition setting to be included in design of the test (Pinder et al., 2011b). For example, a SSG would be considered high in task representation because perceptual and action components are closely related to competition performance, whilst coach rating of athlete performance involves none of these components, so it would be considered low in task representation. In a related manner, the literature indicates that practice drills in AF allow the ball carrier to retain possession of the ball for considerably longer prior to a decision to dispose, than occurs in competition (Woods et al., 2019). The implication of this finding is that coaches need to design practice tasks where athletes make accurate decisions, where ball possession time is like competition. Interdisciplinary research including physiological, psychological, and perceptual-cognitive-motor component tests can provide an indication of what best predicts a measure of match performance such as disposal efficiency. Through this, it is possible to obtain an understanding of which interacting test(s) or measure(s) represents sport performance. This will help coaches and sports scientists select representative talent identification and test batteries for athlete evaluation and training.

This study employed both monodisciplinary and interdisciplinary approaches using AF as an exemplar sport. We used three sports science sub-discipline measures to examine their relationships to two match performance statistics in disposal efficiency and coaches' vote. The purpose of this study were to determine: (a) whether an interdisciplinary approach provides a more comprehenisve understanding of athlete match performance than a monodisciplinary approach, (b) whether an interdisciplinary approach could provide an equation to quantify individual player performance profiles, and (c) representativeness of measures in terms of their capability to predict match performance. It was hypothesized that: (i) an interdisciplinary approach would provide a better model fit in predicting a measure of match performance (disposal efficiency), in comparison to a monodisciplinary approach, (ii) individual player profiles would provide enhanced insight into sport performance, which is less evident in group descriptive analyses, and (iii) measures that closely represent competition would more accurately predict match performance.

5.2 Materials and methods

5.2.1 Participants

A total of 59 male players (M_{age} = 21.27 ± 3.11 years, M_{height} = 186.79 ± 7.17 cm, $M_{body\ weight}$ = 84.0 ± 9.13 kg) from a semi-professional AF league club were recruited for this study. All players were members of the senior playing squad and the inclusion criteria was that participants had to be free from injury at the time of testing. Human Research Ethics Committee (HREC) approval was received from the relevant university committee and participants provided written informed consent. This study was conducted in accordance with the Declaration of Helsinki.

5.2.2 Materials and procedures

The sport of AF requires a unique mix of physical, mental, technical, and decision-making skills (Young & Pryor, 2007). These skills can be classified into the following sub-disciplines of sport science according to Abernethy et al. (2013); Exercise Physiology, Sports Psychology and Motor Control. A test from each sub-discipline was selected and these were; (i) 3 x 1 km time trial (Exercise Physiology), (ii) MT coach rating (Sport Psychology), and (iii) SSG test in AF (Motor Control). Justification for the selection of these tests is outlined below. The match performance measures used were disposal efficiency and coaches' vote. The three tests were all completed towards the end of the pre-season training period and before competition games began. Match performance measures were collated from a total of 20 home and away games over the 2017 competitive season.

3 x 1km Time Trials

Literature reports that the running demands of AF are high (Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Delaney, Thornton, Burgess, Dascombe, & Duthie, 2017). As a result, a primary focus of AF training is to develop players' capacity in this area (Delaney et al., 2017); a performance test that provides a measure of running ability was therefore used in this study. Traditionally, AF clubs have used a 3km time trial in order to assess aerobic capacity (Gastin, Meyer, & Robinson, 2013; Piggott et al., 2015). Recently, in an attempt to ensure that performance tests reflect the intermittent running requirements of the competition environment, an alternative 3 x 1km time trial test has been reported in the literature (Cripps, Jacob, Walker, & Piggott, 2018). The repeated time trial test allows players to attain higher average running speeds (283m/min^{-1}) than the more traditional 3km time trial (252.8 m/min^{-1}) (Cripps et al., 2018). Furthermore, high intensity running has been linked to a player's capacity to win possession of the ball more frequently (Mooney et al., 2011). There is also an expectation from coaches that players can perform high intensity efforts interspersed with frequent short breaks on the interchange bench to recover.

The test required players to complete each 1km trial as quickly as possible running around a grassed oval. Each subsequent trial began 7:30 minutes after the start of the preceding trial. The total time taken by the player to complete the three trials represented the criterion measure. The 3 x 1km time trial has acceptable test-retest reliability assessed using interclass correlation coefficients (ICC=0.97, $p<0.01$) and typical error measurements (4.36%) (Cripps et al., 2018).

Mental Toughness Coach Rating

MT has been defined as a capacity for an individual to produce high levels of objective and subjective performance consistently despite everyday challenges, stressors and significant adversities (Gucciardi et al., 2015). There has been significant interest from researchers, practitioners and the general public in recent years regarding MT as a key factor of superior performance in a variety of domains including sport (Giles et al., 2018). The MT Index (MTI) developed by Gucciardi et al. (2015), is an eight item scale and an example item is; *I am able to execute appropriate skills or knowledge when challenged.* Recently, Piggott, Müller, Chivers, Burgin, et al. (2019) used a coach rating of the MTI and reported that this measure predicted performance in a high-pressure SSG. To assess MT in this study, a senior member of the club’s coaching staff rated each players’ level of MT using the MTI. This test has a low level of task representation because it is a survey and does not require a perceptual-motor response (Piggott, Müller, Chivers, Papaluca, et al., 2019).

Small-Sided Games

A recently developed SSG test in AF by Piggott, Müller, Chivers, Cripps, et al. (2019) was used to measure decision making and skill execution. The study reported that the test was highly reliable and was able to discriminate performance between semi-professional and amateur Australian footballers. In addition, the total score (summation of decision making and skill execution scores) significantly predicted disposal efficiency in competition performance (Piggott, Müller, Chivers, Cripps, et al., 2019). SSG allow players greater opportunities to gain possession of the ball and display their skill level, as well as apply game strategy and tactics (Bonney, Berry, Ball, & Larkin, 2019c). The SSG test has a high level of RTD as perceptual information that occurs in competition is presented to the participant and opportunity is provided to couple action to available perceptual information like the competition setting (Piggott, Müller, Chivers, Cripps, et al., 2019).

In the SSG tests, participants were divided into two teams of six attackers and five defenders. Attackers attempted to maintain possession of the ball in a 40 m x 40 m grid using a handpass or kick, whilst defenders tried to intercept, tackle or spoil. Each skill group completed three sets each in attack and defence and each set was three minutes in duration. Prior to the commencement of the SSG, participants completed a 15min warm up which included running drills, dynamic stretching, basic kicking, and handball exercises. The test was umpired by a research assistant with AF knowledge. Each time an attacking player passed the ball by a kick or handball it was recorded as a trial. The decision making and motor skill execution scores for each disposal (trial), as well as both combined (total score) were coded as objective performance measures. A standard 25 Hz video camera (Panasonic SDR-H250, Australia) was used for recording so that trials could be coded post testing.

Disposal Efficiency

A commercial statistical analytics company (Champion Data, South Bank, Australia) recorded each participants' disposal efficiency, which is the percentage of disposals (kicks or handballs) that were effective during each WAFL competition game. Champion Data is used extensively in AF and provides statistics for professional and semi-professional competitions with reported 99% accuracy (O'Shaughnessy, 2006). In addition, Champion Data statistics have been used in previous published research in AF (Mooney et al., 2011; Piggott et al., 2015).

Coach Vote

Coaches' votes as a measure of match performance have been used in previous research (Mooney et al., 2011; Piggott et al., 2015). Mooney et al. (2011) used coaches' votes as a measure in their research to quantify the player's subjective performance, which encompasses both tactical and technical performance. For this study, each of five coaches, voted after every competition game and each coach had 20 votes they could allocate across the participants who had played. The maximum votes an individual coach could give a participant was three votes. For example, if all five coaches gave a participant two votes each, then that participant would have recorded ten votes for that match.

5.2.3 Data analysis

Statistical analysis was performed using IBM SPSS version 25 (IBM SPSS Statistics for Windows. IBM Corp., Armonk, NY, USA) and Stata version 15

(StataCorp, College Station, Texas, USA). Data was checked for normality using the Shapiro Wilk's test so that the appropriate statistical tests could be employed. Alpha level was set at < 0.05.

Hypothesis one was investigated using a series of univariate GEE. GEE are an extension of general linear models, and are considered an appropriate approach for the analysis of correlated continuous and count data, and have the advantage of unbiased estimation of parameters (Ghisletta & Spini, 2004). In the GEE model, each sub-discipline performance test was the independent variable. For the first series of models, the match performance measure of disposal efficiency was the dependent variable and for the second series of models, coach vote was the match performance measure and dependent variable. Disposal efficiency employed a linear GEE model. For coaches' vote, a negative binomial link GEE model was used because of the over-dispersion of 'zero' votes. The GEE model probability of not receiving a coaches' vote was graphically depicted using STATA (StataCorp. 2001). Each independent sub-discipline test was regarded as a monodisciplinary approach to quantify a component of individual constraints. Performance tests displaying significant prediction of the dependent variables in the univariate GEE, were then integrated into a multivariate GEE model, which was regarded as an interdisciplinary approach. This is consistent with the literature, which has stated that integration of measures from different sub-disciplines using analyses such as stepwise regressions and prediction equations, can be classified as interdisciplinary (Freedson, 2009; Piggott, Müller, Chivers, Papaluca, et al., 2019). To compare the fit of different GEE models, the Quasi Likelihood Under Independence Model Criterion (QIC) was used where the model that obtains the smaller QIC has the better fit (Pan, 2001).

To address hypothesis two, the participants' mean disposal efficiency and coach vote from their match performance across the 2017 season was used. For these measures, participants were allocated into three groups depending on their performance and categorized as; high, medium and low performing. A panel of three experts who coached at semi-professional and professional levels agreed on the following cut-points for disposal efficiency: High (≥70%), Medium (60-70%) and Low ($< 60\%$), and coach vote: High (> 2 votes), Medium (≥ 1 and ≤ 2 votes) and Low (< 1 vote). Differences between categorized performance levels in sub-discipline tests was examined using ANOVA (or non-parametric Kruskal Wallis) with a Bonferroni post hoc comparison. In addition, Cohen's *d* effect sizes were calculated, with 0.2 considered small, 0.5 medium and 0.8 large effects (Cohen, 1998).

In regard to hypothesis three, using the estimates from the GEE predictive equations, we examined a 10 percent change for high and low level representative tests and determined prediction relative to the dependent variable. In addition, the QIC was used to assess model fit for tests of both high and low RTD.

The number of participants that completed the tests were as follows: 3 x 1 km time trial (n = 46), MTC rating (n = 59) and SSG AF test (n = 28). The final multivariate model assessed a total of 21 (M_{age} = 21.24 years, age range: 18-29 years) players who completed all three performance tests. Not all players could complete all three tests due to player injury, load management and training scheduling. In addition, injury restricted participants' availability to participate in every match throughout the year and this is common in contact team sports. For the final multivariate model, the average number of matches played over the season per participant was 15.6, which is similar to 15.5 matches reported in previous research with a similar focus (Gabbett et al., 2011a).

5.3 Results

5.3.1 Monodisciplinary and interdisciplinary approaches

At the univariate (monodisciplinary) level (*Table 5.1*), all three sub-discipline performance tests were significant predictors of match disposal efficiency; 3 x 1km time trials (β = -0.07, p = 0.047), MTC (β = 0.37, p = 0.035) and SSG test (β = 12.51, p = 0.001). At the univariate (monodisciplinary) level, only SSG test was a significant predictor of coaches' vote (β = 1.19, p = 0.003) (*Table 5.2*).

Table 5.1

Univariate Generalised Estimating Equations for Prediction of Disposal Efficiency

Model	Parameter	Estimate (β)	SE	*95% CI*	*p*-value
Model 1 (QIC 176,119)	Intercept	108.45	21.97	65.39 to 151.52	.001
	3 x 1 km	-0.07	0.03	-0.13 to 0.01	.047*
Model 2 (QIC 2234,463)	Intercept	48.06	7.91	33.56 to 63.57	.001
	MTC	0.37	0.18	0.03 to 0.72	.035*
Model 3 (QIC 110,014)	Intercept	-1.62	18.48	-37.85 to 34.61	.930
	SSG Test Score	12.51	3.50	5.65 to19.38	.001*

* Indicates a significant difference *p* <.05. SE = standard error, CI = confidence intervals, MTC = Mental Toughness Coach, QIC = Quasi Likelihood under Independence Model Criterion

Table 5.2

Univariate Generalised Estimating Equations for Prediction of Coaches' Vote

Model	Parameter	Estimate (β)	SE	*95% CI*	*p*-value
Model 1 (QIC 1141)	Intercept	1.78	2.68	-3.48 to 7.04	.507
	3 x 1 km	-0.01	0.01	-0.01 to 0.01	.185
Model 2 (QIC 1424)	Intercept	-3.05	0.98	-4.97 to -1.12	.002
	MTC	0.03	0.02	-0.02 to 0.07	.210
Model 3 (QIC 697)	Intercept	-8.07	2.18	-12.35 to -3.79	.001
	SSG Test Score	1.19	0.40	0.39 to 1.99	.003*

* Indicates a significant difference *p* <.05. SE = standard error, CI = confidence intervals, MTC = Mental Toughness Coach, QIC = Quasi Likelihood under Independence Model Criterion

When the significant independent variables from the univariate disposal efficiency model were integrated into a multivariate (interdisciplinary) model (*Table 5.3*), both MTC (β = 0.37, p = 0.002) and SSG test (β = 12.34, p = 0.001) remained as significant predictors, whilst the 3 x 1km test was not significant (β = -0.06, p = 0.077). A multivariate (interdisciplinary) model of coach vote was not required as only one performance test, the SSG test score, was found to be a significant predictor. The Goodness of Fit measures (QIC's) are reported for all GEE within their respective models (*Table 5.1* to *Table 5.3*). For disposal efficiency, where a multivariate (interdisciplinary) model was developed (*Table 5.3*), the QIC value was lower than the QIC values for the univariate models, indicating a better model fit.

Table 5.3

Multivariate Generalised Estimating Equations for Prediction of Disposal Efficiency (n = 21)

Parameter	**Estimate (β)**	**SE**	***95% CI***	***p*-value**
Intercept (QIC 84,155)	22.88	31.65	-39.15 to 84.92	.470
3 x 1km	-0.06	0.03	-0.13 to 0.01	.077
MTC	0.37	0.12	0.13 to 0.61	.002*
SSG Test Score	12.34	3.08	6.29 to 18.38	.001*

* Indicates a significant difference $p < .05$. SE = standard error, CI = confidence intervals, MTC = Mental Toughness Coach, QIC = Quasi Likelihood under Independence Model Criterion

The predictive equation resulting from the multivariate (interdisciplinary) model for disposal efficiency was:

DE = 22.88 + (-0.06) x 3 x 1k time + 0.37 x MTC score + 12.34 x SSG test score

As an example, if the mean score for each performance test was used, the equation would be:

= 22.88 + (-0.06) x 645.24 + 0.37 x 43.19 + 12.34 x 5.31
= 66%

For coach vote, as a negative binomial link model was used, this limits the ability to create a meaningful predictive equation as presented for disposal efficiency. However, the modelled probability of not receiving a coach vote in relation to a participant’s SSG test score can be graphically depicted (*Figure 5.1*). It can be seen from *Figure 5.1* that when a participant’s SSG test score is approximately 3.5 or higher, then the likelihood of them not receiving a coach vote is substantially reduced (i.e. likelihood of receiving a coach vote is increased).

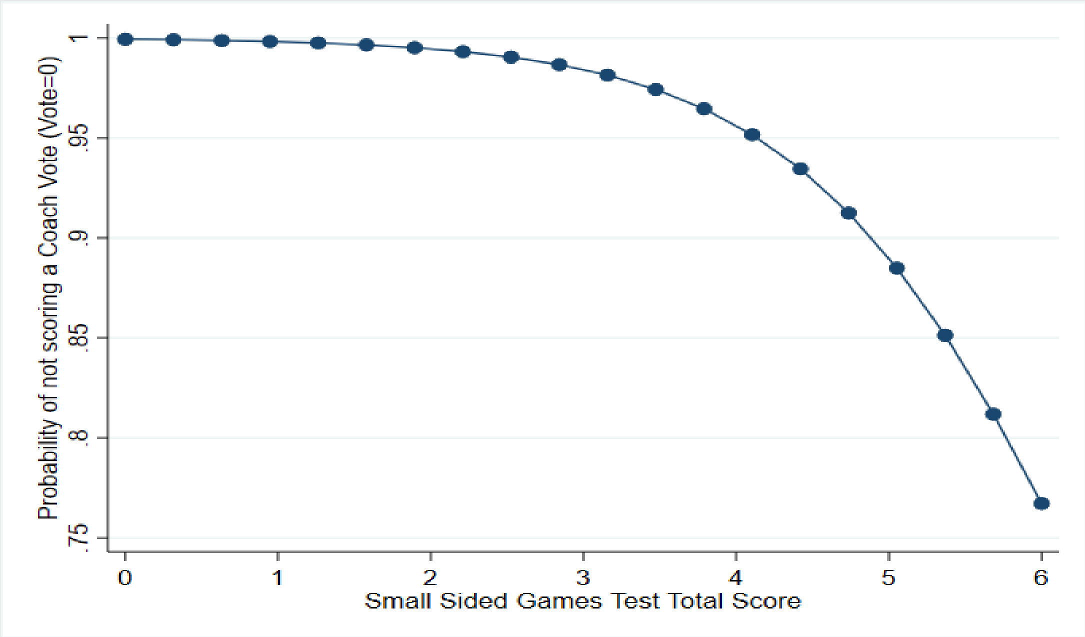


Figure 5.1 The probability of not scoring a coach vote in relation to small-sided games test score

5.3.2 Group and individual differences

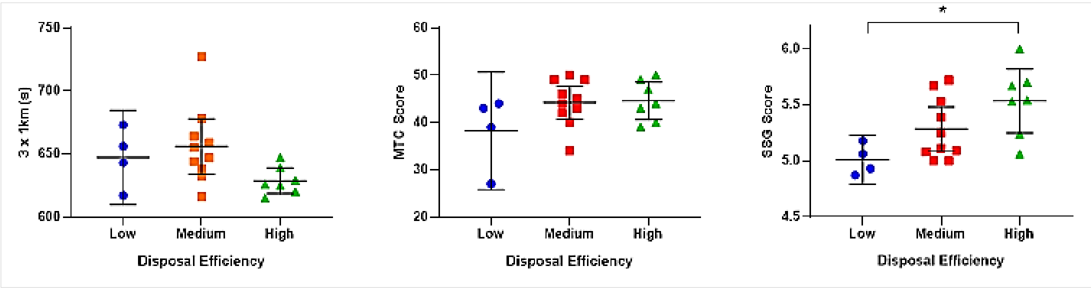
The sub-discipline performance test scores for participants in the categorised groups for disposal efficiency and coach vote are reported in *Figure 5.2* and *Figure 5.3* respectively, with descriptive values provided at *Table 5.4*. For disposal efficiency (*Figure 5.2*), when examining group differences between categories in regards to sub-discipline tests scores, a significant difference was only found overall for SSG test score ($F(2,18) = 4.893$, $p = 0.20$). Bonferroni post hoc comparisons indicated that there was a significant difference ($p = 0.019$, $d = 2.2$) between the high performing group (M = 5.53, SD = 0.31) and the low performing group (M = 5.01, SD = 0.14). For coach vote (*Figure 5.3*), when examining group differences between categories in regards to sub-discipline tests scores, a significant difference was only found overall for the 3 x 1 km test score (χ^2 (2)= 7.112, $p = 0.029$). Pairwise comparisons indicated that there was a significant difference ($p = 0$ .031, $d = 1.62$) between the high performing group (M = 630, SD = 8.51 secs) and the low performing group (M = 665, SD = 29.31 secs).

Table 5.4

Mean Sub-Discipline Scores for Participants who Completed all Tests

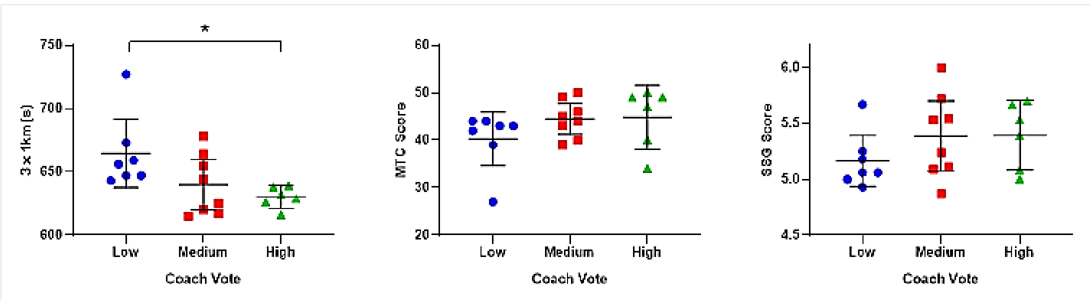
	All	**Disposal Efficiency**			**Coach Vote**		
		Low (< 60%)	**Medium (60-70%)**	**High (> 70%)**	**Low (< 1)**	**Medium (1-2)**	**High (> 2)**
	n= 21	**n = 4**	**n= 10**	**n = 7**	**n = 7**	**n = 8**	**n = 6**
Age	21.24 ± 3.11	19.50 ± 1.30	20.90 ± 2.33	22.71 ± 4.31	19.57 ± 1.72	22.13 ± 3.48	22.00 ± 3.52
3 x 1km (s)	645.24 ± 26.28	647.25 ± 23.61	656.00 ± 30.41	628.71 ± 11.00	664.57 ± 29.31	639.75± 24.02	630.00 ± 8.51
MTC	43.19 ± 5.59	38.25 ± 7.81	44.20 ± 4.85	44.57 ± 4.28	40.29 ± 6.10	44.50 ± 3.90	44.83 ± 6.43
SSG Score	5.31 ± 0.32	5.01 ± 0.014	5.28 ± 0.27	5.53 ± 0.31	5.16 ± 0.25	5.39 ± 0.38	5.40 ± 0.30
Disposal Efficiency	67.33 ± 6.47	-	-	-	-	-	-
Coach Vote	1.50 ± 1.14	-	-	-	-	-	-

Note. MTC = Mental Toughness Coach, SSG = Small-Sided Games



* Indicates significant difference *p* < .05 between sub-groups. Note. MTC = Mental Toughness Coach, SSG = Small Sided Games

Figure 5.2 Mean and 95% CI scores for sub-discipline performance test scores for low, medium and high scoring groups for disposal efficiency



* Indicates significant difference *p* < .05 between sub-groups. Note. MTC = Mental Toughness Coach, SSG = Small Sided Games

Figure 5.3 Mean and 95% CI scores for sub-discipline performance test scores for low, medium and high scoring groups for coach vote

To illustrate individual differences, we have chosen to model three different participants who scored at high, medium and low levels for the SSG test. The predictive equation generated from the multivariate (interdisciplinary) model for disposal efficiency, which incorporates participant 3 x 1 km time, MTC score and SSG test score was used resulting in the following predictions:

1. Participant one (high SSG score) recorded the following scores; 3 x 1km time = 664 secs, MTC score = 46 and SSG = 5.72, with a predicted disposal efficiency of 70%.
2. Participant two (medium SSG score) recorded the following scores; 3 x 1km time = 625 secs, MTC score = 50 and SSG = 5.24, with a predicted disposal efficiency of 68%.
3. Participant three (low SSG score) recorded the following scores; 3 x 1km time = 616 secs, MTC score = 49 and SSG = 5.08, with a predicted disposal efficiency of 66%.

5.3.3 Representative task design

The impact of the level of task representation of performance tests on outcome measures is best illustrated with an example again using the predictive equation for disposal efficiency generated from our multivariate GEE (*Table 5.3*). We compared the effect of an increase in the SSG test (high task representation) score with a comparative increase in the MTC (low task representation) score. If we revisit the above example of using individual participant scores, the participant's predicted mean disposal efficiency is 66%. If the participant increases their SSG (high task representation) score by 10%, from 5.31 to 5.84, this would increase their disposal efficiency to 72.2%. If the participant increases their MTC (low task representation) score by 10%, from 43.19 to 47.51, this would increase their disposal efficiency to 67.3%. In this case, the participants results in the performance test with the higher level of task representation has a greater bearing on the overall outcome variable of disposal efficiency than the performance test with the lower task representation.

In relation to the Goodness of Fit analysis, the SSG test (high task representation) has the lowest QIC value for both disposal efficiency and coach vote indicating the best model fit. The MT rating (low task representation) had the highest QIC value for both disposal efficiency and coach vote indicating a relative poorer model fit.

5.4 Discussion

This study set out to address the call for interdisciplinary research that could provide a more comprehensive understanding of sport performance. We compared whether monodisciplinary and interdisciplinary approaches related to individual constraints contribute to predict measures of match performance in terms of disposal efficiency and coaches' vote. This comparison was crucial to demonstrate that an interdisciplinary approach could better predict match performance than a monodisciplinary approach alone. In addition, our interdisciplinary approach was capable of quantifying individual differences and RTD relative to competition performance. Collectively, this provides a comprehensive understanding of sport performance that is theoretically driven and has practical implications for athlete development.

