UTS UNIVERSITY OF TECHNOLOGY SYDNEY

How different constraints in the practice environment influence skill behaviours in professional Australian football

by Rhys Tribolet

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of

Dr Job Fransen
Associate Professor Mark Watsford

University of Technology Sydney
Faculty of Health

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Certificate of Original Authorship

I, Rhys Tribolet, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Health at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

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Rhys Tribolet

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Date Submitted

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I would like to start by thanking my supervisors, Job Fransen and Mark Watsford. I owe both of you a significant amount by helping me develop into the person I am today. Job – you have been a source of inspiration and guidance throughout my whole candidature and in the few years prior. You have always made time to chat about work and life. You have been a great colleague and an even better mate throughout this process. I am eternally grateful for the opportunity you helped provide to me. I will miss your presence, stories and humour day-to-day, but look forward to seeing you in future overseas trips. Mark – thank you for your support and advice. You have consistently checked-in and provided perspective on my research and in daily life outside of work. Thank you for your friendship now and into the future.

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Thank you to all the UTS staff members and research students who made the environment such a great space to work in. When I spent more time on campus early PhD, it was always such an enjoyable environment to learn and work in.

This journey has been difficult, frustrating and mentally draining. It has taken a large toll. There is an ever-present imposter syndrome that you can constantly feel, even after publishing multiple times and feeling somewhat like you should belong in the company you are in. The trials and challenges, coupled with working in professional sport, has been difficult. It has meant there has been collateral along this journey, largely in the way of missing time with family and friends for having to finish and stay on top of work. There has been a psychological brutality to this work. I am definitely looking forward to living life post PhD.

Nonetheless, whilst this journey has concurrently been extremely difficult, frustrating and mentally draining, I have always had my family to help and encourage me. To my dad Ian, and my mum Bronwyn – you have both been an incredible source of support over the past 3.5 years, and more so over the last 6 months. I hope you both get to enjoy the retirement you deserve. Thank you to my brother Jake, and my sister Katie. You have both been a great source of support throughout my academic career. Thank you to all my friends for their constant support and presence in my life. To all my family and friends, I hope I have made you proud and I hope this thesis reflects everyone's support in my journey so far. I love you all dearly.

Preface

This thesis is for the Degree of Philosophy and is in the format of conventional thesis. The thesis abides by ‘Procedures for Presentation and Submission of Thesis for Higher Degrees – University of Technology, Sydney; Policies and Direction of the University’.

The research design and data collection by the candidate has resulted in four manuscripts being published in peer-reviewed journals and one manuscript under review. The thesis begins with an introduction to provide a background to the research and the research problem, followed by the purpose and significance of each study and their integration with one another. This is followed by a literature review which provides an overview of how complex systems operate in team sports, the characteristics that relate to team sport and how this framework relates to enhancing our understanding of behaviour in Australian football. Each study that follows is presented in manuscript form as submitted to and accepted for publication in peer-reviewed journals. The manuscripts include an abstract, introduction, methods, results, discussion, conclusion and references. Figures and tables appear in the thesis within each manuscript as they appear in publication. Following the final study of the thesis, a general discussion chapter is presented, reviewing and integrating the main findings of the thesis into current literature and presenting an adapted framework, with due consideration of the limitations of the thesis. The final chapter provides a summary of the contribution of the thesis and directions for future research. The University of Technology Sydney (Harvard) referencing style is used throughout this thesis, with a list of references provided in Chapter 11.

Publications Arising from the Work Undertaken in the Thesis

Tribolet, R., Sheehan, W.B. Novak, A.R., Watsford, M.L. & Fransen, J. (2021), How does practice change across the season? A descriptive study of the training structures and practice activities implemented by a professional Australian football team, *International Journal of Sports Science and Coaching,* DOI*:* 10.1177/17479541211019829.

Tribolet, R., Sheehan, W.B. Novak, A.R., Watsford, M.L. & Fransen, J. (2021), A descriptive and exploratory study of factors contributing to augmented feedback duration in professional Australian football practice, *International Journal of Sports Science and Coaching,* DOI: 10.1177/17479541211037038.

Tribolet, R., Sheehan, W.B. Novak, A.R., Watsford, M.L. & Fransen, J. (2021), Factors associated with cooperative network connectedness in professional Australian football practice, *Science and Medicine in* Football, DOI: 10.1080/24733938.2021.1991584.

Tribolet, R., Sheehan, W.B. Novak, A.R., Rennie, M.J., Watsford, M.L. & Fransen, J. (2021), Match simulation practice may not represent competitive match play in professional Australian football, *Journal of Sports Sciences,* DOI: 10.1080/02640414.2021.1995245.

Tribolet, R., Sheehan, W.B. Novak, A.R., Watsford, M.L. & Fransen, J. (2021), An observational study of player behaviours under varying task constraints in professional Australian football players, *In Preparation*.

Related Publications throughout Candidature

Obrien-Smith, J., **Tribolet, R.,** Smith, M.R., Bennett, K.J.M, Pion, J., Lenoir, M., & Fransen, J. (2019), The Use of the Körperkoordinationstest für Kinder in the Talent Pathway in Youth Athletes: A Systematic Review, *Journal of Science and Medicine in Sport*, DOI: 10.1016/j.jsams.2019.05.014.

Sheehan, W.B., **Tribolet, R.,** Rennie, M., Novak, A., Watsford, M., & Fransen, J. (2020), Using cooperative networks to analyse behaviour in professional Australian Football, *Journal of Science and Medicine in Sport,* DOI: 10.1016/j.jsams.2019.09.012.

Sheehan, W.B., **Tribolet, R.,** Rennie, M., Novak, A., Watsford, M., & Fransen, J. (2020), Improving the interpretation of skill indicators in professional Australian Football, *Journal of Science and Medicine in Sport*, DOI: 10.1016/j.jsams.2020.01.016.

Toum, M., **Tribolet, R.,** Watsford, M. & Fransen, J. (2020), The confounding effect of biological maturity on talent identification and selection within youth Australian football, *Science and Medicine in Football*, DOI: 10.1080/