Our study reconfirmed that a monodisciplinary approach is relevant to understand sport performance. Indeed, univariate (monodisciplinary) analyses showed that each physiological, psychological, and perceptual-cognitive-motor skill component of individual constraints predicted disposal efficiency. The perceptual-cognitive-motor skill component also on its own predicted coaches' vote. These findings are consistent with previous monodisciplinary studies in AF that have reported perceptual-cognitive-motor skill can predict; disposal efficiency (Piggott, Müller, Chivers, Cripps, et al., 2019), as well as talent identified and non-talent identified athletes (Woods et al., 2016). Moreover, physiological measures such as 20 m sprint time have also been able to predict talent identified and non-talent identified Australian footballers (Woods, Cripps, Hopper, & Joyce, 2016). Beyond AF, monodisciplinary studies have also been used to discriminate between skill levels using a video-based decision-making test in soccer (Keller, Raynor, Iredale, & Bruce, 2018) and by using a reactive agility test in rugby league (Gabbett & Benton, 2007). Therefore, there is merit to conduct sport performance research that measures these components in a monodisciplinary approach.

The interdisciplinary (multivariate analysis) approach in our study revealed that psychological and perceptual-cognitive-motor components of individual constraints contributed to significantly predict disposal efficiency. This finding is consistent with coach perception that superior performance in sport is related to psychological and perceptual-cognitive-motor skills (Steel, Harris, Baxter, King, & Ellam, 2014; Zaichkowsky & Peterson, 2018). A likely reason for this is that coping with psychological pressure and making accurate decisions allows the player to apply their physical capability efficiently (less energy cost) to dispose of the ball effectively. Although psychological and perceptual-cognitive-motor components were significant predictors, when combined with the physiological component, there was better prediction of disposal efficiency (QIC value, see *Table 5.3*), in comparison to a monodisciplinary approach (QIC value, see *Table 5.1*). This finding is consistent with our prediction in hypothesis one. This finding is also consistent with previous research into AF that has reported better classification of talent identified and non-talent identified athletes based upon combined physical, technical and perceptual-cognitive components (Woods et al., 2016). Accordingly, it needs to be considered that in our study, the physiological component contributed to the multivariate model to allow better prediction. This indicates that physiological capacity is indeed important, as a footballer needs to run or sprint with the ball, but psychological and perceptual-cognitive-motor skill make a greater contribution to disposal of the ball effectively to a teammate. These findings resonate with the concern raised in the literature regarding the predominant focus upon physical or physiological components to explain sport performance (Cardinale, 2017). Rather, our findings demonstrate that psychological and perceptual-cognitive-perceptual skills, interacting with physiological capacity, is crucial to comprehensively understand sport performance.

Significant differences were found between some sub-groups for disposal efficiency in SSG and coaches’ vote for the 3 x 1km trial. These comparisons, however, focus on mean data and are not capable of demonstrating individual differences in performance. The better interdisciplinary prediction of competition performance established an equation, which was used to identify individual differences in sport performance. For example, we reported how scores from physiological, psychological and perceptual-cognitive-motor individual component constraints contributed to calculation of three different participant disposal efficiency scores (i.e., 70%, 68% & 66%). This is consistent with our prediction in hypothesis two. Accordingly, our findings provide fine-grained detail of how individual constraints contribute towards competition task constraint performance. An individual differences approach has been lacking in the sports science literature with researchers focusing more upon group level analyses that presents mean data, rather than considering within-group differences (Woods et al., 2019). The reasons for this could be; first, sports scientists may have been initially interested in determining upon which components groups of athletes could be differentiated from non-athletes, and second, these group differences provided a means of validating measurement instruments through performance discrimination. Our example highlights that individual differences profiles were aligned with constraints theory that predicts the skill goal can be achieved through interaction of individual, task and environmental constraints (Higgins, 1977; Newell, 1986). Accordingly, our findings are consistent with other studies that have used constraints theory to predict and report individual differences in relation to performance at a specific instance in time (Müller, Brenton, Dempsey, Harbaugh, & Reid, 2015) and improvement of performance due to practice (Chow et al., 2008). Therefore, our developed equation could quantify individual performance, which is underpinned by an interacting constraints theoretical framework.

In utilising an interdisciplinary approach, our findings showed that the degree of RTD of a test or measure can influence the predicted competition performance measure. To this, the MTC rating was considered lower in RTD because it is purely a measure that requires an evaluation of athletic performance. This is unlike a performance test such as SSG that is considered high in RTD because it includes perceptual information and action responses that are closely related to the competition setting of AF. Our analyses indicated that a consistent increase of 10% on each test results in different predictions of competition performance. Here, the test with high RTD or the task that closely represents the context of generalisation (competition), results in an increased level of predicted performance. Whilst RTD has been popular in the literature (Gorman & Maloney, 2016; Woods et al., 2019) we are unaware of studies that have compared the relative contributions of higher and lower representative tasks to predict competition performance. There are, however, studies that have reported performance changes across lower to higher representative tasks in line with what would be expected relative to competition (Gorman & Maloney, 2016; Pinder, Davids, Renshaw, & Araújo, 2011a). Accordingly, our findings are consistent with hypothesis three and the theoretical predictions of RTD. It is important to point out that lower RTD does not mean that the task or measure should not be used. Indeed, as mentioned earlier, both psychological and perceptual-cognitive-motor components contributed to predict match performance indicating they are both valuable indicators of *in-situ* performance. It simply needs to be considered that a MTC rating (on its own) can underestimate actual competition performance.

The results of this study have a direct practical application for AF coaches, specifically in the development of players. An example could be that the coaching staff conduct the three tests (3 x 1km time trial, SSG and MTC) at the start of pre-season training period. The coaching staff can use these results to identify player strengths and weaknesses, inform individual development plans for each player and set specific improvement goals for them to achieve. Using this approach, aspects of training can then be individually tailored to developing the player and resources can be allocated accordingly. For example, if it was identified from the SSG testing that a player needs to improve their decision-making component in order to improve their total score, then coaches can create specific decision-making drills for the player to undertake. The playing group can then be retested after a certain time to see if the goals have been achieved.

5.4.1 Limitations and conclusion

There are limitations of this study that need to be considered. First, a potential limitation of interdisciplinary research is that performance needs to be assessed on all sub-discipline measures. This requires an increased time commitment to the research project by the participants than in monodisciplinary studies. In addition, the pool of participants in skilled athlete populations is significantly smaller than in the lesser skilled population. Athletes are also susceptible to injury, which can limit their participation in tasks that require a significant physical or motor component. Therefore, taking into consideration these difficulties, our sample size was appropriate for measures conducted in the field setting (see Müller, Brenton, & Rosalie, 2015; Triolet, Benguigui, Le Runigo, & Williams, 2013). Second, we focused upon two competition performance indicators. There are of course other competition indicators such as number of possessions or contested possessions. Future research is clearly needed to determine how interacting interdisciplinary individual constraints predict a broader range of competition performance indicators.

In summary, we found that an interdisciplinary approach, underpinned by a constraints theoretical framework, provides a more comprehensive understanding of sport performance. This provides support to a constraints theory explanation of sport performance, which could also be extended to interdisciplinary performance change over time due to practice or experience (learning). Our interdisciplinary approach also allowed individual differences and RTD to be quantified. This is vital because athlete development is based upon an individual approach to test and train, which requires the use of suitable representative tests. Collectively, it is surprising that teams of sports science researchers have not frequently collaborated to more comprehensively understand performance. Although we earlier discussed obstacles to interdisciplinary research, multidisciplinary research teams exist across sports science institutes, sports organizations, and universities around the world. Perhaps the findings from this study might stimulate opportunities for collaboration between sports scientists and academics, which can help coaches better prepare individual athletes in a holistic manner for competition.

Chapter 6 General Thesis Conclusions, Limitations, Implications and Future Research

6.1 Conclusions

The primary aim of this thesis was to investigate the value of an interdisciplinary approach to understand match performance, using AF as an exemplar sport. The secondary aim of this thesis was to quantify individual differences in performance and RTD of tests used in the interdisciplinary approach. This second aim relates more to a call in the literature to determine how individuals perform and whether tests used to measure performance represent match contexts.

The findings of the thesis have provided the following conclusions:

- interdisciplinary research that incorporates several sub-discipline measures can be used in a multivariate model to predict disposal efficiency with a better model fit than a monodisciplinary (univariate) model.
- interdisciplinary research can formulate an equation that could identify individual differences in disposal efficiency.
- the higher representative SSG test contributed a greater magnitude to the prediction of competition performance, than the lower representative MTC rating.
- the SSG test has predictive capabilities across both measures of competition performance (disposal efficiency and coach vote).
- SSG can be used to discriminate perceptual-cognitive-motor skill performance in AF players and predict a component of match performance

6.2 Theoretical implications

The findings reported in this thesis have several theoretical implications for research in the broader field of sports science and for the respective sub-disciplines that were featured. First, this thesis provided a consensus of where the field of sports science is positioned currently with respect to interdisciplinary theory driven research within the competition performance domain. Previous literature suggested interdisciplinary research is scarce, needs to be undertaken (Buekers et al., 2016; Burwitz et al., 1994), and suggested theoretical frameworks to underpin its implementation (Cardinale, 2017; Ibáñez-Gijón et al., 2017). Yet, a comprehensive review of interdisplinary research had not been undertaken. This thesis addressed this gap and provided a systematic analysis regarding the quantity of such research in the competition performance domain, the sports and disciplines involved and ratings about the level of task representation of performance tests. To this, Balagué et al. (2017) stated that the reliance on specialised science (or monodisciplinary research) is part of the dynamic evolution of science; over time, the field will continue to evolve towards producing more unified knowledge (unified science). Such unification through interdisicplinary research may also come about through discussion of theoretical framworks such as constraints theory in scientific reviews. Accordingly, this thesis provides valuable information as to where the theoretically driven sports science field is placed along this evolutionary timeline in regards to the competition performance domain. In future, the thesis will provide a reference point to gauge how the field of sports science is continuing to evolve.

Second, constraints theory (Higgins, 1977; Newell, 1986) was used as a framework for this thesis because sport performance involves an intricate coupling between the performer, task and their performance environment. Hence, the value of using an interdiscplinary approach, which integrated performer constraints relative to the task and performance environment, was compared to that of a monodisciplinary approach that considerered performer constraints in isolation. Indeed, previous literature had presented the reasons why interdisciplinary research should be undertaken (Fiore, Hoffman, & Salas, 2008; Phillips et al., 2010), but had not properly tested its value compared to monodisciplinary research. In this thesis, the interdisciplinary approach resulted in a better model fit to predict match disposal efficiency in AF, than a corresponding monodisciplinary approach. This demonstrates that taking into consideration interacting performer (or organism) constraints, relative to the task and performance environment, rather than performer constraints in isolation, provides less error in terms of predicting match performance. This key outcome highlights how an interdiscplinary approach could help improve the reliablity of talent identification pathways in AF. Furthermore, this evidence provides support to the key prediction of constraint theory that performer, task and environmental constraints are tightly coupled (Higgins, 1977; Newell, 1986). Therefore, future sports science research should attempt (where possible) to use an interdisciplinary approach.

Third, constraints theory identifies the importance of the organism (individual) relative to the performance task and environment. Thus, the theory predicts that an individual's goal-directed actions will be determined by individual capabilities relative to the environment and task. The results of this thesis provided support for constraints theory as the interdisciplinary approach facilitated a predictive equation for disposal efficiency that included three measures (i.e., 3 x 1km time, MTC and SSG score), which are individual constraints. By factoring in individual constraints it was possible to model exemplar individualised match performance statistics that would otherwise be masked by traditional averaged data. Therefore, an individual level of analysis can provide information of individualised solutions and/or deficiencies to sport performance that is theoretically driven (Ibáñez-Gijón et al., 2017).

Fourth, whether tests used in sport performance research are representative of *in-situ* (field) or match contexts has been a prominent topic. To this, Vilar et al. (2012) stated that the ultimate objective of a performance test in sport science is to show how the test relates to competitive performance. This thesis provided evidence that a test of higher RTD (SSG), contributes a greater magnitude to prediction of match performance, than a test of lower RTD (MTC). This is important information for the theoretical underpinning of test design and inclusion in a test battery to assess performance. Accordingly, tests that include perceptual-cognitive-motor components are more likely to be representative of in-*situ* performance settings. As mentioned earlier in the thesis, this does not necessarily mean that lower representative test should not be used, because they may be the only means (at the moment) to measure a capability such as in the case of psychological skill. Rather, a combination of higher and lower representative tests may complement each other in their prediction of match performance, as was reported in this thesis.

Finally, in relation to the sub-displine of Sport Psychology, this thesis reports on important theoretical applications with respect to MT. There has been a call in the literature for other methodologies to be considered beyond traditional surveys to advance theoretical understanding (Gucciardi & Gordon, 2013; Mahoney, Ntoumanis et al., 2014). A recommended starting point for this was the measurement of objective performance under low and higher pressure *in-situ* contexts (Mahoney, Ntoumanis et al., 2014). In chapter four, this thesis provided support for a proposed theory of MT; and demonstrate that higher MT scores are predictive of performance in higher pressure situations (Piggott, Müller, Chivers, Burgin, et al., 2019). Therefore, this thesis has made a small contribution to advance theoretical understanding of a Sport Psychology concept to the natural sport setting.

6.3 Applied implications

It is important in applied sports science, that results of research translate into the field to facilitate coaches' and sports scientists' implementation of evidenced based strategies in order to improve athlete performance. First, this body of work provides coaches in AF with evidence of how three performance tests relate to measures of match performance. For example, if a coach decides that one goal over the season is to increase their average team disposal efficiency, then the coach can plan training sessions that include regular use of SSG. Justification for the implementation of SSG is provided in chapter three (Piggott, Müller, Chivers, Cripps, et al., 2019) such that improvement in a SSG performance may improve match disposal efficiency. For example, a coach may use SSG on a weekly basis beginning with low (six vs. three) levels of pressure at the beginning of the pre-season period. As pre-season training progresses, the coach can increase the level of pressure to medium (six vs. four) in order to develop players and then to high (six vs. five) as pre-season games approach. To prepare the players for competition intensity, the coach could even use SSG where there is an even numbers of attackers and defenders (six vs. six) or even an additional defender (six vs. seven). Such SSG scenarios and pressure variations can also be applied in other team based invasion games such as soccer, basketball, touch football, handball and water polo, in order to develop players' decision-making and skill execution.

Second, an important applied implication from this body of work is regarding individual player assessment that can guide individualised development. Specifically, the coaching staff at an AF club could implement the three performance tests (3 x 1km time trial, MTC and SSG) (Piggott, Müller, Chivers, Cripps et al., 2020) at the start of the pre-season training period. The coaching staff can assess the results identifying player strengths and weaknesses, develop individual development plans for each player based on their results and then set specific goals for them to achieve. This integrated approach provides a better profile of each player, and the accompanying specific programs may facilitate improved success in competition and even prolong longevity of a career (Buekers et al., 2016). Therefore, by following the aforementioned steps, coaches would be fulfilling the need to sample constraints on performance of individual performers using an interdisciplinary approach, according to the contemporary model of athlete preparation outlined by Woods et al. (2019). Moreover, as mentioned previously, this thesis supports the notion that the necessary scientific information which may be used to improve performance rarely resides in one sports science sub-discipline (Sands, 2017).

Third, there are also applied implications in the talent identification area resulting from this thesis. The AFL hold the annual Draft Combine where all the top ranked players from around the country gather and perform a series of tests in front of recruiters and coaching staff from all the professional clubs. Skill tests have been a part of the suite of performance tests included in the Draft Combine; these skill tests have also been the focus on previous research regarding their validity and reliability (Cripps et al., 2015). However, in recent years the skill testing has been phased out of the Draft Combine for a variety of reasons. Anecdotally, one of the reasons for this is AFL clubs were placing less value on skill test results when recruiting players as the tests are not deemed to be representative of the game (e.g. when executing the skill, there was no 'opponent' to apply pressure as would occur in competition). The SSG test developed as part of this thesis involves players executing skills under pressure from opposition players. Therefore, the AFL could consider adopting our SSG protocol or a similar one to re-introduce a test from the Motor Control sub-discipline back into the Draft Combine and the relevant talent pathways. When players gather for the Draft Combine and the relevant talent pathways' testing, players could be divided into teams and a series of SSG could be played using the protocols (or similar ones) developed in chapter three. Like the methods used in this thesis, the games could be videoed allowing post game analysis and a total score given for each player which is comprised of decision-making and skill execution components. By doing this, recruiters and club coaches can then watch and analyse players' skills under pressure from opposition players; something that was missing in previous AFL Draft Combines. Furthermore, a large number of players can be tested in a short amount of time making the SSG test a feasible option.

The sport of AF is predominately a winter sport and it is therefore important that players are able to execute their skills in differing weather conditions including rain and wind. Such weather conditions can affect the ability of players to execute attacking skills such as kicking, handballing and marking as well as defensive skills such as tackling. Currently, the AFL Draft Combine is held in the latter months of the year, around October when winter is over and generally, there is less rain and wind. Expanding on the previous paragraph, a further applied implication around talent identification could be that if SSG games were introduced into the AFL Draft Combine, that some of these could be done in simulated wet weather conditions. An area could be set aside to be watered heavily prior to the testing; this would present heavier, more challenging ground through which to navigate and engineer a slippery ball, hence players of all skill levels would find it more difficult to execute skills under these conditions. In addition, large industrial fans could possibly be used on the sideline to generate wind which could even make it more challenging for players to execute skills. By creating such conditions, it would allow recruiters and coaches to compare how individual players perform under different environmental conditions which would provide a more complete overview of the skill set of players. Importantly, these additional scenarios would maintain the fidelity of RTD which was an important novel aspect to the experimental design for the thesis study.

Finally, a further applied implication from this thesis is the support for training sessions to be planned with an interdisciplinary approach. Somewhat similar to researchers and academics working in their own sub-disciplines, sporting clubs can often work independently with coaches working on skill, strength and conditioning coaches working on fitness, sport scientists collecting data and sports psychologists working on mental skills with athletes. The results of this thesis highlight the benefits of an interdisciplinary approach and that disposal efficiency in AF can be influenced by fitness (3 x 1km time trials), coach reported MT, decision making and technical skill (SSG). In planning practice sessions, ideally it would be beneficial to have the input of coaches, sports scientists, sport psychologists, skill acquisition specialists, and strength and conditioning coaches each contributing to the session objectives and designing of drills to achieve these objectives. Rothwell et al. (2020) referred to this as working within department of methodology (DoM), where of a group of practitioners and applied scientists who share integrative tendencies based on a rich mix of empirical and experiential knowledge. For example, a team might be preparing for a game against an opposition who is known to apply unrelenting pressure when defending, resulting in very limited time to make decisions for attacking players when in possession of the ball. The opposition are also a top rated defensive side ranking highly for the number of tackles made per game. Furthermore, they have a tendency or team focus to 'unsettle' the opposition using niggling tactics aimed at shifting the focus of the opposing team and putting players off their game. At a planning meeting for training, the head coach of the AF team could request input from fellow coaches and service providers as to how they best prepare for the upcoming game. The skill acquisition specialist may offer the input of adding an extra defender in drills to replicate the increased pressure and limited time to make decisions when in possession of the ball; the sport psychologist suggests that in the simulated game play the defending team is to niggle the attacking team both verbally and physically in an attempt to shift their focus; the strength and conditioning coaches suggest that they incorporate some partner drills into the latter part of the warm up that focus on breaking tackles when in possession of the ball. As can be seen from these examples, that there are several applied implications resulting from this thesis.

6.4 Future research

In this thesis, it was identified that there was a dearth in interdisciplinary research in the competition performance domain (Piggott, Müller, Chivers, Papaluca, et al., 2019). It was decided to address this by undertaking such research within AF. Therefore, a relevant starting point for future research could be to undertake research using similar frameworks in other team sports such as soccer, field hockey, basketball, water polo, touch football and handball. These sports all feature reasonably prominently in talent identification and talent selection domains (Piggott, Müller, Chivers, Papaluca, et al., 2019), so the knowledge base would be expanded with an interdisciplinary approach in the competition performance domain. If we use the sport of field hockey as an example, a researcher could adopt a similar approach to our study and choose one test from each sub-discipline and discuss with coaches what they believe are the most appropriate measures of match performance. A measure of match performance such as ‘effective touches’ could be used where each time an attacking player has possession of the ball, it is rated using a Likert scale from ‘not effective’ though to ‘very effective’. In regards to a test from each sub-discipline for field hockey, they could possibly use the Multistage Fitness Test (Exercise Physiology), shooting accuracy and pushing speed (Motor Control) and the Psychological Skills Inventory for Sports (Sport Psychology); all tests mentioned here have been used previously in field hockey research (Keogh et al., 2003). Testing could be undertaken in the pre-season period and match performance measures recorded over the season. A factor that needs to be considered when recommending future research is that the clubs or organisations involved, need to have the appropriate resources for the study to be feasible. Regarding field hockey and using Australia as an example, perhaps the National League teams and the affiliated tournament would be an appropriate place for this to occur as they would be resourced appropriately. Teams could do the testing in their state’s preparation time and then tournament games could be used for performance measures. It would be of interest to see if the results from interdisciplinary studies in other sports yield similar results to our study in AF. Such findings may then provide a multi-sport framework that highlights which factors are most influential in sport performance which, in turn, has relevance for coaches and those working in player development roles.

Studies incorporating an interdisciplinary approach involving participants of differing skill levels is also a topic for future research. In this thesis, highly skilled participants from a semi-professional sporting club were recruited. To gain a comprehensive understanding, similar studies at elite and even amateur levels need to be undertaken. Perhaps at the elite level, it may be that the Sport Psychology component becomes more influential in predicting performance, while at the amateur level the same may be indicated for the Exercise Physiology component (Steel et al., 2014). To gain a comprehensive understanding of the interdisciplinary factors that influence sports performance, studies need to be conducted on a broader range of the skill spectrum.

Another direction for future research is to use a similar interdisciplinary approach in underage and talent development pathways. In AF, all states have development pathways and National Championships are played at U16 and U18 age levels. At these important development stages, researchers could use an interdisciplinary approach to investigate the factors that influence performance and determine if these factors are similar or different to those at the adult level. The performance testing could be undertaken in each state when teams gather for their training camps and then the competition performance measures can be taken during the National Championships. It may be that at the younger age group it is the physical capacity measures that have the most influence over performance, which contrasts with what our study found using adults (Piggott et al., 2020). Like the consideration to investigate across different skill levels, to gain a comprehensive understanding of the interdisciplinary factors that influence sports performance, studies need to be conducted across the different age groups of participants that participate in the sport.

A further path for future research is investigating whether other performance tests beyond the 3 x 1km time trial, SSG and MTC can also influence competition performance measures. For example, a measure of resilience such as the Brief Resilience Scale (Smith et al., 2008) or a measure of perseverance and passion for long-term goals such as the GRIT scale (Duckworth, Peterson, Matthews, & Kelly, 2007) could be investigated for use as a measurement tool from Sport Psychology sub-discipline. It could be even argued that these two measures would be more widely recognised globally than the concept of MT, which has been used primarily in Australia and the United Kingdom. In regards to Motor Control, Bonney, Berry, Ball, and Larkin (2019b) developed an AF kicking proficiency assessment tool and perhaps this test could also be used to display predictive capabilities regarding match performance. Recently, the AFL altered the testing in the Draft Combine, replacing the Multistage Fitness Test with the Yo-Yo Intermittent Recovery Test. It may be that the Yo-Yo Test has influential capabilities on competition performance, and this could be an area of future research.

One of the aims of this thesis was to quantify RTD of tests used in the interdisciplinary approach. The tests that were used in chapter five (Piggott et al., 2020), the interdisciplinary study in AF, included the two tests which would be classified as having high task representation (SSG and 3 x 1km time trial) and one which would be classified as having low task representation (MTC). One of the findings from Piggott et al. (2020) was that the tests involving higher task representation displayed a better model fit as opposed to the tests with lower task representation. Therefore, an area of future research would be the development of a Sport Psychology measure that has a higher task representation, and this would extend beyond survey methodology. Bell et al. (2013) created a MT training program as part of a study with elite junior cricketers in England. The intervention involved 46 days made up of a series of camps and a tour to India. During these times, players participated in a series of activities designed to practice dealing with pressure and threat, and included activities centred on skill development, pressure training, testing and goal setting (Bell et al., 2013). Perhaps a modified version of this program could be used as a starting point for work on a MT measure; using similar aspects and delivered over a shorter time period would make it feasible and ensure greater task representation than a survey. Of course, such a test would need to be sport specific and the appropriate validity and reliability measures be ascertained before it could be implemented.

A further direction for future research is to extend the interdisciplinary approach used in this thesis to encompass a transdisciplinary approach. There have been recent appeals made in the literature for sports science to consider a transdisciplinary approach (Rothwell et al., 2020; Vaughan, Mallett, Davids, Potrac, & López-Felip, 2019). Transdisciplinary research is a form of interdisciplinary research involving people from different fields (e.g. academic researchers and industry practioners) working together over extended timeframes to investigate complex life matters using diverse theoretical approaches (Polk, 2014). For example, Toohey et al. (2018) used a transdisciplinary approach to investigate talent identification and development in Australian sport using AF, cricket, kayaking and tennis. One of their conclusions was that developing sporting talent is a complex choreography of psychological, physical, environmental and management factors (Toohey et al., 2018). Part of this thesis demonstrated that performance outcomes can be achieved by athletes in different ways; some may have better decision making and skill execution capabilities, others have higher levels of MT or have a greater running capacity. The interdisciplinary approach used in this thesis was able to identify these different components that influence performance in the sport of AF. A transdisciplinary approach would then examine the complex interactions between these components in greater detail to advance theoretical knowledge and improve applied practice (Vaughan et al., 2019).

6.5 Limitations

Throughout this thesis, whilst accepted scientific methods were employed, there are some limitations that need to be acknowledged. First, only one sport was studied which was AF. It was beyond the scope of this thesis to undertake monodisciplinary and interdisciplinary research across multiple sports. Second, all the participants were from the one club which participated in a semi-professional competition. It was not feasible or practical to conduct this study across multiple clubs due to scheduling constraints. Third, not all participants completed performance tests and it is acknowledge that it would have been beneficial for this to occur. However, as the performance tests were conducted as part of the existing program in a high-performance environment, participants had their workloads monitored according to age, overall fitness levels, injury history and injury occurrence which is characteristic of best practise. This limitation has been noted as a challenge when working in a team sport environment (Gamble, 2006). Fourth, only one performance test from each sub-discipline of Exercise Physiology, Motor Control and Sport Psychology was used in this project. There may be performance tests from other sub-disciplines such as Biomechanics or Functional Anatomy, which may also be important from an interdisciplinary perspective. However, as reported in this thesis, the sub-disciplines chosen have been shown to be relevant to match performance for AF. The final limitation is regarding the performance measure of disposal efficiency. This measure is directly associated with the team in possession of the ball; hence there was no objective performance measure used that is associated with the defending team.

6.6 Summary

This thesis has made a significant contribution to the sports science field in a variety of ways. It has provided a model as to how to undertake research using an interdisciplinary approach, which provides a template for other researchers to follow. This thesis also provides quantitative evidence regarding the benefits of using an interdisciplinary approach in sports performance research as opposed to the more traditional monodisciplinary approach. Evidence is also provided regarding the level of task representation of performance tests, their influence on competition performance measures, as well as how to quantify individual differences. The findings of this thesis will be beneficial to scientists, coaches, and researchers in a variety of sports.

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Appendix A Co-author Contribution

To Whom It May Concern

I, Ben Piggott, contributed to each publication below through generation of concepts, completion of ethics application, data collection, data analysis, preparation of manuscript and submission of manuscript to the relevant journal.

Piggott, B., Müller, S., Chivers, P., Papaluca, C., & Hoyne, G. (2019). Is sports science answering the call for interdisciplinary research? A systematic review. *European Journal of Sport Science. 19*(3): 267- 286. doi:10.1080/17461391.2018.1508506

Piggott, B., Müller, S., Chivers, P., Cripps, A., & Hoyne, G. (2019). Small-sided games can discriminate perceptual-cognitive-motor capability and predict disposal efficiency in match performance of skilled Australian footballers. *Journal of Sports Sciences. 37*(10): 1139-1145. doi:10.1080/02640414.2018.1545522

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I, as co-author, endorse that this level of contribution by the candidate indicated above is accurate.

Sean Müller		10th May 2020
Paola Chivers		10th May 2020
Gerard Hoyne		10th May 2020

Appendix B Publications

B.1 Is sports science answering the call for interdisciplinary research? A systematic review

European Journal of Sport Science

Routledge
Taylor & Francis Group

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Is sports science answering the call for interdisciplinary research? A systematic review

Ben Piggott, Sean Müller, Paola Chivers, Carmen Papaluca & Gerard Hoyne

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ORIGINAL ARTICLE

Is sports science answering the call for interdisciplinary research? A systematic review

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Abstract
Sports science research is traditionally monodisciplinary despite calls for an interdisciplinary focus. The primary purpose of this systematic review was to identify studies on talent identification, talent selection and competition performance to determine whether interdisciplinary research is being conducted. Thirty-six studies met the selection criteria. These studies were critiqued relative to sport, skill level, sport science sub-disciplines included, and whether the research was multidisciplinary or interdisciplinary. The secondary purpose of the review was to critique the level of analysis and level of representative task design in performance tests used in the studies. Twenty-five studies were categorised as interdisciplinary, with 11 categorised as multidisciplinary. Thirteen sports were represented with soccer the most frequent followed by field hockey, Australian Rules football, handball and rugby league. Thirty-two studies completed their analysis at a group level and four at an individual level. A total of 337 performance tests were rated for representative task design with 64 categorised as low, 123 as medium and 150 as high. The results pertaining to interdisciplinary studies and individual analyses are discussed in relation to constraints theory, which predicts that interacting variables can explain sport performance. Sports science research is beginning to fulfil the call for interdisciplinary research. Future research, however, needs to consider individual analyses and representative task design of tests to progress sports science knowledge.

Keywords: *Sports science, interdisciplinary research, multidisciplinary research, constraints theory, individual differences, representative task design*

Highlights

- Sports science research is beginning to fulfil the call for interdisciplinary research.
- Within domains of talent identification, talent selection and competition performance, thirty-six studies met our inclusion criteria with twenty five studies identified as interdisciplinary and eleven identified as multidisciplinary.
- Most multi- or inter-disciplinary research occurs in soccer followed by field hockey, Australian Rules football, handball and rugby league. Functional Anatomy is the most represented sub-discipline followed by Exercise Physiology, Motor Control, Sport and Exercise Psychology and then Biomechanics.
- Future multi- or inter-disciplinary research needs to consider individual analyses and representative task design of tests to progress sports science knowledge.

Sports performance is complex to study because elite athletic skill during competition is comprised of maximal operation of interacting variables including physiological fitness, psychological preparedness, physical development and perceptual-cognitive-motor skill (Buekers et al., 2016). For example, in a game of soccer or Australian Rules football (ARF), a midfielder repeatedly sprints whilst reading the play in order to decide upon which teammate to execute a precision pass of the ball to try and score a goal for their team. Simultaneously, the player can be required to fend off a tackle to retain possession of the ball. Therefore, the integration of knowledge from different sub-disciplines of sports science is of great importance to guide our understanding of elite sports performance. Furthermore, an integrated

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approach could be applied to areas such as talent identification, selection, and development of athletes across different levels of the skill continuum (Buekers et al., 2016).

Despite sports performance involving multiple interacting components, the trend for sports science research has been overwhelmingly monodisciplinary in nature, confined within one sub-discipline (Glazier, 2017). Burwitz, Moore, and Wilkinson (1994) first called for a more integrated approach to understand sport performance over 20 years ago and this has become more emphatic in recent years (Cardinale, 2017). This is because an integrated approach provides a better profile of the strengths and limitations of each athlete, which can then be targeted with specific intervention programmes to attempt to improve success in competition and prolong longevity of a career (Buekers et al., 2016). In addition, sport science practitioners who work with athletes report that the necessary scientific information to improve athlete performance rarely resides in one sports science sub-discipline (Sands, 2017). Moreover, coaches believe that findings from sports science research that integrates different sub-disciplines could inform the structure of individualised assessment and training programmes to improve individual athletic performance (Williams & Kendall, 2007).

Multidisciplinary research will approach a scientific question from a sub-discipline specific viewpoint (Glazier, 2017). In this context, the research could involve scientists from different sub-discipline areas working independently of each other, but collectively their research outcomes could provide a solution to the problem being investigated (Freedson, 2009). An example of multi-disciplinary research would be a group of researchers who assess a squad of elite soccer players. This could involve the individual athletes being taken through a series of assessments. An exercise physiologist could measure the aerobic capacity using a shuttle run; a skill acquisition specialist could measure perceptual-cognitive-motor skill through a sports-specific perceptual-cognitive-motor test and a sport psychologist could measure mental toughness through a survey. The researchers could publish their data independently, but the cost benefit for the head coach is they could identify the key outcomes from the different sub-disciplines and use this information to guide the development of athletes to improve performance.

Interdisciplinary research is more integrative and involves the interaction of specialists across sub-disciplines working together to generate new knowledge in a more holistic approach to understand sport performance (Freedson, 2009). Accordingly, interdisciplinary research would combine the technical expertise of the researchers, for example, an exercise physiologist, skill acquisition specialist, and sport psychologist to understand how athletes perform sports skills under psychological and physiological stresses as would occur in the game setting. The point of difference here is that the scientists work collaboratively to address the specific research question.

Constraints theory (Higgins, 1977; Newell, 1986), which forms part of the ecological-dynamics theory (Davids, Handford, & Williams, 1994), is a valuable framework which supports interdisciplinary research because it helps explain how integrated variables influence the achievement of the task goal (Ibáñez-Gijón et al., 2017). Constraints theory predicts that the immediate environment, task and individual constraints shape how one perceives to guide action in order to achieve the skill goal (Newell, 1986). More specifically, Ibáñez-Gijón et al. (2017) outline that constraints can be conceptualised as interacting ecological and execution scales. The ecological scale refers to the tight linkage between the organism and its environment to achieve the task goal, such that perception and action work in synchrony. The execution scale refers to the use of different degrees of freedom through a variety of coordination patterns to achieve the same task goal. An example of constraints is demonstrated in the last minute of a basketball game where the team in possession of the ball is ahead in score (immediate environment), with the point guard (individual athlete) of the winning team required to dribble the ball up the court, ensuring their team maintains possession for as long as possible to ensure the opposition team has less time to score to cause a turnover in order to score (task). Therefore, constraints involving the ecological scale provides perceptual information of the task and environment to which the execution scale can use a variety of coordination patterns to maintain possession of the ball.

Although constraints theory identifies the importance of the organism (individual), researchers in sports science have often used group comparison design. Groups of participants who can differ in characteristics such as age, skill level, gender, undertake performance tests or training programmes and the results are compared. For example, research involving the Ghent youth soccer project aimed to determine the relationships between physical and performance characteristics and level of skill in players (Vaeyens et al., 2006). Results were presented at the group level with participants being categorised by skill level (elite, sub-elite and non-elite) and age (under 13, 14, and 15), with the conclusion drawn that characteristics that discriminate youth soccer players vary according to age. Such research is useful if the aim is to identify the characteristics which discriminate between groups and ages. An emerging approach of late in sports science research involves individual difference comparisons on performance tests (Phillips, Davids, Renshaw, & Portus, 2010). Investigation of individual differences in sports science is particularly relevant as constraints theory predicts that an individual's goal-directed actions will be determined by the environment and the task. Therefore, an individual level of analysis can provide information of individualised solutions and/or deficiencies to achieve the task goal at either the ecological or execution scales (Ibáñez-Gijón et al., 2017). In turn, this can be highly beneficial to practitioners who attempt to design individualised training programmes for athletes (Davids, Araujo, Seifert, & Orth, 2015).

Importantly, it has been argued that interdisciplinary research should investigate how individuals exploit constraints to achieve the task goal (Ibáñez-Gijón et al., 2017), and that the tasks undertaken in the research should be representative of the game setting (Buekers et al., 2016). Representative task design states that properties of performance tests (constraints) should represent the properties (constraints) of the performance environment to which the results are to be generalised (Vilar, Araújo, Davids, & Renshaw, 2012). For example, in regards to the sub-discipline of Motor Control, perceptual-cognitive-motor tests should be structured to ensure that some or all of the perceptual information sampled from the real-world game setting are available to guide action (Pinder, Davids, Renshaw, & Araújo, 2011). Furthermore, the perceptual-cognitive-motor test should allow the participant to link motor responses or couple action to relevant sensory information in order to guide the execution of a motor-skill action like they would within the competition setting. For example, small-sided games (SSG) have been used in soccer as a perceptual-cognitive-motor test to identify talented players (Fenner, Iga, & Unnithan, 2016). This test would be considered to have a high level of task representation as perceptual information like the game setting is available which can be used to guide motor-skill action typical of a soccer game. Accordingly, representative task design is vital to ensure that the test(s) used include constraints reflective of the competition setting in order to provide an accurate understanding of how the ecological and execution scales function to achieve goal-directed behaviour in sports.

To summarise, an interdisciplinary approach encompassing multiple sub-disciplines of sports science can provide a more comprehensive understanding of sport performance. More recently, a scale-based theoretical framework (Ibáñez-Gijón et al., 2017), couched within the ecological-dynamics theory, outline that sport performance is best understood by investigation of interacting individual constraints, incorporating perception and execution scales, in tasks that are representative of the competition setting.

The primary purpose of this systematic review was to determine the extent of published research in the sports sciences that could be defined as either multidisciplinary or interdisciplinary in its approach. We focused on research papers that had integrated three, four or five sub-disciplines of sports science as this should more accurately reflect the complex interaction of variables that impact on sports performance such as physiological fitness, psychological preparedness, physical development, perceptual-cognitive-motor skill (Glazier, 2017). The secondary purpose of this review was to critique the level of analysis (group or individual) and the level of representative task design (low, medium or high) of the performance tests used within the reviewed studies. Sport scientists' and practitioners' request that sport science research should incorporate more interdisciplinary research is based on the assumption that currently, this approach is limited (Glazier, 2017; Williams & Ward, 2017). The significance of this review is that these opinions and assumptions will be addressed by providing evidence, previously not presented, regarding the extent to which interdisciplinary research has been undertaken in sport science.

Method

Search strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2015), was followed for the initial identification stage of this review using three electronic databases (Academic Search Premier, SportDiscus and PubMed) between January 1994 and April 2018. The following search terms were included: "multidisciplinary", "multidimensional", "interdisciplinary", "game performance", "match performance", "talent development", "sport performance", "biomechanics", "exercise physiology", "motor control", "sport psychology", "exercise psychology". To ensure, a thorough search was conducted, these terms were entered separately and in Boolean combination in each database. In addition, searches through reference lists were also conducted to ensure all possible articles were identified.

Eligibility criteria

Only research articles published between January 1994 and April 2018 and written in English were included in this review. The year 1994 was used as a starting point as this corresponded with the first call for such research (Burwitz et al., 1994). The article had to integrate knowledge and testing measures from three or more recognised sub-disciplines of sports science (Abernethy et al., 2013) including Functional Anatomy, Exercise Physiology, Motor Control, Biomechanics and Sport and Exercise Psychology. The research article had to be in the area of sport performance, which for the purposes of this paper, included talent identification, talent selection and competition performance. Finally, the article had to be a primary research article and not a review.

Classification of integration

For each article identified in the review, a classification was given as to whether the research was multidisciplinary or interdisciplinary. The basis for this classification was the previously mentioned definitions which focussed on the level of integration (Freedson, 2009). For the article to be classified as interdisciplinary, there had to be an integration of knowledge and results from performance tests across three or more sub-disciplines of sports science. To ascertain whether integration occurred, two of the researchers reviewed the identified articles independently of each other. If methods were used in the analysis that integrated information from the different sub-disciplines (e.g. stepwise regressions, predictions equations, modelling) then the article was classified as interdisciplinary. If this did not occur, then the article was classified as multidisciplinary.

Classification of analysis

A classification was given as to whether the analysis was at the group or individual level. To ascertain whether a group or individual analysis was conducted, again two of the researchers reviewed identified articles independently of each other. If the article compared results across performance tests at the group level (e.g. elite and non-elite, selected and not selected, under 18 and 16 years of age, male and female) then a "group" classification was given. If the article compared results across performance tests to investigate individual differences, then an "individual" classification was given. For example, Müller, Gurisik, Hecimovich, Harbaugh, and Vallence (2016) found that a short-term temporal occlusion anticipatory training intervention had individualised benefits to the *in situ* performance of field hockey goalkeepers. Therefore, if correlational methods were used to report relationships between performance tests and competition performance and this was the only statistical method used, the article was classified as "group" as this does not allow differences at the individual level to be investigated.

Rating of representative task design

A rating of representative task design was given for each performance test identified in the review. Functional Anatomy tests were not given a rating as they are considered measurements (e.g. height, weight, skinfolds) and there is no opportunity in this sub-discipline for the participant to engage the sensorimotor system in a goal-directed task. A rating scale was developed and applied by the researchers as follows:

Low representative task design: Perceptual information that occurs in the competition environment may or may not be presented to the participant in the performance test. Opportunity is not provided to couple action to available perceptual information like in the competition environment.

Medium representative task design: Perceptual information that occurs in the competition environment is presented to the participant in the performance test. Opportunity is provided to couple action to incomplete or later occurring perceptual information.

High representative task design: Perceptual information that occurs in the competition environment is presented to the participant in the performance test. Opportunity is provided to couple action to the available perceptual information like in the competition environment.

Results

A summary of the systematic search and selection process is provided in the PRISMA flow diagram (Figure 1).

A total of 113 articles were identified in the original search with 23,806 selected via screening using the set criteria. After the eligibility criteria were applied, 36 articles were considered to integrate multiple sub-disciplines and thus, were included in this review. Table I outlines the authors, and year of publication, sport, skill level, domain of sport performance, sub-disciplines included within each study, level of integration and the level of analysis.

Level of integration and analysis

Of the 36 articles, 69% (25/36) were rated as interdisciplinary in design with the remaining 31% (11/36) rated as multidisciplinary. In regards to the level of analysis, 89% (32/36) analysed their results at the

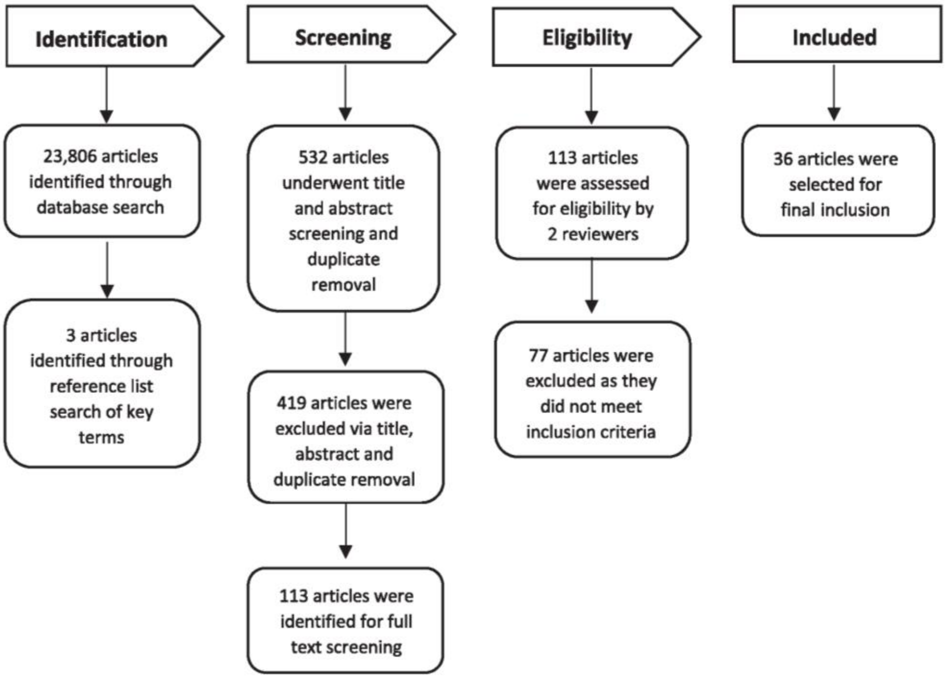

Figure 1. Flow diagram for the article selection process used in this systematic review.

group level, whilst 11% (4/36) completed analysis at the individual level.

Sports and sub-discipline involvement

There were 13 different sports represented in the identified articles. Soccer was the sport that was most represented in integrated research 25% (9/36), followed by field hockey 14% (5/36) and ARF 11% (4/36). Three of the 13 represented sports were individual, eight were team sports and two could be classified as both individual and team (gymnastics and rowing). The proportion of articles in each sports performance domain were talent identification 42% (15/36), talent selection 42% (15/36) and competition performance 17% (6/36). The most highly represented sub-disciplines of research within the 36 articles were Functional Anatomy with 100% (36/36) followed by Exercise Physiology 97% (35/36), Motor Control 89% (32/36) and Sport and Exercise Psychology 36% (13/36). Biomechanics was the least represented with 8% (3/36).

Rating of task representation of performance tests

A total of 337 performance tests (excluding Functional Anatomy) were used across the 36 articles. The performance tests used in the identified articles and the ratings given for representative task design are shown in Table II. Overall, 19% (64/337) of performance tests rated as low, 36% (123/337) as medium and 45% (150/337) as high in regards to the level of representative task design. The percentage of tests in each sub-discipline which had a high rating of representative task design, was 65% in Exercise Physiology, 18% in Motor Control, and 100% in Biomechanics. Sport and Exercise Psychology had no test(s) reporting a high rating of representative design.

Discussion

This systematic review set out to determine whether we were answering the call for interdisciplinary research in the field of sports science. The primary purpose of this systematic review was to identify and critique sports science research articles that integrated multiple sub-disciplines in the domains of talent identification, talent selection, and competition performance. The secondary purpose of this review was to critique the level of analysis and representative task design of the assessments presented in the research articles. The majority of the articles that met the inclusion criteria were classified as

Table I. Sub-disciplines, level of integration and level of analysis in identified articles organised by sport ($n = 36$)

Study and category	Sport & skill level (as reported)	Number, age range and mean age (years) of participants (*reported if available)	Sub-disciplines of Human Movement Science: FA	EP	MC	B	SEP	Level of integration of sub-disciplines	Group or individual analysis
Talent identification									
Woods et al. (2016)	ARF SE	$n = 84$ 17–18 17.5	✓	✓	✓			Inter	G
Cripps et al. (2016)	ARF SE	$n = 94$ 15–16 15.7	✓	✓	✓			Inter	G
Carvalho et al. (2018)	Basketball SE & NE	$n = 58$ 9.5–15.5 13.1	✓	✓			✓	Inter	G
Elferink-Gemser et al. (2007)	Field Hockey SE & NE	$n = 65$ 12–16 14.2	✓	✓	✓		✓	Multi	G
Keogh et al. (2003)	Field Hockey SE & NE	$n = 74$ 19–21 19.9	✓	✓	✓			Multi	G
Elferink-Gemser et al. (2004)	Field Hockey E & SE	$n = 126$ 11–16 13.9	✓	✓	✓		✓	Inter	G
Nieuwenhuis et al. (2002)	Field Hocke SE & NE	$n = 52$ 14–15	✓	✓	✓		✓	Inter	G
Pion et al. (2015)	Gymnastics SE & NE	$n = 243$ 6–9 7.7	✓	✓	✓			Inter	G
Vandorpe et al. (2011)	Gymnastics SE & NE	$n = 168$ 6–8	✓	✓	✓			Inter	G
Matthys et al. (2013)	Handball E, SE & NE	$n = 94$ 13–17	✓	✓	✓			Inter	G
Matthys et al. (2011)	Handball E, SE & NE	$n = 428$ 12–17	✓	✓	✓		✓	Inter	G
Höner et al. (2017)	Soccer SE	$n = 14{,}178$ 11–12 11.32	✓	✓	✓			Inter	G
Figueiredo et al. (2011)	Soccer NE	$n = 143$ 11–14	✓	✓	✓			Inter	G
Hoare and Warr (2000)	Soccer NE	$n = 17$ 15–19	✓	✓	✓			Multi	G
Reilly et al. (2000)	Soccer E & SE	$n = 31$ 15–16	✓	✓	✓		✓	Inter	G

Talent selection									
Cripps et al. (2017)	ARF SE & NE	$n = 50$ 15–16 15.6	✓	✓	✓			Inter	G
Tribolet et al. (2018)	ARF SE	$n = 277$ 12–15	✓	✓	✓			Multi	G
Torres-Unda et al. (2013)	Basketball SE & NE	$n = 62$ 13–14	✓	✓	✓			Multi	G
Bartolomei et al. (2018)	Field Hockey SE & NE	$n = 30$ 25.4	✓	✓	✓			Multi	G
Massuca et al. (2014)	Handball E & SE	$n = 193$ 23.6	✓	✓	✓		✓	Inter	G
Tredrea et al. (2017)	Rugby League NE & SE	$n = 160$ 15–18	✓	✓			✓	Inter	G
Gabbett et al. (2011b)	Rugby League E & SE	$n = 86$ 23.3	✓	✓	✓			Inter	G
Huijgen et al. (2014)	Soccer SE & NE	$n = 113$ 16–18	✓	✓	✓		✓	Inter	G
Vandendriessche et al. (2012)	Soccer E	$n = 78$ 15–16 15.2	✓	✓	✓			Multi	G
Coelho e Silva et al. (2010)	Soccer SE & NE	$n = 128$ 13–14	✓	✓	✓		✓	Inter	G
Figueiredo et al. (2009)	Soccer NE	$n = 159$ 11–14.9	✓	✓	✓		✓	Multi	G
Vaeyens et al. (2006)	Soccer E, SE & NE	$n = 232$ 10–14 12.2	✓	✓	✓			Inter	G
Rikberg and Raudsepp (2011)	Volleyball E & SE	$n = 65$ 16–17 16.7	✓	✓	✓		✓	Inter	G
Gabbett et al. (2007)	Volleyball SE & NE	$n = 28$ 15.5	✓	✓	✓			Inter	G
Falk et al. (2004)	Water Polo E & SE	$n = 24$ 14–15	✓	✓	✓		✓	Multi	G
Competition performance									
Gómez-Molina et al. (2017)	Marathon Running NE	$n = 78$ 31.5	✓	✓		✓		Inter	I
Novak et al. (2018a)	Mountain Biking SE	$n = 12$ 32.2	✓	✓	✓			Inter	I
Novak et al. (2018b)	Mountain Biking NE	$n = 8$ 36.8	✓	✓	✓			Inter	I
Barrett and Manning (2004)	Rowing E	$n = 15$ 26	✓	✓		✓		Multi	G

(*Continued*)

Table I. Continued.

Study and category	Sport & skill level (as reported)	Number, age range and mean age (years) of participants (*reported if available)	Sub-disciplines of Human Movement Science					Level of integration of sub-disciplines	Group or individual analysis
			FA	EP	MC	B	SEP		
Gabbett et al. (2011a)	Rugby League E	n = 58 23.8	✓	✓	✓			Multi	G
Morais et al. (2017)	Swimming SE	n = 91 11.6	✓		✓	✓		Inter	I

Notes: FA = Functional Anatomy, EP = Exercise Physiology, B = Biomechanics, Motor Control = Motor Control, SEP = Sport & Exercise Psychology, Multi = multidisciplinary, Inter = interdisciplinary, I = individual, G = group E = elite (highest level e.g. national representative or national competition) SE = sub-elite (level below elite e.g. state/regional representative) NE = non-elite (club level), tick = included, ARF = Australian Rules football.

interdisciplinary, indicating that sport science is responding to the call of Burwitz et al. (1994) for more interdisciplinary research.

There are several possible reasons why the field of sports science has progressed towards interdisciplinary research. First, there simply may be improved collaborations between researchers from the different sub-disciplines of sports science. For example, researchers with expertise in Functional Anatomy, Exercise Physiology and Motor Control have combined to incorporate sub-discipline knowledge to better understand sport performance (Gabbett et al., 2011a). Second, progressive evidence across monodisciplinary to interdisciplinary studies have reported better prediction of the intended outcome. For example, Woods, Raynor, Bruce, and McDonald (2016) created a video decision-making test for ARF players (Motor Control sub-discipline), which was able to discriminate decision-making performance between talent identified and non-talent identified players. Thereafter, the test was incorporated into an interdisciplinary study which included measures from Functional Anatomy, Exercise Physiology and Motor Control (technical skill) to provide a more comprehensive discriminator and stronger predictor of talent (Woods et al., 2016). It is likely that these combined tests provide a stronger prediction because they incorporate a combination of constraints that are representative of talent and performance in the competition setting. Third, sports science researchers may have developed a better understanding of advanced statistical analyses to deal with multiple sub-discipline measures (such as linear regression modelling, step-wise discrimination analysis and receiver operating curves) (see Gabbett et al., 2011b; Woods et al., 2016). Utilisation of more complex statistical analyses allows sports science researchers to integrate knowledge and variables from the different sub-disciplines, including their interactions, to generate a more holistic understanding of the complex interplay between sub-discipline knowledge to create new knowledge of athlete performance.

The move towards interdisciplinary sports science research will provide a better understanding of how individual, task and immediate environmental constraints interact (Higgins, 1977; Newell, 1986) to explain sport performance. This is because a constraints approach has the capability, as argued by Ibáñez-Gijón et al. (2017), to inform how the perception scale (e.g. decision-making) interacts with the execution scale (e.g. coordination) to achieve the goal of the designated sport skill. Here, a critical point to determine the more consistent adoption of an interdisciplinary approach is to consider how these scales are captured in terms of individualised

Table II. Sub-disciplines tests, ratings of representative task design and main findings in identified articles organised by sport ($n = 36$)

Study and category	Exercise physiology tests	*R*	Motor control tests	*R*	Biomechanics tests	*R*	Sport & exercise psychology tests	*R*	Main findings
Talent identification									
Woods et al. (2016)	DVJ	H	AF kicking test	M					Handballing accuracy on non-dominant side,
ARF	MSFT	H	AF handball test	M					decision-making score and DVJ non-dominant
			Decision-making	L					leg take off displayed largest ES btn talent
			(video based)						identified and non-identified players.
Cripps et al. (2016)	VJ	M	AFL kicking test	M					ES comparisons revealed very large to moderate
ARF	DVJ	H	AFL handball test	M					effects btn maturation groups for
	Sprint (20 m)	H							anthropometric measures, sprint, VJ & DVJ.
	MSFT	H							Small to moderate effects btn groups for
									coaches' perception of skill.
Carvalho et al.	Line drill run	H					WOFO	L	Sig variation for body size, line drill run, YY1R1,
(2018)	YYIR1	H					DPMQ	L	and aspects of WOFO and DPMQ (mastery
Basketball									and will to excel) for players of differing
									maturity levels.
Elferink-Gemser	Peak shuttle sprint	H	Peak shuttle dribble	M			PSIS	L	E players performed better than SE players on
et al. (2007)	Repeat shuttle sprint	H	Dribble repeat shuttle	M					technical and tactical tests. Female E scored
Field Hockey	Slalom sprint	H	Slalom dribble	M					better than SE on interval endurance and
	Interval endurance	H	Tactics in sport questionnaire	L					aspects of PSIS (motivation and confidence).
Keogh et al. (2003)	Sprint (10,40 m)	H	Agility (Illinois) dribble	M					Sprinting, % body fat, agility, dribbling control,
Field Hockey	RSA (10,40 m)	H	Shooting accuracy	M					aerobic and muscular power, and shooting
	MSFT	H	Pushing speed	M					accuracy can discriminate btn female players of
	VJ	M							varying standards.
	Hand grip strength	L							
	Agility (Illinois)	H							
Elferink-Gemser	Peak shuttle sprint	H	Peak shuttle dribble	M			PSIS	L	E youth scored better than SE players on technical
et al. (2004)	Repeat shuttle sprint	H	Dribble repeat shuttle	M					(dribble performance in peak and repeated
Field Hockey	Slalom sprint	H	Slalom dribble	M					shuttle run), tactical (general tactics; tactics for
	Interval endurance	H	Tactics in sport questionnaire	L					possession and non-possession of ball) and
									psychological variables of PSIS (motivation)

(*Continued*)

Table II. Continued.

Study and category	Exercise physiology tests	R	Motor control tests	R	Biomechanics tests	R	Sport & exercise psychology tests	R	Main findings
Nieuwenhuis et al. (2002) Field Hockey	MSFT	H	Agility dribble	M			CSAI-2	L	Successful players performed sig better than less successful players in regard to frontal thigh skinfold, MSFT, 40 m sprint, agility dribble, metre stick test, slalom dribble, push for accuracy air, and each subscale of AMSSE (motivation)
	VJ	M	Metre stick test	M			AMSSE	L	
	Multi-level sit ups	L	Push for accuracy ground	M					
	Sit and reach	L	Hit for accuracy stationary ball	M					
	Sprint (40 m)	H	Hit for accuracy rolling ball	M					
	Agility (505)	H	Push for accuracy air	M					
			Slalom dribble	M					
			Reverse stick pass for accuracy	M					
			Hit for distance and accuracy	M					
Pion et al. (2015) Gymnastics	Sit and reach	H	Motor coordination skills (KTK):						Gymnasts with score in best quartile of basic motor skills, shoulder strength, leg strength and three gross motor coordination items had sign ↑ chance of survival in program.
	Sprint (40 m)	H	KTK balance beam	H					
	CMJ	H	KTK jumping sideways	H					
	Knee push ups	H	KTK moving sideways	H					
	Sit ups	M	KTK hopping for height	H					
	Rope skipping (60 s)	M	Basic locomotion motor skills (running backwards, skipping, hopping, shuffle pass, cross steps, bouncing, jumping jacks, tuck jumps, giant jumps)	H					
Vandorpe et al. (2011) Gymnastics	Sit and reach	H	Motor coordination skills (KTK):						E potential gymnasts outperformed SE gymnasts on all physical and coordinative variables. Discriminant analysis revealed motor coordination is most important in discriminating btn young female E and SE gymnasts.
	Sprint (20 m)	H	KTK balance beam	H					
	CMJ	H	KTK jumping sideways	H					
	Knee push ups	M	KTK moving sideways	H					
	Sit ups	M	KTK hopping for height	H					
	Rope skipping (60 s)	M	Basic locomotion motor skills (running backwards, skipping, hopping, shuffle pass, cross steps, bouncing, jumping jacks, tuck jumps, giant jumps)	H					
	Leg lifts	M							
	Rope climbing	M							
Matthys et al. (2013) Handball	Sit and reach	L	Slalom dribbling	M					E players performed sig better than SE on YYIR1, shuttle run, cross hoping, handball shuttle run, slalom dribbling, and 30 m sprint. YYIR1 and coordination with and without the ball were most discriminating factors btn playing levels.
	YYIR1	H							
	CMJ	M							
	Five jump test	M							
	Sit ups	L							
	Hand grip	L							
	Cross hopping	M							
	Shuttle run	H							
	Handball shuttle run	H							
	Sprint (5, 10, 20, 30 m)	H							

(*Continued*)

Table II. Continued.

Study and category	Exercise physiology tests	*R*	Motor control tests	*R*	Biomechanics tests	*R*	Sport & exercise psychology tests	*R*	Main findings
Matthys et al. (2011) Handball	Sit and reach YYIR1 CMJ Five jump test Sit ups Hand grip Cross hopping Shuttle run Handball shuttle run Sprint (5, 10, 20, 30 m)	L H M M L L M H H H	Slalom dribbling	M			TEOSQ	L	E players had sig greater aerobic capacity, strength and power (U14: CMJ, sit ups, handgrip U16: CMJ, five jump test) and speed and agility than SE when maturation was controlled for. E and SE did not differ in TEOSQ.
Höner et al. (2017) Soccer	Sprint (20 m) Agility	H H	Slalom dribbling Ball control Shooting	M M M					Empirical evidence provided on relevance of speed related and technical skills with results demonstrating that motor predictors prognostic validity over 9 years period.
Figueiredo et al. (2011) Soccer	YYIETL1 Sprint Agility CMJ	H H H M	Ball control Dribbling Shooting accuracy Passing	M M M M					Except for the CMJ, predictors of functional capacities and soccer skills differed btn age groups.
Hoare and Warr (2000) Soccer	VJ Sprint (5, 10, 20 m) Agility (505) MSFT	M H H H	Juggling Dribbling Passing & receiving Agility with ball SSG (3v3, 6v6)	M M M M H					It is possible to select potential E female soccer players based on anthropometric, physiological and skill attributes.
Reilly et al. (2000) Soccer	Sprints (5, 15, 25, 30 m) MSFT VJ Agility	H H M H	Shooting Slalom dribble Anticipation test (video based)	M M L			TEQOSQ CSAI-2	L L	Most discriminating measures btn E and SE groups were agility, sprint time, aspects of TEQOSQ (ego orientation) and anticipation test. E players were sig leaner, possessed more aerobic power and were more tolerant of fatigue. E players were better at dribbling but not shooting.
Talent Selection									
Cripps et al. (2017) ARF	VJ DVJ Sprint (20 m) MSFT	M H H H	AFL Kicking test AFL Handball test	M M					Talent identified players at U16 level are likely to be more biologically more mature than non-talented players. Further differences btn groups were evident in measures of standing and sitting height, DVJ non-dominant foot and handball test scores. Strongest measures to define player status were standing height, DVJ non-dominant foot and handball test scores.

(*Continued*)

Table II. Continued.

Study and category	Exercise physiology tests	R	Motor control tests	R	Biomechanics tests	R	Sport & exercise psychology tests	R	Main findings
Tribolet et al. (2018) ARF	Agility (T test)	H	Kick technique	M					There were sig age related differences for anthropometry, fitness and coach skill ratings. Selected players were more mature, taller, heavier, more explosive, faster at changing directions and had superior kick technique and marking results.
	SBJ	M	Kick game	H					
	Knee Push ups	L	Marking	M					
			Handballing	M					
			*Coach rank of above						
			Motor coordination skills (KTK):						
			KTK balance beam	L					
			KTK jumping sideways	L					
			KTK moving sideways	L					
Torres-Unda et al. (2013) Basketball	Endurance test	H	Slalom dribble test	M					E players are taller, heavier and high higher muscle percentage that non-E players. E players perform better in jump, endurance, sprint and slalom dribble test.
	Sprint (20 m)	H	Point average score in games	L					
	CMJ-S	H							
Bartolomei et al. (2018) Field Hockey	Hand grip	L	Pushing speed	M					Division 1 players when compared to Division 2 players had lower % body fat and performed 14.5% better on shooting accuracy. There were no sig differences between groups for shooting speed, slalom agility and performance dribble.
	CMJ	M	Shooting accuracy	M					
	Sprint (30 m)	H	Dribble test	M					
	MSFT	H							
	Agility (slalom)	H							
Massuca et al. (2014) Handball	Sprint (30 m)	H	Handball skill test:				TEOSQ	L	E players scored better on all fitness tests (sprint 30 m, grip strength, SJ, CMJ, sit ups, YYIE2) as well as handball specific tests (pass and reception, shooting, 1 v 1 actions, create and occupy space, tactical skills, reactive ability) than SE players. No statistically sig results btn E and SE players for TEOSQ.
	Grip strength	L	(coach rank on):				BVLQ	L	
	SJ	M	Pass and reception	M					
	CMJ	M	Shooting	M					
	Sit ups	L	1 v 1 actions	M					
	YYIE2	H	Create and occupy space	M					
			Tactical skills	M					
			Reactive ability	M					
Tredrea et al. (2017) Rugby League	CMJ	M					MTQ48	L	Sprint (10 m), Vo2 max and body mass sig predicted selection in U16 players whilst push-ups, sprint (10 m), body mass and chronological age sig predicted selection in U18 players.
	Sprint (10, 40 m)	H							
	Push ups	M							
	Chin ups	M							
	MSFT	M							
Gabbett et al. (2011b) Rugby League	Sprint (10, 40 m)	H	Tackling (1v1)	H					Selected players were older, more experienced, leaner, had faster 10 m and 40 m sprint times, had superior VJ, MSFT, tackling proficiency, and dual task draw and pass ability than non-selected players. Skinfold thickness and dual-task draw and pass proficiency were only variables that contributed sig to discriminant analysis of selected and non-selected players.
	Agility (505)	H	Draw and pass (2v1) (single condition)	H					
	VJ	M							
	RSA (20 m)	H	Draw and pass (2v1) (dual task)	H					
	MSFT	H							
			Reactive agility	M					
			Pattern recall and prediction (video)	L					

(*Continued*)

Table II. Continued.

Study and category	Exercise physiology tests	*R*	Motor control tests	*R*	Biomechanics tests	*R*	Sport & exercise psychology tests	*R*	Main findings
Huijgen et al. (2014) Soccer	Peak shuttle sprint Repeated shuttle sprint Slalom sprint ISRT	H H H H	Peak shuttle dribble Repeated shuttle dribble Slalom dribble TACSIS	M M M L			TEOSQ PSIS – Youth	L L	Selected players performed sig better than non-selected players in peak and repeated shuttle sprint, peak and repeated shuttle dribble, and aspects of TACSIS (positioning and deciding). Discriminant function analysis showed the combination of peak dribbling, aspects of TACSIS (positioning and deciding) and peak sprinting classified 69% of talented players correctly.
Vandendriessche et al. (2012) Soccer	Hand grip Sit and reach SBJ VJ *T*-test Sprint (5, 10, 20, 30 m)	L L M M H H	U Gent dribbling KTK balance beam KTK jumping sideways KTK moving sideways KTK hopping for height	M L L L L					More mature players possessed higher morphological measures and outperformed later maturing peers on all fitness tests except sit and reach and sprint 5 m. Soccer specific (U Gent dribbling) and non-specific (KTK tests) motor coordination tests did not differentiate btn maturity levels.
Coelho e Silva et al. (2010) Soccer	SJ CMJ Agility RSA YYIE1	M M H H H	Ball control with body Dribbling speed Shooting accuracy Wall pass	M M M M			TEOSQ	L	Compared to non-selected players, selected players had an ↑ maturity status, were heavier, taller, performed better in explosive power, repeated sprints, ball control and were more ego oriented (aspect of TEOSQ). Selection of players was associated with advanced skeletal maturity, ego orientation, years training in sport, muscular power, agility and speed.
Figueiredo et al. (2009) Soccer	YYIETL1 Sprint Agility CMJ	H H H M	Ball control Dribbling Shooting accuracy Passing	M M M M			TEOSQ	L	E players were older chronologically and skeletally, larger in body size and performed better in functional capacities and three skill tests that club players and dropouts. Baseline TEOSQ did not differ among dropouts and club and elite players at follow up.

(*Continued*)

Table II. Continued.

Study and category	Exercise physiology tests	*R*	Motor control tests	*R*	Biomechanics tests	*R*	Sport & exercise psychology tests	*R*	Main findings
Vaeyens et al. (2006) Soccer	Sit and reach SBJ VJ Hand grip strength BAH Abdominal strength Abdominal endurance Sprint (30 m) Shuttle sprint Agility ESHR STR	L M M L L L L H H H H H	Slalom dribble Lob pass Shooting accuracy Juggling	M M M M					E players scored better than SE players on strength, flexibility, sprint, aerobic endurance, anaerobic capacity and several technical skills.
Rikberg and Raudsepp (2011) Volleyball	Sit ups Agility (Illinois) VJ	L H H	Volleyball skill test (coach rank on): Passing Setting Serving Spiking Game intelligence (coach observe in game) Decision-making (video)	 M M M M H L			AGQ-S SPPC SEBS	L L L	Selected players scored better than non-selected players in VJ, passing, spiking, game intelligence characteristics, and reported higher mastery approach goals (AGQ-S), perceived sport competence (SPPC), and enjoyment of sport (SEBS). Most discriminating variables were game intelligence, mastery approach goals, perceived sport competence and passing technique.
Gabbett et al. (2007) Volleyball	VJ Spike jump OH med ball throw Sprint (5, 10 m) Agility (*T*-test) MSFT	H H M H H H	Spike accuracy Spike technique Serving accuracy Serving technique Setting accuracy Setting technique Passing accuracy Passing technique *Accuracy involved hitting specified target and technique involved coach rank of skill whilst performing accuracy test	M M M M M M M M					Discriminant analysis showed that passing technique and serving technique were the only significant variables to distinguish btn successful and unsuccessful talent identified players.

(*Continued*)

Table II. Continued.

Study and category	Exercise physiology tests	*R*	Motor control tests	*R*	Biomechanics tests	*R*	Sport & exercise psychology tests	*R*	Main findings
Falk et al. (2004) Water Polo	Swimming ability: Freestyle 400 m Freestyle 200 m Freestyle 100 m Freestyle 400 m Freestyle 50 m Breast-stroke 50 m Butterfly 100 m VJ in water	 H H H H H H H H	Ball dribble Goal throw Distance throw Game intelligence (coach observe in game)	M M M H					Players who made final selection (after 2 years in program) were superior on the majority of swim tasks, dribbling and game intelligence and this superiority was maintained for the 2 years period.
Competition performance									
Gómez-Molina et al. (2017) Half-Marathon Running	Vo2 Max HR Max RCT% Vo2 Max Peak speed RCT speed *Measures taken during incremental run test	H H H H H			Min contact time Max step rate Max step length RCT contact time RCT step rate RCT step length *Measures taken during incremental run test	H H H H H H			Performance was predicted by a model which included peak speed, RCT speed and years of running experience.
Novak et al. (2018a) Mountain Biking	Grip strength Vo_2 Max MAP PPA peak PPA mean *Measures taken during incremental cycle test	L H H H H	Decision-making test (video based)	L					Performance was predicted using a model which included Vo2 Max relative to total cycling mass, maximal mean power across 5 and 30 s peak left hand grip strength and response time for correct decisions in the decision-making test.
Novak et al. (2018b) Mountain Biking	Grip strength Vo2 Max MAP PPA peak PPA mean *Measures taken during incremental cycle test	L H H H H	Decision-making test (video based)	L					Performance was predicted using a model which included Vo2 Max rel to total cycling mass, max power output sustained over 60 s rel to total cycling mass, peak left hand grip strength, and two-line decision-making score.

(*Continued*)

Table II. Continued.

Study and category	Exercise physiology tests	*R*	Motor control tests	*R*	Biomechanics tests	*R*	Sport & exercise psychology tests	*R*	Main findings
Barrett and Manning (2004)	Peak strength	H			Kinematic variables (taken during race. E.g. trunk angle at catch)	H			Individual variables that had highest significant correlations with 2 km race time were 2 km ergo time, mass, height, oar length and peak strength.
	Forward flexion	L							
Rowing	Low back flexion	L							
	Hamstring flexion	L							
	Plantar flexion	L							
	2 km ergo time	H							
	*Peak strength taken during 2 km ergo time								
Gabbett et al. (2011a)	Sprint (10,40 m)	H	Tackling (1v1)	H					Line break assists was sig associated with greater playing experience, dual-task draw and pass proficiency, reactive agility, pattern recall and prediction ability. Faster speed (40 m) was sig associated with a higher number of tries scored. Greater age and playing experience, better lower body muscular power, and faster 10 m and 40 m speed were sig associated with the number of tackle attempts, tackles completed and proportion of missed tackles.
	Max velocity	H	Draw and pass (2v1) (single condition)	H					
Rugby League	Agility (505)	H	Draw and pass (2v1) (dual task)	H					
	VJ	M	Reactive agility	M					
	RSA	H	Pattern recall and prediction (video)	L					
	Prolonged high intensity intermittent running	H							
Morais et al. (2017)	Swim velocity	H	Stoke frequency	H	Intra-cyclic velocity	H			Performance over 3 seasons was predicted using a model including age, arm span, stroke length and propelling efficiency.
Swimming	*Measures taken during 25 m maximal swim		Stroke length	H	Propelling efficiency	H			
			*Measures taken during 25 m maximal swim		Stroke index	H			
					*Measures taken during 25 m maximal swim				

Notes: EP = Exercise Physiology, MC = Motor Control, B = Biomechanics, SEP = Sport & Exercise Psychology, R = Rating, H = High, M = Medium, L = Low, KTK = Korperkoordinationstest fur Kinder, COD = Change of Direction, VJ = Vertical Jump, DVJ = Dynamic Vertical Jump, RSA = Repeat Sprint Ability, HIR = High Intensity Running, MFST = Multi-Stage Fitness Test, TEQOSQ = Task and Ego Orientation in Sport Questionnaire, CSAI-2 = Competitive State Anxiety Inventory-2, SBJ = Standing Broad Jump, BAH = Bent Arm Hang, ESHR = Endurance Shuttle Run, STR = Shuttle Tempo Run, 20 m pro run = 20metre progressive run, YYIE1 = Yo-Yo Intermittent Endurance Level 1, YYIETL1 = Yo-Yo intermittent endurance level 2, YYIR1 = Yo-Yo Intermittent Recovery Level 1, CMJ = Counter Movement Jump, CMJ-S = Counter Movement Jump with Arm Swing, SSG = Small-sided games, PSIS = Psychological Skills Inventory for Sports, AMSSE = Achievement Motivations Scale for Sporting Environments, SJ = Squat jump, TEOSQ = Task and Ego Achievement Goal Orientations, AGQ-S = Achievement Goals Questionnaire for Sport, SPPC = Self-Perception Profile for Children (athletic subscale used only), SEBS = Satisfaction/Enjoyment/Boredom in Sport (enjoyment subscale used only), AF = Australian Football, Australian Football League, WOFO = The Work and Family Orientation Questionnaire, DPMQ = Deliberate Practice Motivation Questionnaire, BVLQ = Biosocial Variables and Lifestyle Questionnaire, MTQ48 = Mental Toughness Questionnaire 48, ISRT = Interval Shuttle Run Test, TACSIS = Tactical Skills Inventory for Sport, OH = Overhead, RCT = Respiratory Compensation Threshold, MAP = Maximal Aerobic Power, PPA = Peak Power Assessment, E = Elite, SE = Sub-elite, btn = between, rel = relative, ES = Effect Size, sig = Significantly, * = further study details.

constraints and representative tasks that encapsulate interacting constraints.

In relation to individualised comparisons, the finding in this review that the majority of the articles completed their analysis at the group level is not entirely surprising. This is likely because the traditional approach to sampling, experimental design and statistical analyses are focused upon larger group-based differences or correlational relationships, which are deemed to be generalisable to a broader population. Accordingly, the domains of talent identification and talent selection lend themselves to group study designs because they include relatively larger samples such as "talent identified and non-talent identified" (Woods et al., 2016), "elite and sub-elite" (Elferink-Gemser, Visscher, Lemmink, & Mulder, 2004, 2007) and "successful and less successful" (Nieuwenhuis, Spamer, & Rossum, 2002) participants. In recent times, however, sport science research has incorporated understanding of attainment of expertise in sport (Baker & Farrow, 2015). Expertise research has moved towards the investigation of individual differences as this approach allows the study of variables that constitute an exceptional test batsman or footballer or soccer player to be unravelled from others, rather than being masked by group scores (Phillips et al., 2010). As the field of sport expertise continues to grow, it is reasonable to expect that there will be more research conducted at the individual level. This is because expert performers can achieve the task goals in different ways and to levels of success; so analysing their individual differences will also be useful for coaches (Davids et al., 2015). Therefore, developing protocols that explore skill differences among individuals is needed to understand individualised constraints to sport performance.

In regards to representative task design, the review identified a range from low to high representative design tasks across the sub-disciplines. For example, in the decision-making test used in the performance prediction study for mountain bikers, participants had to watch a video of an experienced mountain biker riding trails and then choose the fastest line option as quickly as possible by touching an arrow (Novak, Bennett, Fransen, & Dascombe, 2018a). This test was rated as a low level of representative task design as it was video based and did not require participants to couple action to available perceptual information as in the competition environment. Despite this, the decision-making test was found to contribute significantly to a model which was able to predict overall time-trial performance (within 2% accuracy), along with VO_2 Max relative to total cycling mass, maximal mean power across five and 30 s and peak left hand grip strength (Novak et al., 2018a). Accordingly, low representative design tests can still be valuable as long as they, for example, represent the perceptual information (constraint) used in the competition setting. Alternatively, all Biomechanics tests were rated as high in representative task design. For example, Morais, Silva, Marinho, Lopes, and Barbosa (2017) calculated "propelling efficiency" from swimming kinematic data when participants performed three maximal 25 m time trials with analysis showing that propelling efficiency was part of a model that was able to predict performance along with age, arm span and stroke length. In contrast, there were no Sport and Exercise Psychology tests rated as having a high level of representative task design and this is because all the tests in the identified studies relied solely on survey methodology. Again, it is not our contention that the Sport and Exercise Psychology survey tests are not valuable, in fact some could discriminate between groups such as Task and Ego Achievement Goal Orientations Questionnaire (Coelho e Silva et al., 2010), but there appears to be scope to expand these measures to incorporate in-situ sport-specific representative tests that may provide new insights into psychological skills. This approach is now beginning to gain momentum in the sport psychology literature (see Bell, Hardy, & Beattie, 2013).

It is not surprising that soccer features most prominently in terms of integrated sports science research. The majority of professional soccer clubs and national associations run youth academies in order to identify talent which is a priority for such organisations, as focusing resources on developing a talented pool of future athletes from a young age can equate to a more effective financial investment (Fenner et al., 2016). These soccer academies and other similar programmes then become the focus of integrated research as the clubs attempt to develop those young players who had been identified as future elite players through a talent identification programme.

The proliferation of talent academies that attempt to identify and develop future elite players across all sports is one logical reason why the majority of integrated sports science research occurs in the talent identification domain. An effective talent identification programme increases the likelihood of success and can generate significant financial rewards. It is not uncommon to see millions of dollars invested in evidence-based strategies in order to gain a competitive advantage (Hogan & Norton, 2000). These programs can become the focus of research by sports scientists and can result in large-scale studies that undertake a battery of multidisciplinary tests. A challenge for talent academies is to ensure the tests involved in these studies are representative of the performance demands of the sport (Johnston, Wattie, Schorer, & Baker, 2018).

In contrast, the least amount of integrated research occurred in the competition performance domain. One possible reason for this is that for competition performance research to occur, sports scientists need to be able to measure the individual performance of an athlete in a competition environment. This can be relatively easy in sports such as swimming, running and cycling, as time can be used as a valid measure, but it is more challenging in team sports. For example, how does a rugby league coach measure the performance of an individual player in a game? Gabbett, Jenkins, and Abernethy (2011a) measured performance in rugby league by coding game-specific events in both attack and defence from video replays and included items such as runs, line breaks, tries, try assists, tackle breaks, dominant tackles, ineffective tackles and tackling efficiency. Access to such competition performance data generally occurs at only the professional levels of sport where games are broadcast on television or sports scientists are hired to independently film and code the match performance which are time-intensive and hence, a possible reason for the lack of integrated research in competition performance. Furthermore, such applied research can be limited in sample size, due to their being a relatively smaller number of professional athletes in a team, compared to those talent identification programmes that attempt to select potential athletes from a larger group. The value of such highly representative smaller samples in high-performance sport may not be fully appreciated, which can lead to less published research (Cardinale, 2017).

Functional Anatomy and Exercise Physiology were the most commonly occurring sub-disciplines included within integrated sports science research. Body composition and anthropometric assessments are classified as Functional Anatomy and these are standard practice for coaches and athletes (Ratamess, 2012). Previous literature which reviewed sports science research also concluded that Exercise Physiology was a dominant research sub-discipline (Williams & Kendall, 2006). The lack of representation from Biomechanics in integrated sports science research could be due to feasibility, as research in this sub-discipline often relies on expensive and non-portable equipment which can restrict data collection to laboratory-based investigations rather than field settings. Feasibility of research methods is an important consideration for engaging athlete and coach compliance (Robertson, Burnett, & Cochrane, 2014). Feasibility of Biomechanical tests was overcome in one article identified in the review, by using video capture and motion analysis during a competition event (Barrett & Manning, 2004). Improved portability of testing equipment and the development of non-invasive wearable sensors will increase the opportunity to conduct Biomechanics research in the field (*in situ*) or competition settings (Williams & Kendall, 2006), as well as integrate Biomechanics into sports science research.

In summary, this systematic review of 36 articles published has provided evidence that the field of sports science is beginning to undertake integrated research that combines multiple sub-disciplines. The majority of this research was classified as interdisciplinary incorporating knowledge, methods and measures from three or more sub-disciplines to better understand sport performance. Talent identification is the domain where there is the most prolific integrated sports science research, followed by the talent selection and competition performance domains. Group analysis was used in all talent selection and talent identification studies, whereas individual analysis was more common in competition performance studies. Levels of representative task design varied from low to high in the performance tests used in the articles identified, however, close to half of all performance tests were considered to have a high level of representative task design. When undertaking future interdisciplinary sports science research, individual differences and representative task design need to be carefully considered.

Disclosure statement

No potential conflict of interest was reported by the authors.

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B.2 Small-sided games can discriminate perceptual cognitive-motor capability and predict disposal efficiency in match performance of skilled Australian footballers

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SPORTS PERFORMANCE

Small-sided games can discriminate perceptual-cognitive-motor capability and predict disposal efficiency in match performance of skilled Australian footballers

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ABSTRACT

This study determined if small-sided games could discriminate perceptual-cognitive-motor skill in Australian Rules Footballers. Higher skilled Western Australian Football League (WAFL) (n = 17) and lesser skilled Amateur (n = 23) players were recruited. Participants played three small-sided games of three minutes. Each disposal was scored for decision-making and motor skill execution, with these scores combined for a total score. Mann-Whitney U tests indicated significantly superior mean decision-making by higher skilled (Median = 2.90, Range = 0.30) over lesser skilled (Median = 2.80, Range = 0.73) (p = .012) players. Execution score was not significantly different between groups. Linear mixed model analysis found higher skilled players (M = 5.32, SD = 1.19) scored significantly higher than lower skilled players (M = 4.90, SD = 1.52) on total score (p = .009). Large effect sizes were found for decision-making and total score relative to games and position played in WAFL players. High agreement of scoring was observed for an elite (inter-rater) and a novice (intra-rater) coaches. Linear mixed model analysis indicated mean total scores of WAFL players significantly predicted disposal efficiency in match performance (p = .011). Small-sided games can be easily implemented to identify talented players and assess perceptual-cognitive-motor skill.

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Representative task design; decision-making; motor skill execution; small-sided games; sports-specific assessment

Australian Rules Football (ARF) is a dynamic invasion sport, where players move the ball toward the attacking end by running, kicking or handballing with the end aim to kick a goal (Cripps, Hopper, & Joyce, 2015). Because of the fast paced and dynamic nature of ARF, professional teams invest significant time and financial resources to identify skilful players (Cripps, Hopper, Joyce, & Veale, 2015); superior decision-making (Berry, Abernethy, & Côté, 2008) and accurate execution to achieve the skill goal (Parrington, MacMahon, & Ball, 2015) are key components of skilful players. Therefore, development of a test that is highly representative of the game, which can discriminate skilled players, and predict a match performance component, would be valuable for talent identification and athlete development.

Performance in sports such as ARF is comprised of two components, "how" which refers to technique (motor skill execution) and "what" which refers to decision-making (perceptual–cognitive skill) (Starkes, Cullen, & MacMahon, 2004). Sports-specific tests commonly focus on technical execution to identify talented players and they can be used to guide further skill development in established players (Elferink-Gemser, Visscher, Lemmink, & Mulder, 2004; Gabbett, Jenkins, & Abernethy, 2011b). For example, the ARF skill test kicking component requires the player to turn with ball in possession, run a short distance and kick to one of six stationary target players (Cripps et al., 2015; Woods, Raynor, Bruce, & McDonald, 2015). In the handball component, the player runs to receive the ball and is required to handball at one of six stationary target players (Cripps et al., 2015; Woods et al., 2015). These tests, however, do not incorporate the dynamic nature of ARF play to probe combined perceptual-cognitive-motor components of sports-specific skill.

Perceptual-cognitive skill has been predominantly assessed in team sports using video simulation tests to probe decision-making (Berry et al., 2008; Gorman, Abernethy, & Farrow, 2015; Lorains, Ball, & MacMahon, 2013; Woods, Raynor, Bruce, & McDonald, 2016). Typically, a participant is required to watch video of sports-specific game scenarios and at the conclusion of the footage make a written, verbal or button-press choice of the best option to pass the ball. It has been reported that talent-identified and expert ARF players made more accurate decisions compared to non-talent identified and sub-elite ARF players, respectively (Lorains et al., 2013; Woods et al., 2016). Accordingly, fine-grained skill group discrimination is possible with video tests, but the focus is more on the perceptual-cognitive component of the skill.

Some researchers argue that representative task design (RTD) needs to be taken into consideration when designing sports-specific tests in order to better capture how perception informs action and to produce more generalisable findings (Vilar, Araújo, Davids, & Renshaw, 2012). Accordingly, Araújo and Davids (2015) outlined three principles for designing representative sports-specific tests that include; visual-perceptual information (stimuli), action fidelity (coupling of action) and performance achievement. Visual-perceptual information refers to sports-specific stimuli such as the creation of space by a teammate in ARF that invites a kick or handball from another teammate in possession of the ball. Action

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fidelity refers to the capability of the player to perform their skills such as to run, kick and handball like in a game of ARF. Performance achievement can vary depending upon the sport; in ARF this can relate to the correct decision to pass to a teammate in space and the accurate execution of the pass. Therefore, the challenge exists to design a highly representative test that incorporates decision-making and motor skill execution for ARF.

In-situ tests are one way to increase the level of RTD where perceptual information and action fidelity are closely related to the game setting (Müller, Brenton, & Rosalie, 2015). Small-sided games can be used as an in-situ test, where small teams of players compete against each other, to mimic the dynamic change of player positions under limited space and time to execute perceptual-cognitive-motor skills that mirror the competition setting. For example, Farrow, Pyne, and Gabbett (2008) compared skill demands of open (small-sided games) and closed (repetition drills) skills in ARF. Results indicated that small-sided games required greater decision-making coupled with skill execution compared to closed skill drills (Farrow et al., 2008). This implies that small-sided games are more representative of perceptual-cognitive-motor skill required for ARF competition. The motor skill execution tests, currently used in ARF skills testing, tend to isolate action fidelity from contextualised visual-perceptual information (Davids, Araújo, Correia, & Vilar, 2013). Therefore, use of small-sided games as a perceptual-cognitive-motor skill test could preserve the tight coupling of critical perceptual information to guide the execution of a motor skill that is more reflective of the competition setting (Pinder, Davids, Renshaw, & Araújo, 2011).

The primary purposes of this study were to determine; (i) whether perceptual-cognitive-motor differences (decision, execution and total score) exist between higher and lower skilled ARF players during a small sided games test, (ii) the reliability of scoring decision-making and motor skill execution in a highly dynamic small-sided game, and (iii) whether test scores in the small-sided games predicted disposal efficiency in match performance of ARF. A secondary exploratory purpose of this study was to determine whether perceptual-cognitive-motor differences existed within the highly skilled group relative to the number of senior games played and position. We hypothesized that: (a) higher skilled players will achieve significantly higher scores than lower skilled players in decision making, motor skill execution and total score, and (b) scores from higher skilled players would predict disposal efficiency in match performance of ARF.

Method

Participants

A total of 40 male participants were recruited for this study from two Western Australian Football League (WAFL) competitions. A higher skilled group (n = 17) comprised of one semi-professional WAFL club who participate in the state league. The lower skilled group (n = 23) was recruited from two West Australian Amateur Football League (WAAFL) Clubs. A priori power analysis was conducted based on $\alpha = 0.05$, power ($1-\beta$) = 0.8, effect size = 0.15, and two groups (WAFL and Amateur) with a total sample of 351 trials required. The inclusion criteria for the higher skilled group was that participants had to have played at least one senior game at WAFL level within the previous two years. Players from either skill group were excluded if they had an injury at the time of testing which prevented them performing as they would in a typical game situation. The age of the higher skilled group was (Mage = 23.0 years, age range: 20–29) and the lower skilled group was (Mage = 23.9, age range: 19–30). Ethical approval was granted by the Ethics Committee from the University of Notre Dame, Australia (ref: 016050F) and participants provided written informed consent.

Design and procedure

Participants completed the small-sided games test at the end of their pre-season period. Participants were divided into teams consisting of six attackers versus five defenders (one defender on the bench who could rotate into the team). The higher skilled and lesser skilled participants completed the testing at separate times to ensure that particpants in each session were of the same skill level, that is, higher skilled defenders versus higher skilled attackers. Only the attacker participants were assessed and were given the task of maintaining possession of the football for a three minute period (one set) in a 40 m x 40 m grid. The task of keeping possession of the ball is highly representative of competition at the AFL elite level. To this, Woods, Robertson, and Collier (2017) reported that AFL coaches have adopted tactics from other team invasion sports such as field and ice hockey, soccer and basketball where players use posssesion tactics to maintain control of the game and search for attacking opportunities. A grid size of 40 m x 40 m was selected, as this size had been previously used to investigate open skills in ARF (Farrow et al., 2008). In addition, the grid size allowed for players to execute disposals by foot over short (~ 25 m), medium (~ 35 m) and long (~ 50 m) (diagonal pass) and also by hand over distances less than 15 m (shortest legal kick distance), which is highly representative of AFL elite match play (Appleby & Dawson, 2002). Furthermore, the grid size enabled the raters to view the full field when scoring from the video footage; if raters are to be able to asssess decision making accurately they need to be able to view all options available to the participant.

Instructions given to participants included:

- Attackers were required to maintain possession by passing the ball by hand or foot as they would in a match.
- Defenders could disrupt the attacker's possession of the ball by intercepting, spoiling (knocking ball away from opponent during marking contest) and tackling (body check only). A body check involves a defender restraining the attacker with arms and not taking them to ground as they would in game situation. This was done to limit the chance of injury.
- If the attacking team disposed of the ball and it was intercepted or the ball went out of bounds, then closest

player on the attacking team was given possession of the ball and the test continued.

Each attacking player wore a different coloured vest to enable each pass to be analysed easily from the video record. At the conclusion of the three minute attacking set there was a one minute change over period for the defenders and the attackers to alternate roles. Each participant was required to complete three sets each in attack and defence. The test was umpired by a research assistant with ARF knowledge. Each skill group completed the testing in one session which was recorded using a standard 25 Hz video camera (Panasonic SDR-H250, Australia), which was positioned approximately 10 m off the ground, a distance of 20 m from the grid and at the halfway point of one of the grid sidelines.

The scoring system for the small-sided games, which was developed through pilot testing in consultation with two experts who had coached at AFL elite level, is outlined in Table 1. The execution scoring component of the test was based on a scale used in a previous ARF skills test and adapted for small-sided games (Woods et al., 2015). Decision-making was adapted from previous literature (Práxedes, Moreno, Gil-Arias, Claver, & Villar, 2018) and scored as follows; (i) if the attacking player was free and had no opposition player directly marking them, this was judged the "most correct decision" in order to pass (3 points), (ii) if the attacking player was marked by a defender (not the most free player), but the distance between attacker and marking defender was enough that a pass was not intercepted, this was judged the "next correct decision" in order to pass (2 points), and (iii) the remainder of the attacking players, all marked by defenders who were close enough and could easily prevent the attacker from maintaining possession, was judged as "incorrect decision" (0 points). It took approximately two hours to complete video analysis of 40 participants for this study.

The reliability of scoring was assessed by inter- and intra-rater reliability. A novice coach scored all trials by viewing the video record of the small-sided games. Intra-rater reliability was assessed by the same novice coach (two weeks apart) and inter-rater reliability was assessed by an expert ARF coach (Level 3) on 129 (25%) of trials using the video record, which were randomly selected.

To explore the relationship between perceptual-cognitive-motor performance in the small sided game test and match performance, disposal efficiency (a match statistic) was collected throughout the 2017 WAFL season. Disposal efficiency is one of the match statistics provided by a commercial statistical analytics company (Champion Data, South Bank, Australia) and is defined as the percentage of disposals that are effective. Champion Data statistics report a 99% accuracy rate for match statistics (O'Shaughnessy, 2006) and have been used in previous research involving ARF (Mooney et al., 2011; Piggott, McGuigan, & Newton, 2015).

Table 1. Composite score for test trials.

Measure	Rating
Decision-Making	3 = Most correct decision
	2 = Next correct decision
	0 = Incorrect decision
Execution	3 = Ball reaches target player on full
	2 = Ball reaches target player on full; however the target player had to change direction to ensure this occurs
	1 = Ball reaches target player but not on full
	0 = Ball does not reach target player at all
Total	Decision Making + Execution Scores

Data analysis

Statistical analysis was performed using IBM SPSS version 24 (IBM SPSS Statistics for Windows. IBM Corp., Armonk, NY, USA). Data was checked for normality using the Shapiro Wilk's test so that the appropriate statistical tests could be employed. Alpha level was set at .05. Cohen's *d* effect sizes were calculated, with 0.2 considered small, 0.5 medium and 0.8 large effects (Cohen, 1998).

Each time an attacking player passed the ball by a kick or handball it was recorded as a trial, with a total of 516 trials completed. The dependent variables were decision, execution and total score. For each participant, a mean score for decision, execution and total score was calculated across all completed trials.

Skill group (higher and lower skilled players) differences for perceptual-cognitive-motor outcome measures were examined using a linear mixed model (LMM). Linear mixed models were used as they permit correct modelling of repeated observations (Garson, 2012), controlling for between-subject variability, increasing statistical power and the precision of the estimate, while controlling for any effects over time (e.g., set) (West, Welch, & Galecki, 2007). Residual diagnostics plots of the final reported models were assessed to ensure the LMM assumptions were met. Participants were included as a random effect, with a random slope and intercept, whilst set, skill group (categorical [SPSS factors]) and trial (continuous [SPSS covariate]) were included as fixed effects. First, three LMM's compared skill groups on each of decision, execution and total scores. The LMM models for execution and decision scores were found to violate the assumptions for the LMM, hence, Mann-Whitney U Tests were used to investigate the differences between skill group scores for each decision and execution. The reliability of scoring the small sided games test was assessed using inter- and intra-rater reliability which were calculated using two-way mixed intra-class correlation coefficients (ICC) accordingly to Portney and Watkins (2009). The following cut-off interpretations were used for ICC values; less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 are indicative of poor, moderate, good, and excellent reliability, respectively. The relationship between total score, number of senior games played and position was investigated using Kruskal-Wallis tests (as LMM violated assumptions). Number of senior games played were group into three ranges, 1–25 (n = 9), 26–50 (n = 2), and 50+ (n = 6), whilst position played included, forwards (n = 4), midfield (n = 4), defenders (n = 6), and "ruck" (n = 3). For only higher skilled players, a LMM was used to explore whether mean total score predicted their disposal efficiency in competition matches (n = 257).

Results

The higher and lower skilled groups averaged 13.32 (*SD* = 4.40) and 11.95 (*SD* = 3.92) involvements, respectively. The range of involvements for the higher skilled group was 5–23 and the lower skilled group was 5–20.

Group differences

The descriptive data for decision, execution and total score of the small-sided games test relative to skill groups is shown in Figure 1. Mann-Whitney U tests reported a significantly higher median score between higher (Decision: *Median* = 2.90, *Range* = 0.30; Total: *Median* = 5.36, *Range* = 1.13) and lower skilled (Decision: *Median* = 2.80, *Range* = 0.73; Total: *Median* = 5.11, *Range* = 1.97) players for decision ($p = .012$, $d = 0.26$) and total score ($p = .037$, $d = 0.30$). There was no significant difference between the two groups for execution score ($p = 0.90$), although higher skilled players still performed at a higher level ($d = 0.25$).

The LMM analysis found that the set the trial occurred in and trial number were not significant factors in the test total score model and were removed from the final reported model. The first LMM (Table 2) found higher skilled players scored significantly higher than lower skilled players on the total score ($\beta = 0.45$, $p = .009$). Kruskal-Wallis tests showed that there was a statistically significant difference in decision scores ($\chi^2 2$) = 8.82, $p = 0.012$, between players with 1–25 games ($M = 2.86$) and 51+ games ($M = 2.98$), as well as between players with 26–50 games ($M = 2.79$) and 51+ games ($M = 2.98$). Large effect sizes were found between the decision scores of 51+ and 26–50 ($d = 2.01$), as well as 51+ and 1–25 ($d = 2.23$) games played. There was no significant difference for total score ($p = 0.102$) and execution ($p = 0.211$) relative to games played. However, large effect sizes were found between 51+ and 1–26 games played, for total score ($M = 5.56$, $M = 5.18$) ($d = 1.25$) and execution ($M = 2.58$, $M = 2.31$) ($d = 0.86$). Kruskal-Wallis tests showed no significant differences for decision, execution or total score for position of play. For decision, large effect sizes were found between midfield ($M = 2.94$) and forward ($M = 2.83$) ($d = 1.02$) players, as well as midfield ($M = 2.94$) and "ruck" ($M = 2.85$) ($d = 1.35$) players. For total score, large effect sizes were also found between midfield ($M = 5.62$) and forward ($M = 5.36$) ($d = 0.85$) players, as well as midfield ($M = 5.62$) and "ruck" ($M = 4.97$) ($d = 3.00$) players.

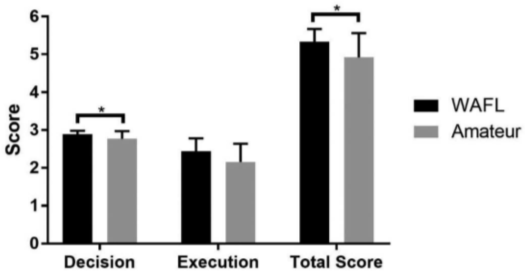

Figure 1. Mean scores for decision, execution and total score of small-sided games test.

* indicates significant difference p < .05 between groups. Error bars represent standard deviation.

Table 2. Linear mixed model parameter estimates for total score.

Parameter	Estimate (β)	SE	*95% CI*	*p*-value
Intercept	4.89	0.11	4.67–5.10	< .001*
WAFL[a]	0.45	0.16	0.12–0.77	.009*

* Indicates a significant difference p < .05
[a]Comparison group is amateur and parameter estimate is set to zero.
SE = standard error
CI = confidence intervals

Table 3. Linear mixed model parameter estimates for prediction of match disposal efficiency.

Parameter	Estimate (β)	SE	*95% CI*	*p*-value
Intercept	−3.78	24.22	−55.41–47.84	.878
Total Score	13.18	4.53	3.53–22.82	.011*

* Indicates a significant difference p < .05
SE = standard error
CI = confidence intervals

Reliability of test scoring

Inter-rater reliability for decision ($r = .91$, range = 0.88–0.94) and execution ($r = .95$, range = 0.94–0.97) indicated excellent levels of agreement. Intra-rater reliability for decision ($r = .90$, range = 0.89–0.93) and execution ($r = .95$, range = 0.94–0.97) also indicated good and excellent levels of reliability respectively.

Relationship between test and match performance

The second LMM (Table 3) found that higher skilled players mean total score significantly predicted higher disposal efficiency in competition matches ($\beta = 13.18$, $p = .011$).

Discussion

The primary purpose of this study was to develop a perceptual-cognitive-motor test based upon small-sided games specifically for ARF and determine whether it could discriminate skilled performance, be reliabily scored, and predict a match performance component. The small-sided games demonstrated fine-grained discrimination between WAFL (higher) and Amateur (lesser) skilled players, and also predicted a component of match performance in the WAFL players. Scoring of the dynamic test was highly reliable. The secondary exploratory purpose of this study was to determine whether games and position of play could discriminate perceptual-cognitive-motor skill within higher skilled players. Collectively, it appears that the ARF small-sided games test can be easily implemented to identify skilful players and to guide coaching intervention to target deficiency in components of perceptual-cognitive-motor skill.

The results demonstrate fine-grained skill level discrimination in relation to the decision-making ("what") component of perceptual-cognitive-motor skill in a highly dynamic test. Fine-grained discrimination of decision-making concurs with previous research which found talent-identified U18 ARF players were more accurate at making correct game-based decisions when compared to their non-talent identified peers on a video decision-making test (Woods et al., 2016). Despite the difference in methodologies employed in their study and ours, both video-based and in-situ tests appear able to discriminate between skilled players. We believe that the test in our study had a greater level of task representation (players could couple action to sports-specific in-situ visual-perceptual information), compared to the video simulation tests, where perception is decoupled from overt action. Alternatively, it could be argued that the highly dynamic nature of visual-perceptual information is appropriately simulated in both video and in-situ tests such as they both map onto the perceptual information that occurs in the competition setting (Müller et al., 2015). Therefore, either video simulation or small-sided games could be used as representative tests to assess decision-making skill in team sports (Araújo & Davids, 2015).

There was no significant difference between higher skilled and lower skilled players in regards to the motor skill execution component of the test. This finding is in contrast with previous research that has found motor skill execution tests can discriminate between skilled players in ARF (Woods et al., 2015). Part of the reason for the differing results could be due to the design of the skill tests. The skill tests used in previous research (Cripps et al., 2015; Woods et al., 2015) involved participants disposing of the football to stationary targets after being cued by the experimenter, which can be classified as a closed skill. This is not representative of the competition environment of ARF as there is an absence of defenders and the targets are stationary. The motor skill execution component in our study was couched in a more representative open skill task that is like the competition setting, due to the presence of defenders, as well as targets (fellow attackers) who could change position as they would in the competition setting (see Farrow et al., 2008). Accordingly, through increased representative task design of skill tests, it appears that it is not necessarily the motor skill execution component that is the limiting factor of expertise in ARF, but rather the perceptual-cognitive component. Therefore, a skill test that probes the perceptual-cognitive component is vital for coaches to identify and develop athletes.

One possible reason why higher skilled player's decision-making scores were significantly different to lower skilled players could be related to their exposure to type of training. Typically, coaches at a WAFL Club structure training where decision making is a large focus. The majority of coaches at this level have completed higher coaching accreditations (Level 2 and Level 3) and these coaches are encouraged to include decision-making tasks into training (Pill, 2015). In field hockey, another team invasion sport, it has been found that match play and coach-led practice are influential factors in the development of perceptual-cognitive skill (Drake & Breslin, 2017). In addition, WAFL clubs have the resources in terms of video feedback at both the team and individual level, which could be used to review game tactics and decision-making, which may also be used to improve the perceptual-cognitive skill of their players. Further research, however, is required to confirm whether higher qualified coaches design decision-making practice tasks that lead to enhancement of this skill in WAFL players.

An important consideration for using a highly dynamic test based on small-sided games as a performance test for ARF is whether the test can be accurately scored. Inter-rater reliability of scoring our test showed strong agreement between expert and novice coaches and within the novice coach. The previously mentioned AFL motor skill tests reported inter-rater reliability for kicking (r = 0.96) and handball (r = 0.89) (Cripps et al., 2015). Therefore, even though the small-sided games test is highly dynamic with several players changing position within the grid continuously across the time allocation for the game, the scoring of the test is reliable and achieves similar results to other tests used in AFL, which are less dynamic.

A crucial finding from this study was that total score on the test for higher skilled players, comprised of deciding who to dispose the ball to and then executing the disposal, also predicted disposal efficiency in match performance. This indicates that the small-sided games test not only can discriminate between fine-grained skill levels, but has predictive validity. For example, based upon Table 3, a 1 point increase in total score would result in a 13% increase in match disposal efficiency, although the large confidence intervals should be noted. Previous studies that have employed motor skill execution tests in ARF have not reported whether the test scores predict match performance (Cripps et al., 2015; Woods et al., 2015). This could be due to the nature of the samples used in previous studies where match statistics are not readily available; there was no match performance data for the lesser skilled group in our study. Nonetheless, our study provides useful information that the perceptual-cognitive-motor skill components probed and evaluated in small-sided games can reflect, to a degree, skill capability under match conditions in ARF. This is consistent with relationships reported between higher performance on in-situ skill tests and match performance in rugby league (Gabbett, Jenkins, & Abernethy, 2011a). There is also evidence that performance on video simulation decision-making tests is related to match performance (Gabbett et al., 2011a), once again indicating that in-situ tests are not the sole representative task predictors of match performance.

The significant differences found in our study between skill levels reflect small effect sizes for decision (d= 0.26) and total score (d= 0.37). A reason for these small differences could be that the actual difference in the skill level between higher (WAFL) and lesser (Amateur) skilled players is small or fine-grained. In comparison to other literature, for example, Lorains et al. (2013) reported no significant difference in decision-making accuracy between elite and sub-elite ARF players, but a significant difference between elite and novice players (~ 22%) on a normal speed video decision-making test. In contrast, Berry et al. (2008) found a moderate to large effect size in the superior decision-making of expert and lesser skilled ARF players. In a related manner, the exploratory analysis within the higher skilled group in our study revealed large effect sizes relative to the greater number of games played (50+) and midfield position of play. Breed, Mills, and Spittle (2018) have also reported a difference between highly skilled and skilled ARF players (moderate effect size) on a video-based decision-making test. Therefore, considered on balance with the samples in the literature, our small-sided games test appears to have the sensitivity to detect even small differences in skill levels, as well as differences within a highly skilled group based upon experience. This is highly valuable for coaches to be able to assess players in a highly representative task. Coaches can employ the test with each player receiving a score for decision making, motor skill execution and total score. Coaches can then identify players who score lower relative to the group and need to work on decision making or motor skill execution or a combination of both with drills designed accordingly. Furthermore, coaches could set target scores for players to achieve and the test can be used as a way of measuring development in the players.

A potential limitation of using an in-situ test such as small-sided games is the number of trials per participant can vary. This variation in trial numbers per participant has been argued in the literature as representative of the game situation skill involvements, and can also be due to accessibility to participant time to partake in the test (Müller et al., 2015). The mean number of disposals per player for the higher skilled group in the small-sided games test of 13.32 (*SD* = 4.4), compared to 14.38 (*SD* = 5.05) across the 2017 WAFL season, with a range of involvement being 5–23, compared to a range of 8–28 across the 2017 WAFL season, is favourable. Therefore, the small-sided games test has comparable player involvement to a game situation in regards to number of involvements.

Practical application and conclusion

Performance tests need to be easily administered within scheduled practice times if they are to be consistently used by athletes, coaches and scientists alike (Robertson, Burnett, & Cochrane, 2014). The small-sided games test for ARF has high practical application and feasibility because, (a) players complete a highly game-representative test, (b) it is relatively time efficient (approximately 30 mins to assess 12 players), (c) requires limited equipment (video camera, a set of coloured bibs and a football), and (d) takes two hours for video analysis of the total sample in this study. Coaches may be reluctant to implement skill tests when they do not closely represent the normal game context and when implementation encroaches upon the actual training time. As small-sided games have high task representation, these tests could also be adopted for use in other sports.

A further benefit from using a performance test based on a small-sided games, is that it gives coaches a platform to train and assess new tactics both in attack and defence. An example could be the coach wants to assess perceptual-cognitive-motor skill capability of players when in possession of the ball with a "zone defence" compared to a "man-on-man defence". Alternatively, a coach may set a challenge to the defending team of how many times can they re-possess (gain possession) the ball from the attacking team over a - three minute duration. Such a challenge is relevant as the current trend in ARF is suggestive of a blended game-style; one that adopts both a possession and re-possession style of play (Woods et al., 2017). Furthermore, manipulations of objectives and rules in small-sided games by coaches can increase opportunities for common attacking and defensive sub-phases to emerge frequently (Davids et al., 2013).

In conclusion, the small-sided games test in ARF can assist coaches to assess and train players' perceptual-cognitive-motor skills that are reflective of the natural game environment. Accordingly, small-sided games can be easily implemented to identify talented players, as well as assess and train the perceptual-cognitive-motor skill capability of skilled players.

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B.3 Coach rating combined with small-sided games provides further insight into mental toughness in sport

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Coach Rating Combined With Small-Sided Games Provides Further Insight Into Mental Toughness in Sport

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Literature indicates that mental toughness contributes to successful performance when faced with challenge. This study used an exemplar sport of Australian Rules football to investigate whether skilled performance thrived across increased challenge in small-sided games. Higher (n = 14) and lower (n = 17) skilled Australian footballers were recruited. First, coaches rated participants' mental toughness (MTC) using the Mental Toughness Index. Second, participants competed in small-sided games where challenge was manipulated by varying the attacker to defender ratio to create lower and higher pressure scenarios. Decision-making, motor skill execution, and a combined total were measured. MTC rating was higher for higher skilled players. Total score of higher skilled players was significantly superior to lower skilled players in higher and lower pressure scenarios (p = 0.003). A "pressure differential score," calculated to determine whether participants maintained performance across increased challenge, indicated a significant decrease in performance (total score) from lower to higher pressure scenarios for lower skilled (p = 0.011), but not for higher skilled (p = 0.060) players. Furthermore, MTC scores were predictive of high pressure scenario total scores (p = 0.011). Findings suggest higher levels of mental toughness may contribute to maintain performance across the increased challenge of pressure within small-sided games. Practitioners can subjectively rate athlete mental toughness and then structure small-sided games to objectively measure performance under pressure scenarios. This provides an interdisciplinary approach to assess and train psychomotor skill.

Keywords: mental toughness, psychomotor skill, pressure scenarios, perceptual-cognitive-motor skill, sports specific assessment

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INTRODUCTION

In the Australian Football League (AFL) grand final of 2010, both St Kilda and Collingwood had scored 68 points when the siren sounded for full time; a draw. The rules of the competition stated that the final had to be replayed the following week. In the week preceding the rematch, Collingwood coach, Michael Malthouse, penned a newspaper article titled "Mental toughness will decide premiership" (Malthouse, 2010). Collingwood went on to win the grand final replay by 56 points. They were able to perform to a higher level than their opposition, despite the challenge of having already played in a grand final seven days earlier in front of 90,000 spectators, and the adversity of having fatigued and injured players. According to their coach, the success of Collingwood in the replay of 2010 grand final would suggest that mental toughness (MT) played a major role. MT is a concept that indeed warrants further investigation in sports-specific *in situ* settings.

Mental toughness has gained significant interest from the general public, practitioners, and researchers in recent years because it is considered a key factor of superior performance in a variety of domains including sport (Giles et al., 2018). Based upon scientific evidence of MT in a variety of domains such as business, military, education, and sport, the focus has been upon defining the phenomenon and formulation of a theoretical framework from which hypotheses could be tested (Gucciardi et al., 2015). Accordingly, MT has been defined as a personal capacity to produce consistently higher levels of subjective or objective performance, despite everyday challenges, stressors and significant adversities (Gucciardi et al., 2015). Research into MT has also developed and validated several introspective questionnaires in order to measure MT in several domains, and in turn, test and further refine its theoretical framework (Newland et al., 2013). Some of these questionnaires include the Mental Toughness Questionnaire-48 (MTQ48) (Clough et al., 2002), the Sport mental toughness questionnaire (SMTQ) (Sheard et al., 2009), and the Mental toughness index (MTI) (Gucciardi et al., 2015). Therefore, the vast majority of what is known about MT measurement is based upon introspective survey methodology.

Surveys can provide scientists with valuable information about psychological and emotional states of participants, but there has been a call for incorporation of other methodologies that can provide insight to the link between psychomotor skill capability and MT in athletes (Gucciardi et al., 2008, 2013; Gucciardi and Gordon, 2013; Mahoney J. et al., 2014). The broader field of sport psychology has relied predominantly on introspective surveys and interviews, often undertaken sometime after the competition event. This relies on the athlete having to reflect on their own performance, which can be quite subjective. There is scope, however, to utilize an alternative methodology to better understand the link between psychomotor skill performance and MT in sport. For example, Mahoney J. et al. (2014) recommended that a key starting point for future investigation of MT, is objective measurement of performance under manipulation of lower and higher pressure *in situ* contexts in sport. This would enable a quantitative assessment of a component prediction of MT theory through varying degrees of pressure that creates increased challenge to performance. This form of assessment places a participant in a game-like pressure context and would help coaches to identify those players who thrive or succumb to the pressure (Mahoney J. et al., 2014). Accordingly, it has been suggested that a characteristic of mentally tough athletes is for their performance to thrive (i.e., performance maintained to a greater degree) when under increased task pressure or challenge (Jones et al., 2007; Gucciardi et al., 2008).

The importance of MT to superior performance in sport is well recognized among coaches, athletes and sport scientists (Connaughton and Hanton, 2009). Several studies in sport have reported that athletes with higher self-reported scores on MT questionnaires tend to perform better in competition (Drees and Mack, 2012; Newland et al., 2013; Mahoney J.W. et al., 2014; Cowden, 2016). For example, Cowden (2016) reported that amongst professional tennis players, achievement of higher MT scores were correlated with a greater likelihood of winning a national tournament. Drees and Mack (2012) also reported that higher MT scores of high school wrestlers was positively correlated with the season winning percentage. Moreover, Mahoney J.W. et al. (2014) reported a negative relationship such that higher MT scores of adolescent cross-country runners correlated with faster race times. In collegiate basketball players, Newland et al. (2013) reported that MT score partially predicted basketball performance (measured using a metric that combined shot percentage, points, rebounds, assists, steals, turnovers and personal fouls). To our knowledge, there has been no integration of MT survey methodology with systematic manipulation of sports-specific pressure and assessment of perceptual-cognitive-motor skill to further understanding of MT.

Small-sided games (SSG) have been used with several invasion sports such as soccer, field-hockey and Australian rules football (ARF) to assess the perceptual-cognitive-motor skill of athletes (e.g., see Práxedes et al., 2018). Assessment of the correct decision, such as to pass the ball to a teammate or retain possession of the ball, provides a measure of perceptual-cognitive or decision-making skill (Starkes et al., 2004). Alternatively, assessment of the capability to successfully pass the ball to a teammate provides a measure of motor skill execution (Starkes et al., 2004). Recently, Piggott et al. (2019) designed a sports-specific ARF test based upon SSG (six attackers vs. five defenders) in order to assess the perceptual-cognitive-motor skills of Australian footballers. The authors reported that higher skilled players were significantly superior on the total score (decision-making plus execution) compared to lesser skilled Australian footballers. By manipulation of the ratio of defenders to attackers it is possible to increase or decrease pressure in SSG (see Davids et al., 2013), which can then form scenarios to investigate how athletes deal with challenge (as predicted in MT theory) that may affect performance.

This study incorporated existing MT survey methodology with an *in situ* sports-specific test. ARF was used as the exemplar sport skill to further understand the link between MT and psychomotor skill in sport. A sports-specific *in situ* test for ARF was designed based upon SSG that measured participants' decision-making and motor skill execution under higher and lower pressure scenarios. The purpose of this study was to investigate whether: (i) differences existed between higher and lower skilled ARF players during pressure scenarios of a SSG test, which provided a proxy to test a component of MT theory that performance in terms of perceptual-cognitive-motor skill would thrive (be maintained) under increased pressure, and (ii) whether MTC scores predicted performance scores in the high pressure scenario. Based upon MT theory and the above literature, it was hypothesized that: (a) higher skilled players will perform signficantly better than lower skilled players in both pressure scenarios, (b) higher skilled, rather than lesser skilled players, would better maintain performance across lower to higher pressure scenarios, and (c) MTC questionnaire scores can predicthigh pressure scores inn SSG.

MATERIALS AND METHODS

Participants

A total of 31 male participants were recruited for this study. A higher skilled group (n = 14) comprised of one semi-professional West Australian Football League (WAFL) club who participated in the state league. The lower skilled group (n = 17) was recruited from two West Australian Amateur Football League (WAAFL) clubs. For a participant to be included in the higher skilled group they had to have played a minimum of one senior WAFL game within the previous two years. The age of the WAFL group was (Mage = 23.0 years, age range: 20–29 years) and the WAAFL group was (Mage = 23.9 years, age range: 19–30 years). Based upon Piggott et al. (2019), a power analysis was conducted using $\alpha = 0.05$, power $(1-\beta) = 0.8$, effect size = 0.15, and two skill groups, which indicated that appropriately 351 trials in total were required. Ethical approval was received from the relevant university committee and participants provided written informed consent.

Materials and Procedures

Mental Toughness

All testing was completed at the end of the pre-season training period and before competition games began for the 2017 season. The first component of this study involved coach rating of each participant using the MTI, an eight item scale that when developed displayed strong factor loadings and composite reliabilities were reported to be excellent (ρ=0.86 *to* 0.89) (Gucciardi et al., 2015). Example items from the scale include *I am able to regulate my focus when performing tasks* and *I am able to execute appropriate skills or knowledge when challenged.* The MTI has been used in previous research with athletes and has been reported to correlate with competition performance (e.g., Gucciardi et al., 2015). The measuring of coach rated MT (MTC) has also been used in previous research (Bell et al., 2013; Cowden et al., 2014) and is a way of overcoming self-attribution bias that can occur when using self-report. To establish face validity for coach rated MT using the MTI, a panel of expert AFL coaches was consulted and all agreed that the questionnaire was an appropriate measure of assessment. A senior member of each of the teams' coaching staff involved in the study completed the MTC rating for each participant that they coached.

Small-Sided Games

The second component of this study involved both skill groups and relates to item 7 on the MTI: *I am able to execute appropriate skills or knowledge when challenged.* This refers in part to MT theory mentioned earlier and was deemed the easiest to manipulate in terms of pressure contexts in a sports-specific *in situ* test. For this study, the previous data set from Piggott et al.'s (2019) was built upon to include another series of SSG involving six attackers versus three defenders. The two series of SSG were termed "higher pressure" (six vs. five) and "lower pressure" (six vs. three), respectively. Both scenarios involved attackers attempting to maintain possession of the ball in a 40 m × 40 m grid using a handpass or kick, whilst defenders tried to spoil or tackle. After a 15 min warm-up, each skill group completed three sets each in attack and defense. The test was umpired by a research assistant with ARF knowledge. Each skill group completed the higher pressure scenario in one session and the lower pressure scenario in another session at least one week apart due to logistics. Each time an attacking player passed the ball by a kick or handball it was recorded as a trial. Decision-making and motor skill execution scores for each disposal (trial), as well as both combined (total score) were coded as objective performance measures. Each session was recorded using a standard 25 Hz video camera (Panasonic SDR-H250, Australia) for later coding (see Piggott et al., 2019, for details of this method).

The scoring system used in both higher and lower pressure scenarios is outlined in **Table 1**. In relation to item 7 of the MTI, we reasoned that decision-making score reflects "knowledge," the execution score reflects "skills," and "challenge" reflects the increase in defenders from three to five in the *in situ* scenarios. The reliability of scoring the scenarios was assessed by inter- and intra-rater reliability. A novice coach scored all trials by viewing the video record of the SSG. Intra-rater reliability was assessed by the same novice coach (two weeks apart) and inter-rater reliability was assessed by an expert ARF coach (Level 3) on 136 (14%) randomly selected trials, across both high and low pressure scenarios, using the video record.

Data Analysis

Statistical analysis was performed using IBM SPSS version 24 (IBM SPSS Statistics for Windows. IBM Corp., Armonk, NY, United States). Data was checked for normality using the Shapiro Wilk's test so that the appropriate statistical tests could be employed. Alpha level was set at 0.05.

TABLE 1 | Composite score for test trials.

Measure	Rating
Decision-making	0 = Incorrect decision
	2 = Next correct decision
	3 = Most correct decision
Execution	0 = Ball does not reach target player at all
	1 = Ball reaches target player but not on full
	2 = Ball reaches target player on full; however, the target player had to change direction to ensure this occurs
	3 = Ball reaches target player on full
Total	Decision Making + Execution Scores

Adapted from Piggott et al. (2019). "Small-sided games can discriminate perceptual-cognitive-motor capability and predict disposal efficiency in match performance of skilled Australian footballers." Journal of Sports Sciences, p. 3.

During the SSG, each time an attacking player passed the ball by a kick or handball it was recorded as a trial, with a total of 980 trials recorded; 423 in the higher pressure scenario and 557 in the lower pressure scenario. The participants' total score for the SSG was the dependent variable, which equalled the sum of the decision and execution scores for each trial with the maximum score achievable being six. Total score had previously been reported to discriminate superior performance of higher and lower skilled Australian footballers (see Piggott et al., 2019).

Inter- and intra-rater reliability of the scoring of the SSG test was assessed using a two-way mixed intra-class correlation coefficients (ICC) according to Portney and Watkins (2009). The cut-off interpretations used for the ICC values were; less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 indicative of poor, moderate, good, and excellent reliability, respectively.

Hypothesis one predicted that higher skilled players will perform significantly better than lower skilled players in both pressure scenarios. To address this hypothesis, repeated measures of trials were examined for between skill group differences for total score on the SSG test, in both higher and lower pressure scenarios, using generalised estimating equations (GEE). GEEs use the generalized linear model to estimate more efficient and unbiased regression parameters relative to ordinary least squares regression that accounts for the form of within-subject correlation of responses on dependent variables of many different distributions (Ballinger, 2004). A 2 (skill group) × 2 (pressure scenario) mixed between-within factorial GEE model was used to examine main and interaction effects. Total score was the dependent scale variable in the GEE model. For *post hoc* comparisons, a Bonferroni adjustment was applied. Cohen's *d* effect sizes were also calculated, with 0.2 considered small, 0.5 medium and 0.8 large effects (Cohen, 1998).

Hypothesis two predicted that higher skilled, rather than lesser skilled players, would better maintain performance across lower to higher pressure scenarios. To address this hypothesis, a mean of the trials' total score for each participant was calculated for each higher and lower pressure scenarios on the SSG test for both skill groups. A "pressure differential score" was then calculated by subtracting higher pressure scenario mean total score from lower pressure scenario mean total score. For example, if a participant had a lower pressure mean total score of 5.4 and higher pressure mean total score of 4.6, their pressure differential score would be; 5.4 – 4.6 = 0.8. A pressure differential score closer to zero indicated better sustained performance across lower to higher pressure scenarios; which meant participants were able to maintain perceptual-cognitive-motor skills when challenged. A one-sample *t*-test was used to compare the mean pressure differential scores to a no-performance-change score of zero for higher and lower skilled players.

Hypothesis three predicted a relationship between MTC questionnaire scores and SSG high pressure scores. To address this hypothesis, a GEE regression model was used to investigate the relationship between MTC and high pressure scenario total score.

RESULTS

Reliability of SSG Test Scoring

Inter-rater reliability for decision ($r = 0.91$, range = 0.88 to 0.94) and execution ($r = 0.98$, range = 0.98 to 0.99) indicated excellent levels of agreement. Intra-rater reliability for decision ($r = 0.86$, range = 0.80 to 0.90) and execution ($r = 0.96$, range = 0.95 to 0.97) also indicated good and excellent levels of reliability, respectively.

Skill Group Differences for SSG

The estimated marginal means derived from the GEE model are presented in **Figure 1**. The model indicated significantly superior overall performance by higher skilled players over lower skilled players ($\beta = 0.22$, SE = 0.07, $p = 0.003$). In addition, performance under the low pressure scenario was significantly higher than under the high pressure scenario ($\beta = -0.47$, SE = 0.15, $p = 0.002$). The interaction between skill level and pressure was not significant ($\beta = 0.20$, $SE = 0.18$, $p = 0.282$). However, pairwise comparisons revealed a significantly higher total score by higher skilled players ($M = 5.32$, $SE = 0.08$), over lower skilled players ($M = 4.90$, $SE = 0.14$), under the higher pressure scenario ($p = 0.049$, $d = 0.31$). Pairwise comparisons also revealed a significantly higher total score by higher skilled players ($M = 5.59$, $SE = 0.05$), over lower skilled players ($M = 5.37$, $SE = 0.06$), under the lower pressure scenario ($p = 0.017$, $d = 0.22$). When the total score of higher skilled players was compared across lower ($M = 5.59$, $SE = 0.05$) to higher ($M = 5.32$, $SE = 0.08$) pressure scenarios, a significant difference was found ($p = 0.034$, $d = 0.12$). A significant difference was also found for lower skilled players across lower ($M = 5.37$, $SE = 0.06$) to higher ($M = 4.90$, $SE = 0.14$) pressure scenarios ($p = 0.014$, $d = 0.35$).

In relation to performance across scenarios, the pressure differential score indicated that for lower skilled players there was a significant difference compared to a no-performance-change score of zero, $t(16) = -2.89$, $p = 0.011$. This indicates performance decrement for lower skilled players. Conversely, no significant difference was found for pressure differential score for higher skilled players, $t(13) = -2.06$, $p = 0.060$. This indicates maintenance of performance for highly skilled players. There was a medium effect size ($d = 0.46$) for the pressure differential scores between higher ($M = 0.22$, $SD = 0.40$) and lower ($M = 0.48$, $SD = 0.68$) skilled players.

MTC Scores and Relationship to SSG

The MTC scores for higher and lower skilled groups were ($M = 43.71$, $SD = 4.41$) and ($M = 42.50$, $SD = 5.37$), respectively. There was no significant difference between the two groups for MTC; $t(26) = 0.519$; $d = 0.24$).

When examining the relationship between subjective and objective measures, MTC scores were able to predict high pressure scenario total scores ($\beta = 0.04$, SE = 0.01, $p = 0.011$).

DISCUSSION

The purpose of this study was to integrate methodologies in order to test a component of MT theory that predicts whether an athlete

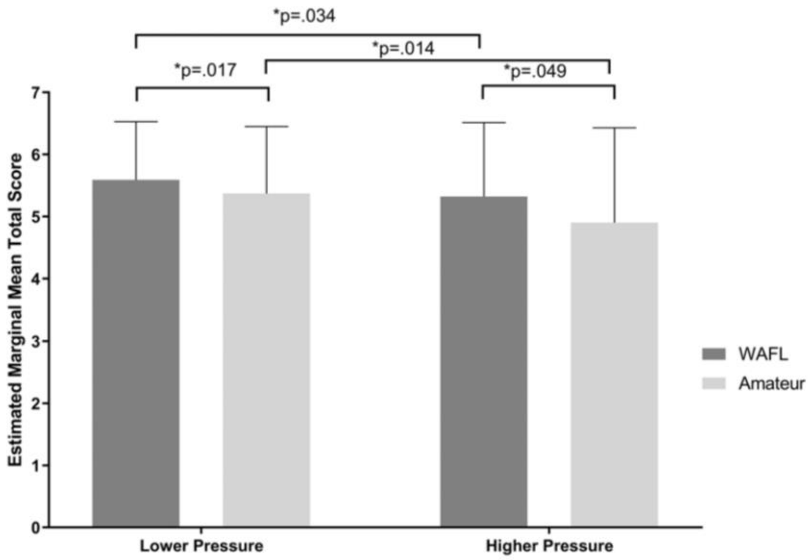

FIGURE 1 | Estimated marginal means for total score in small-sided games test based on GEE model. Pairwise comparisons are depicted *$p < 0.05$. Error bars represent standard error.

will thrive under pressure situations and maintain performance. This was done in interlinked components; first, a validated questionnaire was used for coaches MT rating of participants. Second, perceptual-cognitive-motor skill differences between higher and lower skilled ARF players were compared across two pressure conditions of a SSG test. Third, the relationships between quantitative and qualitative measures was explored. Fourth, the reliability of scoring the SSG test was checked through inter- and intra-rater reliability. Skill group differences were found in each pressure scenario, with higher skilled players better able to maintain performance across the pressure scenarios. Furthermore, MTC was predictive of performance under high pressure. Therefore, this study made initial steps to address the call for MT research methodology to be extended and incorporate experimental designs that involve systematic manipulation of pressure contexts within an *in situ* setting (Mahoney J. et al., 2014).

Both higher and lower pressure scenarios were able to discriminate skill levels, with higher skilled players performing at a superior level than lower skilled players. Previously, MT research in sport has used only survey methodology to attempt to discriminate between skill levels or categories; such as starters and non-starters in basketball (Newland et al., 2013) and team ranking in tennis (Cowden et al., 2014). This study showed that perceptual-cognitive-motor total score in the lower pressure (six vs. three) scenario was also able to discriminate between higher and lower skilled players. This builds upon Piggott et al.'s (2019) study providing further evidence of the capability of SSG's to discriminate between closely related skill levels of ARF. The design of tasks that involve differing levels of pressure that are highly representative of the competition environment and can discriminate between skill levels provides an important method to test MT theory. Therefore, supporting evidence was provided for hypothesis one.

A unique aspect of this study, was the calculation of the pressure differential score to test a component prediction of MT theory. The theory predicts that mentally tough athletes are able to thrive under pressure (Jones et al., 2007; Gucciardi et al., 2008). The pressure differential score enabled direct investigation of how participants met this challenge by quantification of the degree to which they maintained performance across increased pressure scenarios. Our study showed that higher skilled players could maintain their perceptual-cognitive-motor skill performance across increased pressure scenarios as evidenced by a lower pressure differential score. In contrast, lower skilled players were less able to maintain their perceptual-cognitive-motor skill performance across increased pressure scenarios as evidenced by an increase pressure differential score. Therefore, supporting evidence was provided for hypothesis two. This addressed the call in the literature for an objective measure of MT under manipulation of lower and higher pressure contexts (Mahoney J. et al., 2014).

The findings of this study have also furthered understanding of a subjective measure of MT and its relationship to an objective measure of perceptual-cognitive-motor skill performance. This is important because Gucciardi and Gordon (2013) stated that there was a lack of evidence supporting the link between MT and an objective measure of performance. The significant predictive relationship between coaches' MT rating of athletes and *in situ* performance in the higher pressure scenario provides support for the theory that higher levels of MT correspond with higher levels of performance. This evidence supports hypothesis three and is consistent with previous studies that have shown a relationship between self-reported MT and competition performance (Drees and Mack, 2012; Newland et al., 2013; Mahoney J.W. et al., 2014; Cowden, 2016). This indicates that either coach or self-report of MT is relevant to motor skill performance, but our study is unique as we have been able to demonstrate through manipulation of the pressure component in which the task is performed, we showed that MTC has predictive capabilities in relation to *in situ* perceptual-cognitive-motor skill.

PRACTICAL IMPLICATIONS AND LIMITATIONS

The integration of methods to test theory and evidence presented in this study provides opportunities for practical application in terms of assessment and development of athletes. Accordingly, a multi-method approach to MT could be used (Gucciardi et al., 2013). For example, an ARF coach, in consultation with a sport psychologist, could complete the MTI for an athlete as part of their development. The coach could then discuss their responses with the athlete and how they derived each score per item. On item 7 of the MTI (*I am able execute appropriate skills or knowledge when challenged*), the coach may score the athlete three out of seven and could explain that the athlete needs to improve their decision-making and/or skill execution when under pressure situations in competition. The coach would then work with a sport psychologist to design a six week training plan that develops MT. In addition, the coach assisted by a skill acquisition specialist can design a perceptual-cognitive-motor skill training program for a variety of game-specific pressure contexts. Prior to the commencement of the six week training program, the athlete would complete the SSG games test and may record a high pressure score of 4.0 and low pressure score 5.4 (pressure differential = 1.4). The athlete and the coach could set a goal for the athlete to achieve a pressure differential of <1.0 when retested at the completion of the training program.

A potential limitation of the study is that when using SSG and *in situ* methodology, the number of trials per participant can vary. However, Müller et al. (2015) argue that this variation is representative of the game situation. Previously, we have shown using SSG player involvements (trials) is comparable to player involvement (statistics) in competition (Piggott et al., 2019).

CONCLUSION AND FUTURE RESEARCH

Researchers in the domain of mental toughness have called for an extension of methodology beyond traditional surveys often used in sports psychology research. This study used an *in situ* methodology within ARF to create two scenarios; lower pressure and higher pressure SSG scenarios. These two scenarios were able to discriminate between higher and lower skilled players. Also, the pressure differential score showed that the higher skilled players, but not the lower skilled players, could sustain their performance across lower to higher pressure scenarios. This is in line with a component prediction of MT theory. MTC scores were predictive of total scores in the high pressure scenario, indicating a causal relationship between objective and subjective measures of MT. Therefore, through careful manipulation of a SSG task, a prediction of MT theory was tested, which provides support for further application of SSG in field-based sport settings.

Further research is necessary to replicate these findings with other sports, as well as further probe the causal relationship between mental toughness and perceptual-cognitive-motor skill. In relation to the first point, future research could determine the variance that mental toughness scores account for in the SSG task performance. This will help determine how much mental toughness contributes to performance in SSG. In relation to the second point, a psychological skills training program aimed at improving mental toughness could be compared to a perceptual-cognitive-motor skill training program, with their relative benefits assessed using small-sided game pressure scenarios. A psychological skill intervention has been reported to improve mental toughness and performance in cricket batting (see Bell et al., 2013), but has not specifically been compared to perceptual-cognitive-motor skill training and performance in small-sided game scenarios. Collectively, fruitful opportunities exist to further understand how mental toughness and perceptual-cognitive-motor skills contribute to performance of sports skills.

DATA AVAILABILITY

The datasets generated for this study will not be made publicly available to maintain confidentiality.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Human Research Ethics Committee University of Notre Dame Australia. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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B.4 Interdisciplinary sport research can better predict competition performance, identify individual differences, and quantify task representation

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ORIGINAL RESEARCH
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Interdisciplinary Sport Research Can Better Predict Competition Performance, Identify Individual Differences, and Quantify Task Representation

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Sport performance consists of interacting individual, task and environmental constraints, but research has used a monodisciplinary, rather than an interdisciplinary approach to understand performance. This study used Australian football (AF) as the exemplar sport to investigate the value of an interdisciplinary approach to understand sport performance. Through this, it was also possible to quantify individual differences and representative task design. Fifty-nine semi-professional Australian footballers participated. Based upon accessibility, combinations of these players completed physiological (3 × 1 km trial) and perceptual-cognitive-motor (small-sided game, SSG) tests, with coach rating of psychological skill (mental toughness coach, MTC). Univariate monodisciplinary models indicated that all tests predicted disposal efficiency; 3 × 1 km trial ($p = 0.047$), SSG ($p = 0.001$), and MTC ($p = 0.035$), but only the SSG predicted coaches' vote ($p = 0.003$). A multivariate interdisciplinary model indicated that SSG and MTC tests predicted disposal efficiency with a better model fit than the corresponding univariate model. The interdisciplinary model formulated an equation that could identify individual differences in disposal efficiency. In addition, the interdisciplinary model showed that the higher representative SSG test contributed a greater magnitude to the prediction of competition performance, than the lower representative MTC rating. Overall, this study demonstrates that a more comprehensive understanding of sport performance, individual differences, and representative tasks, can be obtained through an interdisciplinary approach.

Keywords: interdisciplinary research, individual differences, representative task design, sports science, Australian football

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INTRODUCTION

Sport performance has been frequently studied based upon physical or physiological components such as agility and aerobic capacity (Cardinale, 2017). Coaches and applied scientists, however, believe that competition performance involves an interaction between physiological, psychological, and perceptual-cognitive-motor components (Cardinale, 2017; Zaichkowsky and Peterson, 2018;

Bonney et al., 2019a). For example, mid-field players in Australian football (AF) and soccer run approximately 10 kilometers per game, whilst attempting to make accurate skill decisions under high-pressure situations. Accordingly, several recent books (e.g., Ericsson et al., 2018; Zaichkowsky and Peterson, 2018) and scientific publications (e.g., Glazier, 2015; Cardinale, 2017) have discussed the importance of psychological and perceptual-cognitive-motor components, which need to be considered with physiological components, to provide a more comprehensive understanding of sport performance. This presents an opportunity to extend mechanistic (or theoretical) understanding of sport performance from an interdisciplinary perspective, which has applied implications in terms of identification of strengths and deficiencies of individual athletes for remediation.

Recent reviews of the sports science literature have found that interdisciplinary research continues to be scarce (Buekers et al., 2016; Piggott et al., 2019c). There are several possible reasons for why this is the case. First, sports science researchers may not be aware of suitable theoretical frameworks that can underpin interdisciplinary research questions, experimental design, and analyses (Buekers et al., 2016). Second, interdisciplinary research is highly dependent upon the organization of a team of scientists who have less preference upon a monodisciplinary approach to understand sport performance (Buekers et al., 2016). Third, interdisciplinary research can require greater resources and participant time, which may limit sport performance to be investigated from a monodisciplinary perspective (Buekers et al., 2016). Nonetheless, Buekers et al. (2016) and Piggott et al. (2019c) have presented solutions to these barriers in the form of theoretical frameworks to guide experiment and test design. These authors also mentioned the incentive for researchers to conduct interdisciplinary research, which is its capacity to provide a comprehensive understanding of athletic performance.

A useful framework to underpin interdisciplinary research is constraints theory (Higgins, 1977; Newell, 1986), because it takes into consideration interacting variables that can shape achievement of the motor skill goal. Constraints include interacting components related to the individual, task and immediate environment that can guide achievement of the motor skill goal (Higgins, 1977; Newell, 1986). An example of constraints is demonstrated in the last minute of a rugby game, when the team in possession of the ball is behind by four points (environment). The halfback (individual) of the losing team throws a pass to the winger, the fastest player on their team who has open space in front of him. This gives the halfback an opportunity to score a try (task), whilst avoiding being tackled by an opponent(s), which would result in the team winning the game. In relation to individual constraints; physiological, psychological, and perceptual-cognitive-motor components interact with the environment and task constraints to attempt successful achievement of the motor skill goal. Therefore, constraints theory predicts that interacting variables, aligned with an interdisciplinary approach, are crucial to comprehensively understand performance in sport.

Underpinned by constraints theory, it is possible to develop research questions, experimental design, and analyses to further understanding of sport performance. AF can be chosen as an exemplar sport because it includes interacting physiological, psychological, and perceptual-cognitive-motor individual constraints (Bonney et al., 2019a). A key task constraint of AF competition is effective disposal of the ball to a teammate without being tackled or the pass being intercepted. This refers to the skill (or task) goal in competition, which can be measured using disposal efficiency (Piggott et al., 2019b). Disposal efficiency is defined as the percentage of disposals that are effective or hit their intended target and is one of the match statistics provided by a commercial analytics company (Champion Data, South Bank, Australia). Passing the ball in AF occurs under a highly dynamic environmental constraint, because there are multiple players in close proximity to the ball carrier who can tackle from any direction. Therefore, by systematically integrating constraints on the individual, it is possible to determine, as predicted by constraints theory, whether disposal efficiency can be better predicted through a monodisciplinary or interdisciplinary approach. This contributes to theoretical understanding through interacting constraints that may influence sport performance.

Although constraints theory predicts performance based upon the individual, sports science researchers have focused upon group designs, rather than sub-groupings or analyses that can reveal individual differences (Piggott et al., 2019c). The latter analyses have important practical implications, as coaches are interested in the strengths, deficiencies, and development of individual athletes, so that interventions can be tailored to improve individual athlete competition performance. For example, underpinned by constraints theory, Chow et al. (2008) reported individual differences in hip, knee, and ankle joint coordination when novices learned to chip kick a soccer ball to targets of varying distance and size. This study demonstrated that more than one coordination pattern can be used to learn a skill. In another example, Piggott et al. (2019b) used a sub-grouping analysis relative to games played and position of play within skilled Australian footballers. They reported superior decision-making in SSG's relative to increased exposure to competition and playing in the mid-field position. This study demonstrated that task experience and position of play can influence decision-making capability. Accordingly, it has been suggested that in order for sport performance research to best guide athlete preparation, individual, or sub-groups analyses are necessary to better elucidate interaction with task and environment constraints (Woods et al., 2019).

Design of tests or selection of measurement instruments is also an important consideration for interdisciplinary research to best capture interacting constraints of sport performance. This refers to representative task design, which includes properties of the test or measurement instrument and their generalization to the intended context (Araújo and Davids, 2015), which in sport is the competition setting. It has been argued that properties (constraints) of a test such as perceptual information and action responses need to be sampled from the competition setting to be included in design of the test (Pinder et al., 2011b). For example, a SSG would be considered high in task representation because perceptual and action components are closely related to competition performance, whilst coach rating of athlete performance involves none of these components, so it would be considered low in task representation. In a related manner, the literature indicates that practice drills in AF allow the ball carrier to retain possession of the ball for considerably longer prior to a decision to dispose, than occurs in competition (Woods et al., 2019). The implication of this finding is that coaches need to design practice tasks where athletes make accurate decisions, where ball possession time is like competition. Interdisciplinary research including physiological, psychological, and perceptual-cognitive-motor component tests can provide an indication of what best predicts a measure of match performance such as disposal efficiency. Through this, it is possible to obtain an understanding of which interacting test(s) or measure(s) represents sport performance. This will help coaches and sports scientists select representative talent identification and test batteries for athlete evaluation and training.

This study employed both monodisciplinary and interdisciplinary approaches using AF as an exemplar sport. We used three sports science sub-discipline measures to examine their relationships to two match performance statistics in disposal efficiency and coaches' vote. The purpose of this study were to determine: (a) whether an interdisciplinary approach provides a more comprehensive understanding of athlete match performance than a monodisciplinary approach, (b) whether an interdisciplinary approach could provide an equation to quantify individual player performance profiles, and (c) representativeness of measures in terms of their capability to predict match performance. It was hypothesized that: (i) an interdisciplinary approach would provide a better model fit in predicting a measure of match performance (disposal efficiency), in comparison to a monodisciplinary approach, (ii) individual player profiles would provide enhanced insight into sport performance, which is less evident in group descriptive analyses, and (iii) measures that closely represent competition would more accurately predict match performance.

MATERIALS AND METHODS

Participants

A total of 59 male players ($M_{age} = 21.27 \pm 3.11$ years, $M_{height} = 186.79 \pm 7.17$ cm, $M_{bodyweight} = 84.0 \pm 9.13$ kg) from a semi-professional AF league club were recruited for this study. All players were members of the senior playing squad and the inclusion criteria was that participants had to be free from injury at the time of testing. Human Research Ethics Committee (HREC) approval was received from the relevant university committee and participants provided written informed consent. This study was conducted in accordance with the Declaration of Helsinki.

Materials and Procedures

The sport of AF requires a unique mix of physical, mental, technical, and decision-making skills (Young and Pryor, 2007). These skills can be classified into the following sub-disciplines of sport science according to Abernethy et al. (2013); exercise physiology, sports psychology and motor control. A test from each sub-discipline was selected and these were; (i) 3 × 1 km time trial (exercise physiology), (ii) mental toughness coach rating (sport psychology), and (iii) SSG test in AF (motor control). Justification for the selection of these tests is outlined below. The match performance measures used were disposal efficiency and coaches' vote. The three tests were all completed toward the end of the pre-season training period and before competition games began. Match performance measures were collated from a total of 20 home and away games over the 2017 competitive season.

3 × 1 km Time Trials

Literature reports that the running demands of AF are high (Coutts et al., 2010; Delaney et al., 2017). As a result, a primary focus of AF training is to develop players' capacity in this area (Delaney et al., 2017); a performance test that provides a measure of running ability was therefore used in this study. Traditionally, AF clubs have used a 3 km time trial in order to assess aerobic capacity (Gastin et al., 2013; Piggott et al., 2015). Recently, in an attempt to ensure that performance tests reflect the intermittent running requirements of the competition environment, an alternative 3 × 1-kilometer time trial test has been reported in the literature (Cripps et al., 2018). The repeated time trial test allows players to attain higher average running speeds (283 m/min $^{-1}$) than the more traditional 3 km time trial (252.8 m/min $^{-1}$) (Cripps et al., 2018). Furthermore, high intensity running has been linked to a player's capacity to win possession of the ball more frequently (Mooney et al., 2011). There is also an expectation from coaches that players can perform high intensity efforts interspersed with frequent short breaks on the interchange bench to recover.

The test required players to complete each 1-kilometer trial as quickly as possible running around a grassed oval. Each subsequent trial began 7:30 min after the start of the preceding trial. The total time taken by the player to complete the three trials represented the criterion measure. The 3 × 1 km time trial has acceptable test-retest reliability assessed using interclass correlation coefficients (ICC = 0.97, $p < 0.01$) and typical error measurements (4.36%) (Cripps et al., 2018).

Mental Toughness Coach Rating

Mental toughness (MT) has been defined as a capacity for an individual to produce high levels of objective and subjective performance consistently despite everyday challenges, stressors and significant adversities (Gucciardi et al., 2015). There has been significant interest from researchers, practitioners and the general public in recent years regarding MT as a key factor of superior performance in a variety of domains including sport (Giles et al., 2018). The MT Index (MTI) developed by Gucciardi et al. (2015), is an eight item scale and an example item is; *I am able to execute appropriate skills or knowledge when challenged.* Recently, Piggott et al. (2019a) used a coach rating of the MTI and reported that this measure predicted performance in a high-pressure SSG. To assess MT in this study, a senior member of the club's coaching staff rated each players' level of MT using the MTI. This test has a low level of task representation because it is a survey and does not require a perceptual-motor response (Piggott et al., 2019c).

Small-Sided Games

A recently developed SSG test in AF by Piggott et al. (2019b) was used to measure decision making and skill execution. The study reported that the test was highly reliable and was able to discriminate performance between semi-professional and amateur Australian footballers. In addition, the total score (summation of decision making and skill execution scores) significantly predicted disposal efficiency in competition performance (Piggott et al., 2019b). SSG's allow players greater opportunities to gain possession of the ball and display their skill level, as well as apply game strategy and tactics (Bonney et al., 2019b). The SSG test has a high level of representative task design as perceptual information that occurs in competition is presented to the participant and opportunity is provided to couple action to available perceptual information like the competition setting (Piggott et al., 2019c).

In the SSG tests, participants were divided into two teams of six attackers and five defenders. Attackers attempted to maintain possession of the ball in a 40 × 40 m grid using a hand pass or kick, whilst defenders tried to intercept, tackle, or spoil. Each skill group completed three sets each in attack and defense and each set was 3 min in duration. Prior to the commencement of the SSG's, participants completed a 15-min warm up which included running drills, dynamic stretching, basic kicking, and handball exercises. The test was umpired by a research assistant with AF knowledge. Each time an attacking player passed the ball by a kick or handball it was recorded as a trial. The decision making and motor skill execution scores for each disposal (trial), as well as both combined (total score) were coded as objective performance measures. A standard 25 Hz video camera (Panasonic SDR-H250, Australia) was used for recording so that trials could be coded post testing.

Disposal Efficiency

A commercial statistical analytics company (Champion Data, South Bank, Australia) recorded each participants' disposal efficiency, which is the percentage of disposals (kicks or handballs) that were effective during each WAFL competition game. Champion Data is used extensively in AF and provides statistics for professional and semi-professional competitions with reported 99% accuracy (O'Shaughnessy, 2006). In addition, Champion Data statistics have been used in previous published research in AF (Mooney et al., 2011; Piggott et al., 2015).

Coach Vote

Coaches' votes as a measure of match performance have been used in previous research (Mooney et al., 2011; Piggott et al., 2015). Mooney et al. (2011) used coaches' votes as a measure in their research to quantify the player's subjective performance, which encompasses both tactical and technical performance. For this study, each of five coaches, voted after every competition game, and each coach had 20 votes they could allocate across the participants who had played. The maximum votes an individual coach could give a participant was three votes. For example, if all five coaches gave a participant two votes each, then that participant would have recorded ten votes for that match.

Data Analysis

Statistical analysis was performed using IBM SPSS version 25 (IBM SPSS Statistics for Windows. IBM Corp., Armonk, NY, USA) and Stata version 15 (StataCorp, College Station, Texas, USA). Data was checked for normality using the Shapiro Wilk's test so that the appropriate statistical tests could be employed. Alpha level was set at < 0.05.

Hypothesis one was investigated using a series on univariate Generalized Estimating Equations (GEE). GEEs are an extension of general linear models, and are considered an appropriate approach for the analysis of correlated continuous and count data, and have the advantage of unbiased estimation of parameters (Ghisletta and Spini, 2004). In the GEE model, each sub-discipline performance test was the independent variable. For the first series of models, the match performance measure of disposal efficiency was the dependent variable and for the second series of models, coach vote was the match performance measure and dependent variable. Disposal efficiency employed a linear GEE model. For coaches' vote, a negative binomial link GEE model was used because of the over-dispersion of "zero" votes. The GEE model probability of not receiving a coaches' vote was graphically depicted using STATA (StataCorp. 2001). Each independent sub-discipline test was regarded as a monodisciplinary approach to quantify a component of individual constraints. Performance tests displaying significant prediction of the dependent variables in the univariate GEEs, were then integrated into a multivariate GEE model, which was regarded as an interdisciplinary approach. This is consistent with the literature, which has stated that integration of measures from different sub-disciplines using analyses such as stepwise regressions and prediction equations, can be classified as interdisciplinary (Freedson, 2009; Piggott et al., 2019c). To compare the fit of different GEE models, the Quasi Likelihood under Independence Model Criterion (QIC) was used where the model that obtains the smaller QIC has the better fit (Pan, 2001).

To address hypothesis two, the participants' mean disposal efficiency and coach vote from their match performance across the 2017 season was used. For these measures, participants were allocated into three groups depending on their performance and categorized as; high, medium and low performing. A panel of three experts who coached at semi-professional and professional levels agreed on the following cut-points for disposal efficiency: High ($\geq$70%), Medium (60–70%) and Low ($<$ 60%), and coach vote: High ($>$ 2 votes), Medium ($\geq$ 1and $\leq$ 2 votes) and Low ($<$ 1 vote). Differences between categorized performance levels in sub-discipline tests was examined using ANOVA (or non-parametric Kruskal Wallis) with a Bonferroni *post hoc* comparison. In addition, Cohen's *d* effect sizes were calculated, with 0.2 considered small, 0.5 medium and 0.8 large effects (Cohen, 1998).

In regards to hypothesis three, using the estimates from the GEEs predictive equations, we examined a 10 percent change for high and low level representative tests and determined prediction relative to the dependent variable. In addition, the QIC was used to assess model fit for tests of both high and low representative task design.

TABLE 1 | Univariate generalized estimating equations for prediction of disposal efficiency.

Model	Parameter	Estimate (β)	SE	95% CI	p
Model 1 (QIC 176,119)	Intercept	108.45	21.97	65.39 to 151.52	0.001
	3 × 1 km	−0.07	0.03	−0.13 to 0.01	0.047*
Model 2 (QIC 2234,463)	Intercept	48.06	7.91	33.56 to 63.57	0.001
	MTC	0.37	0.18	0.03 to 0.72	0.035*
Model 3 (QIC 110,014)	Intercept	−1.62	18.48	−37.85 to 34.61	0.930
	SSG Test Score	12.51	3.50	5.65 to 19.38	0.001*

Indicates a significant difference p <0.05. SE, standard error; CI, confidence intervals; MTC, Mental Toughness Coach; QIC, Quasi Likelihood under Independence Model Criterion.

TABLE 2 | Univariate generalized estimating equations for prediction of coaches' vote.

Model	Parameter	Estimate (β)	SE	95% CI	p-value
Model 1 (QIC 1141)	Intercept	1.78	2.68	−3.48 to 7.04	0.507
	3 × 1 km	−0.01	0.01	−0.01 to 0.01	0.185
Model 2 (QIC 1424)	Intercept	−3.05	0.98	−4.97 to −1.12	0.002
	MTC	0.03	0.02	−0.02 to 0.07	0.210
Model 3 (QIC 697)	Intercept	−8.07	2.18	−12.35 to −3.79	0.001
	SSG Test Score	1.19	0.40	0.39 to 1.99	0.003*

Indicates a significant difference p < 0.05. SE, standard error; CI, confidence intervals; MTC, Mental Toughness Coach; QIC, Quasi Likelihood under Independence Model Criterion.

The number of participants that completed the tests were as follows: 3 × 1 km time trial ($n = 46$), mental toughness coach rating ($n = 59$), and SSG AF test ($n = 28$). The final multivariate model assessed a total of 21 ($M_{age} = 21.24$ years, Age range: 18–29 years) players who completed all three performance tests. Not all players could complete all three tests due to player injury, load management, and training scheduling. In addition, injury restricted participants availability to participate in every match throughout the year and this is common in contact team sports. For the final multivariate model, the average number of matches played over the season per participant was 15.6, which is similar to 15.5 matches reported in previous research with a similar focus (Gabbett et al., 2011).

TABLE 3 | Multivariate generalized estimating equations for prediction of disposal efficiency ($n = 21$).

Parameter	Estimate (β)	SE	95% CI	p
Intercept (QIC 84,155)	22.88	31.65	−39.15 to 84.92	0.470
3 × 1 km	−0.06	0.03	−0.13 to 0.01	0.077
MTC	0.37	0.12	0.13 to 0.61	0.002*
SSG Test Score	12.34	3.08	6.29 to 18.38	0.001*

Indicates a significant difference p < 0.05. SE, standard error; CI, confidence intervals; MTC, Mental Toughness Coach; QIC, Quasi Likelihood under Independence Model Criterion.

RESULTS

Monodisciplinary and Interdisciplinary Approaches

At the univariate (monodisciplinary) level (**Table 1**), all three sub-discipline performance tests were significant predictors of match disposal efficiency; 3 × 1 km time trials ($\beta = -0.07$, $p = 0.047$), mental toughness coach ($\beta = 0.37$, $p = 0.035$), and SSG test ($\beta = 12.51$, $p = 0.001$). At the univariate (monodisciplinary) level, only SSG test was a significant predictor of coaches' vote ($\beta = 1.19$, $p = 0.003$) (**Table 2**).

When the significant independent variables from the univariate disposal efficiency model were integrated into a multivariate (interdisciplinary) model (**Table 3**), both mental toughness coach ($\beta = 0.37$, $p = 0.002$) and SSG test ($\beta = 12.34$, $p = 0.001$) remained as significant predictors, whilst the 3 × 1 km test was not significant ($\beta = -0.06$, $p = 0.077$). A multivariate (interdisciplinary) model of coach vote was not required as only one performance test, the SSG test score, was found to be a significant predictor. The Goodness of Fit measures (QIC's) are reported for all GEE's within their respective models (**Tables 1–3**). For disposal efficiency, where a multivariate (interdisciplinary) model was developed (**Table 3**), the QIC value was lower than the QIC values for the univariate models, indicating a better model fit.

The predictive equation resulting from the multivariate (interdisciplinary) model for disposal efficiency was:

DE = 22.88 + (-0.06) x 3 x 1k time + 0.37 x MTC score + 12.34 x SSG test score

As an example, if the mean score for each performance test was used, the equation would be:

$= 22.88 + (-0.06) \times 645.24 + 0.37 \times 43.19 + 12.34 \times 5.31$
$= 66\%$

For coach vote, as a negative binomial link model was sed, this limits the ability to create a meaningful predictive quation as presented for disposal efficiency. However, the ıodeled probability of not receiving a coach vote in relation ɔ a participant's SSG test score can be graphically depicted Figure 1). It can be seen from **Figure 1** that when a articipant's SSG test score is approximately 3.5 or higher, ıen the likelihood of them not receiving a coach vote is substantially reduced (i.e. likely of receiving a coach vot is increased).

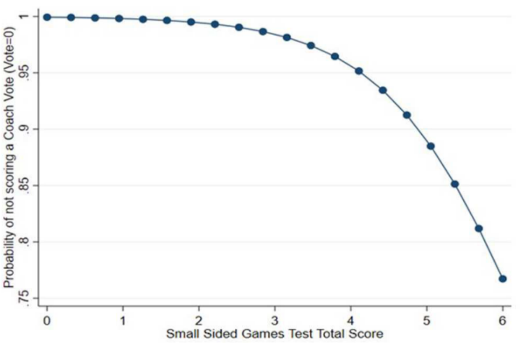

FIGURE 1 | The probability of not scoring a coach vote in relation to small sided games test score.

Group and Individual Differences

The sub-discipline performance test scores for participants iı the categorized groups for disposal efficiency and coach vot are reported in **Figures 2, 3** respectively, with descriptive value provided at **Table 4**. For disposal efficiency (**Figure 2**), wheı examining group differences between categories in regards tı sub-discipline tests scores, a significant difference was onl found overall for SSG test score [$F_{(2,18)} = 4.893$, $p = 0.20$] Bonferroni post hoc comparisons indicated that there wa a significant difference ($p = 0.019$, $d = 2.2$) between th high performing group ($M = 5.53$, $SD = 0.31$) and th low performing group ($M = 5.01$, $SD = 0.14$). For coacl vote (**Figure 3**), when examining group differences betweeı categories in regards to sub-discipline tests scores, a significan difference was only found overall for the 3 × 1 km tes score [$X^2(2) = 7.112$, $p = 0.029$]. Pairwise comparison indicated that there was a significant difference ($p = 0.031$ $d = 1.62$) between the high performing group ($M = 63($ $SD = 8.51$ s) and the low performing group ($M = 66$ $SD = 29.31$ s).

To illustrate individual differences, we have chosen to modı three different participants who scored at high, medium, anı low levels for the SSG test. The predictive equation generateı from the multivariate (interdisciplinary) model for disposa efficiency, which incorporates participant 3 × 1 km timı

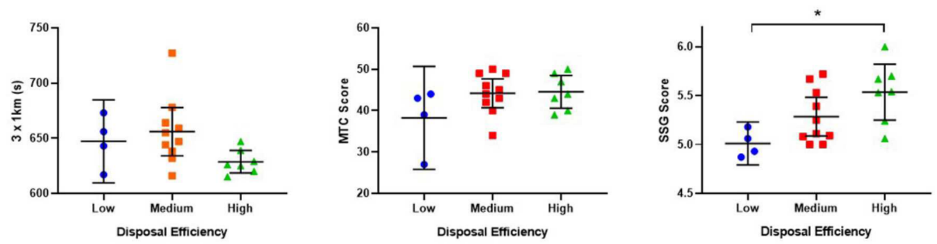

FIGURE 2 | Mean and 95% CI scores for sub-discipline performance test scores for low, medium and high scoring groups for disposal efficiency. *Indicates significant difference $p < 0.05$ between sub-groups. MTC, Mental Toughness Coach; SSG, Small sided games.

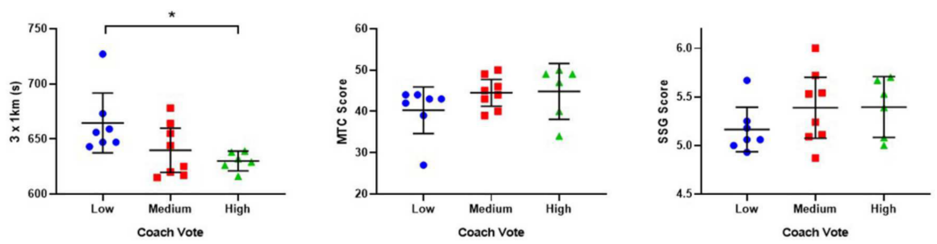

FIGURE 3 | Mean and 95% CI scores for sub-discipline performance test scores for low, medium, and high scoring groups for coach vote. *Indicates significant difference $p < 0.05$ between sub-groups. MTC, Mental Toughness Coach; SSG, Small sided games.

TABLE 4 | Mean sub-discipline scores for participants who completed all tests.

	All	Disposal efficiency			Coach vote		
	n = 21	Low (< 60%) *n* = 4	Medium (60–70%) *n* = 10	High (> 70%) *n* = 7	Low (< 1) *n* = 7	Medium (1–2) *n* = 8	High (> 2) *n* = 6
Age	21.24 ± 3.11	19.50 ± 1.30	20.90 ± 2.33	22.71 ± 4.31	19.57 ± 1.72	22.13 ± 3.48	22.00 ± 3.52
3 × 1 km (s)	645.24 ± 26.28	647.25 ± 23.61	656.00 ± 30.41	628.71 ± 11.00	664.57 ± 29.31	639.75± 24.02	630 ± 8.51
MTC	43.19 ± 5.59	38.25 ± 7.81	44.20 ± 4.85	44.57 ± 4.28	40.29 ± 6.10	44.50 ± 3.90	44.83 ± 6.43
SSG Score	5.31 ±. 32	5.01 ±.014	5.28 ± 0.27	5.53 ± 0.31	5.16 ± 0.25	5.39 ± 0.38	5.40 ± 0.30
Disposal efficiency	67.33 ± 6.47	–	–	–	–	–	–
Coach vote	1.50 ± 1.14	–	–	–	–	–	–

MTC, Mental Toughness Coach; SSG, Small Sided Games.

MTC score and SSG test score was used resulting in the following predictions:

1. Participant one (high SSG score) recorded the following scores; 3 × 1 km time = 664 s, MTC score = 46 and SSG = 5.72, with a predicted disposal efficiency of 70%.
2. Participant two (medium SSG score) recorded the following scores; 3 × 1 km time = 625 s, MTC score = 50 and SSG = 5.24, with a predicted disposal efficiency of 68%.
3. Participant three (low SSG score) recorded the following scores; 3 × 1 km time = 616 s, MTC score = 49 and SSG = 5.08, with a predicted disposal efficiency of 66%.

Representative Task Design

The impact of the level of task representation of performance tests on outcome measures is best illustrated with an example again using the predictive equation for disposal efficiency generated from our multivariate GEE (**Table 3**). We compared the effect of an increase in the SSG test (high task representation) score with a comparative increase in the MTC (low task representation) score. If we revisit the above example of using individual participant scores, the participant's predicted mean disposal efficiency is 66%. If the participant increases their SSG (high task representation) score by 10%, from 5.31 to 5.84, this would increase their disposal efficiency to 72.2%. If the participant increases their MTC (low task representation) score by 10%, from 43.19 to 47.51, this would increase their disposal efficiency to 67.3%. In this case, the participant results in the performance test with the higher level of task representation has a greater bearing on the overall outcome variable of disposal efficiency than the performance test with the lower task representation.

In relation to the Goodness of Fit analysis, the SSG test (high task representation) has the lowest QIC value for both disposal efficiency and coach vote indicating the best model fit. The mental toughness rating (low task representation) had the highest QIC value for both disposal efficiency and coach vote indicating a relative poorer model fit.

DISCUSSION

This study set out to address the call for interdisciplinary research that could provide a more comprehensive understanding of sport performance. We compared whether monodisciplinary and interdisciplinary approaches related to individual constraints contribute to predict measures of match performance in terms of disposal efficiency and coaches' vote. This comparison was crucial to demonstrate that an interdisciplinary approach could better predict match performance than a monodisciplinary approach alone. In addition, our interdisciplinary approach was capable of quantifying individual differences and representative task design relative to competition performance. Collectively, this provides a comprehensive understanding of sport performance that is theoretically driven and has practical implications for athlete development.

Our study reconfirmed that a monodisciplinary approach is relevant to understand sport performance. Indeed, univariate (monodisciplinary) analyses showed that each physiological, psychological, and perceptual-cognitive-motor skill component of individual constraints predicted disposal efficiency. The perceptual-cognitive-motor skill component also on its own predicted coaches' vote. These findings are consistent with previous monodisciplinary studies in AF that have reported perceptual-cognitive-motor skill can predict; disposal efficiency (Piggott et al., 2019b), as well as talent identified and non-talent identified athletes (Woods et al., 2016a). Moreover, physiological measures such as 20 m sprint time have also been able to predict talent identified and non-talent identified Australian footballers (Woods et al., 2017). Beyond AF, monodisciplinary studies have also been used to discriminate between skill levels using a video-based decision-making test in soccer (Keller et al., 2018) and by using a reactive agility test in rugby league (Gabbett and Benton, 2007). Therefore, there is merit to conduct sport performance research that measures these components in a monodisciplinary approach.

The interdisciplinary (multivariate analysis) approach in our study revealed that psychological and perceptual-cognitive-motor components of individual constraints contributed to significantly predict disposal efficiency. This finding is consistent with coach perception that superior performance in sport is related to psychological and perceptual-cognitive-motor skills (Steel et al., 2014; Zaichkowsky and Peterson, 2018). A likely reason for this is that coping with psychological pressure and making accurate decisions allows the player to apply their physical capability efficiently (less energy cost) to dispose of the ball effectively. Although psychological and perceptual-cognitive-motor components were significant predictors, when combined with the physiological component, there was better prediction of disposal efficiency (QIC value, see **Table 3**), in comparison to a monodisciplinary approach (QIC value, see **Table 1**). This finding is consistent with our prediction in hypothesis one. This finding is also consistent with previous research into AF that has reported better classification of talent identified and non-talent identified athletes based upon combined physical, technical, and perceptual-cognitive components (Woods et al., 2016b). Accordingly, it needs to be considered that in our study, the physiological component contributed to the multivariate model to allow better prediction. This indicates that physiological capacity is indeed important, as a footballer needs to run or sprint with the ball, but psychological and perceptual-cognitive-motor skill make a greater contribution to disposal of the ball effectively to a teammate. These findings resonate with the concern raised in the literature regarding the predominant focus upon physical or physiological components to explain sport performance (Cardinale, 2017). Rather, our findings demonstrate that psychological and perceptual-cognitive-perceptual skills, interacting with physiological capacity, is crucial to comprehensively understand sport performance.

Significant differences were found between some sub-groups for disposal efficiency in SSG and coaches' vote for the 3 × 1 km trial. These comparisons, however, focus on mean data and are not capable of demonstrating individual differences in performance. The better interdisciplinary prediction of competition performance established an equation, which was used to identify individual differences in sport performance. For example, we reported how scores from physiological, psychological and perceptual-cognitive-motor individual component constraints contributed to calculation of three different participant disposal efficiency scores (i.e., 70, 68, and 66%). This is consistent with our prediction in hypothesis two. Accordingly, our findings provide fine-grained detail of how individual constraints contribute toward competition task constraint performance. An individual differences approach has been lacking in the sports science literature with researchers focusing more upon group level analyses that presents mean data, rather than considering within-group differences (Woods et al., 2019). The reasons for this could be; first, sports scientists may have been initially interested in determining upon which components groups of athletes could be differentiated from non-athletes, and second, these group differences provided a means of validating measurement instruments through performance discrimination. Our example highlights that individual differences profiles were aligned with constraints theory that predicts the skill goal can be achieved through interaction of individual, task and environmental constraints (Higgins, 1977; Newell, 1986). Accordingly, our findings are consistent with other studies that have used constraints theory to predict and report individual differences in relation to performance at a specific instance in time (Müller et al., 2015a) and improvement of performance due to practice (Chow et al., 2008). Therefore, our developed equation could quantify individual performance, which is underpinned by an interacting constraints theoretical framework.

In utilizing an interdisciplinary approach, our findings showed that degree of representative task design of a test or measure can influence the predicted competition performance measure. To this, the MTC rating was considered lower in representative task design because it is purely a measure that requires an evaluation of athletic performance. This is unlike a performance test such as SSG that is considered high in representative task design because it includes perceptual information and action responses that are closely related to the competition setting of AF. Our analyses indicated that a consistent increase of 10% on each test results in different predictions of competition performance. Here, the test with high representative task design or the task that closely represents the context of generalization (competition), results in an increased level of predicted performance. Whilst representative task design has been popular in the literature (e.g., Gorman and Maloney, 2016; Woods et al., 2019), we are unaware of studies that have compared the relative contributions of higher and lower representative tasks to predict competition performance. There are, however, studies that have reported performance changes across lower to higher representative tasks in line with what would be expected relative to competition (Pinder et al., 2011a; Gorman and Maloney, 2016). Accordingly, our findings are consistent with hypothesis three and the theoretical predictions of representative task design. It is important to point out that lower representative task design does not mean that the task or measure should not be used. Indeed, as mentioned earlier, both psychological and perceptual-cognitive-motor components contributed to predict match performance indicating they are both valuable indicators of *in-situ* performance. It simply needs to be considered that a MTC rating (on its own) can under estimate actual competition performance.

The results of this study have a direct practical application for AF coaches, specifically in the development of players. An example could be that the coaching staff conduct the three tests (3 × 1 km time trial, SSGs and MTC) at the start of pre-season training period. The coaching staff can use these results to identify player strengths and weaknesses, inform individual development plans for each player and set specific improvement goals for them to achieve. Using this approach, aspects of training can then be individually tailored to developing the player and resources can be allocated accordingly. For example, if it was identified from the SSG testing that a player needs to improve their decision-making component in order to improve their total score, then coaches can create specific decision-making drills for the player to undertake. The playing group can then be retested after a certain time to see if the goals have been achieved.

LIMITATIONS AND CONCLUSIONS

There are limitations of this study that need to be considered. First, a potential limitation of interdisciplinary research is that performance needs to be assessed on all sub-discipline measures. This requires an increased time commitment to the research project by the participants than in monodisciplinary studies. In addition, the pool of participants in skilled athlete populations is significantly smaller than in the lesser skilled population. Athletes are also susceptible to injury, which can limit their participation in tasks that require a significant physical or motor component. Therefore, taking into consideration these difficulties, our sample size was appropriate for measures conducted in the field setting (see Triolet et al., 2013; Müller et al., 2015b). Second, we focused upon two competition performance indicators. There are of course other competition indicators such as number of possessions or contested possessions. Future research is clearly needed to determine how interacting interdisciplinary individual constraints predict a broader range of competition performance indicators.

In summary, we found that an interdisciplinary approach, underpinned by a constraints theoretical framework, provides a more comprehensive understanding of sport performance. This provides support to a constraints theory explanation of sport performance, which could also be extended to interdisciplinary performance change over time due to practice or experience (learning). Our interdisciplinary approach also allowed individual differences and representative task design to be quantified. This is vital because athlete development is based upon an individual approach to test and train, which requires the use of suitable representative tests. Collectively, it is surprising that teams of sports science researchers have not frequently collaborated to more comprehensively understand performance. Although we earlier discussed obstacles to interdisciplinary research, multi-disciplinary research teams exist across sports science institutes, sports organizations, and universities around the world. Perhaps the findings from this study might stimulate opportunities for collaboration between sports scientists and academics, which can help coaches better prepare individual athletes in a holistic manner for competition.

DATA AVAILABILITY STATEMENT

The datasets for this article are not publicly available because of confidentiality reasons. Requests to access the datasets should be directed to Ben Piggott, benjamin.piggott@nd.edu.au.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Notre Dame Australia Human Research Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix C Ethics Approval

THE UNIVERSITY OF NOTRE DAME AUSTRALIA

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31 August 2015

Professor Gerard Hoyne & Mr Ben Piggott
School of Health Sciences
The University of Notre Dame Australia
Fremantle Campus

Dear Gerard and Ben,

Reference Number: 015116F

Project Title: "The relationship between physical capacity, perceptual motor skill, mental toughness and individual match performance in a semi-professional Australian Rules Football team."

Your response to the conditions imposed by a sub-committee of the university's Human Research Ethics Committee, has been reviewed and assessed as meeting all the requirements as outlined in the *National Statement on Ethical Conduct in Human Research* (2014). I am pleased to advise that ethical clearance has been granted for this proposed study.

All research projects are approved subject to standard conditions of approval. Please read the attached document for details of these conditions.

On behalf of the Human Research Ethics Committee, I wish you well with your study.

Yours sincerely,

Dr Natalie Giles
Research Ethics Officer
Research Office

cc: Prof Naomi Trengove, Dean, School of Health Sciences

Appendix D Participant Information Sheet

THE UNIVERSITY OF NOTRE DAME AUSTRALIA

PARTICIPANT INFORMATION SHEET

The relationship between physical capacity, perceptual motor skill, mental toughness and individual match performance in a semi-professional Australian Rules Football Team

Dear

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

What is the project about?

The research project investigates the major factors that contribute to match performance of individual athletes in a team sport. This study will look at how individual specific measures in physical capacity, skill and mental toughness relate to the individual's game performance over a competitive season in the West Australian Football League (WAFL). This study will be the first to use a holistic approach to investigate how an individual's characteristics from sub-disciplines of human movement science (strength and conditioning, learning and sports psychology) contribute to the quality of individual match performance in a semi-professional environment of Australian Rules Football (ARF). The results of this study may help guide the appropriate allocation of training resources to enable players to fulfil their playing potential. The study could provide a training model that that may be transferable to other sports to ensure the holistic development of athletes.

Who is undertaking the project?

This project is being conducted by Ben Piggott and will form the basis for the degree of PhD at The University of Notre Dame Australia, under the supervision of Professor Gerard Hoyne, Dr Sean Müller, Dr Paola Chivers and Matt Burgin.

What will I be asked to do?

If you consent to take part in this research study, it is important that you understand the purpose of the study and the procedures you will be asked to undergo / tasks you will be asked to complete. Please make sure that you ask any questions you may have, and that all your questions have been answered to your satisfaction before you agree to participate.

You will be asked to undertake tests of:

- **Mental Toughness:** this involves participating in a series of game play type drills that are instructed by the head coach. These drills are very similar to routine training drills. As part of these drills, information regarding speed, skill execution and decision making will be analysed by the coaching staff. In addition, coach will complete the Mental Toughness Index survey in addition to above in relation to my performance.
- **Physical Capacity:** measured by a suite of performance tests which are commonly used in Australian Rules Football (ARF) including measures of aerobic capacity (Yo-Yo Intermittent Recovery Test, 3 x 1km km time trial) vertical jump, 20m speed as well as strength tests (bench press, squat, deadlift and chin up tests).

- **Skill:** similar to a training drill, react to scenarios that will occur in front of you and respond to the situation by passing the ball to whoever you think is the best option. This will occur at the start and end of pre-season as well as once throughout the season. Information regarding the decision made and the execution of the skill will be recorded by the researchers.
- I am aware that I will be videoed as during the completion of the mental toughness and skill tests.
- Participate in competition games (including wearing a GPS device) as would normally occur as part of the East Fremantle Football Club. Common measures used in ARF match performance assessment such as game statistics, coach vote and GPS output regarding my performance will also be collated by the researcher.

Are there any risks associated with participating in this project?

There is minimal risk associated with participating in the project. Ensuring that participants perform a generic warm up prior to testing will minimise this risk.

What are the benefits of the research project?

The benefits to the sports science community from such a project include the development of two new tests (in situ mental toughness and ARF PMST). As these have high task representation and are easy for the sports community to understand and apply, they could be then adopted by other ARF teams and also adapted for other sports. For the participants involved, they will receive valuable feedback as to their level in the varying tests (mental toughness, PMST and physical capacity) implemented and therefore highlight areas that could be improved; hence improving overall performance. As previously mentioned, there are no additional risks from being involved in the program than would normally occur from being involved in these teams.

What if I change my mind?

Participation in this study is completely voluntary. Even if you agree to participate, you can withdraw from the study at any time without discrimination or prejudice. If you withdraw, all information you have provided will be destroyed.

Will anyone else know the results of the project?

Information gathered about you will be held in strict confidence. This confidence will only be broken if required by law.

For the purpose of this project, participant confidentiality will be ensured by recording data under player ID codes. This data will then be stored in a secure file. Participant information will not be identified in future publications.

Once the study is completed, the data collected from you will be de-identified and stored securely in the School of Health Sciences at The University of Notre Dame Australia for at least a period of five years. The data may be used in future research but you will not be able to be identified. The results of the study will be published as a journal article and a thesis.

Will I be able to find out the results of the project?

Once we have analysed the information from this study we will email a summary of our findings through to your coach. You can expect to receive this feedback in December 2017.

Who do I contact if I have questions about the project?

If you have any questions about this project please feel free to contact either myself on 9433 0961 or my principal supervisor, Gerard, 94330236. My supervisor and I are happy to discuss with you any concerns you may have about this study.

What if I have a concern or complaint?

The study has been approved by the Human Research Ethics Committee at The University of Notre Dame Australia (approval number #######). If you have a concern or complaint regarding the ethical conduct of this research project and would like to speak to an independent person, please contact Notre Dame's Ethics Officer at (+61 8) 9433 0943 or research@nd.edu.au. Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

How do I sign up to participate?

If you are happy to participate, please sign both copies of the consent form and submit it in the box provided.

Thank you for your time. This sheet is for you to keep.

Yours sincerely,

Professor Gerard Hoyne

Ben Piggott

Dr Sean Sean Müller

Dr Paola Chivers

Matt Burgin

Appendix E Consent Form

THE UNIVERSITY OF NOTRE DAME AUSTRALIA

CONSENT FORM

The relationship between physical capacity, perceptual motor skill, mental toughness and individual match performance in a semi-professional Australian Rules Football Team

- I agree to take part in this research project.
- I have read the Information Sheet provided and been given a full explanation of the purpose of this study, the procedures involved and of what is expected of me.
- I understand that I will be asked to undertake tests of:
  - **Mental Toughness:** this involves participating in a series of game play type drills that are instructed by the head coach. These drills are very similar to routine training drills. As part of these drills, information regarding speed, skill execution and decision making will be analysed by the coaching staff. In addition, coach will complete the Mental Toughness Index survey in addition to above in relation to my performance.
  - **Physical Capacity:** measured by a suite of performance tests which are commonly used in Australian Rules Football (ARF) including measures of aerobic capacity (Yo-Yo Intermittent Recovery Test, 3x 1 km time trial, vertical jump, 20m speed as well as strength tests (bench press, squat, deadlift and chin up tests).
  - **Skill:** similar to a training drill, react to scenarios that will occur in front of you and respond to the situation by passing the ball to whoever you think is the best option. This will occur at the start and end of pre-season as well as once throughout the season. Information regarding the decision made and the execution of the skill will be recorded by the researchers.
  - I am aware that I will be videoed as during the completion of the mental toughness and skill tests.
  - Participate in competition games (including wearing a GPS device) as would normally occur as part of the East Fremantle Football Club. Common measures used in ARF match performance assessment such as game statistics, coach vote and GPS output regarding my performance will also be collated by the researcher.

- The researcher has answered all my questions and has explained possible problems that may arise as a result of my participation in this study.
- I understand that I may withdraw from participating in the project at any time without prejudice.
- I understand that all information provided by me is treated as confidential and will not be released by the researcher to a third party unless required to do so by law.
- I agree that any research data gathered for the study may be published provided my name or other identifying information is not disclosed.
- I understand that research data gathered may be used for future research but my name and other identifying information will be removed

Name of participant			
Signature of participant		Date	

- I confirm that I have provided the Information Sheet concerning this research project to the above participant, explained what participating involves and have answered all questions asked of me.

Signature of Researcher		Date	

Appendix F Mental Toughness Index

INSTRUCTIONS: Using the scale below, please indicate how true each of the following statements is an indication of how you typically think, feel, and behave as an athlete – *remember there are no right or wrong answers so be as honest as possible.*

1	2	3	4	5	6	7
False, 100% of the time						*True, 100% of the time*

1	I believe in my ability to achieve my goals	1	2	3	4	5	6	7
2	I am able to regulate my focus when performing tasks	1	2	3	4	5	6	7
3	I am able to use my emotions to perform the way I want to	1	2	3	4	5	6	7
4	I strive for continued success	1	2	3	4	5	6	7
5	I execute my knowledge of what is required to achieve my goals	1	2	3	4	5	6	7
6	I consistently overcome adversity	1	2	3	4	5	6	7
7	I am able execute appropriate skills or knowledge when challenged	1	2	3	4	5	6	7
8	I can find a positive in most situations	1	2	3	4	5	6	7

Reference

Gucciardi, D. F., Hanton, S., Gordon, S., Mallett, C. J., & Temby, P. (in press). The concept of mental toughness: Tests of dimensionality, nomological network and traitness. *Journal of Personality.*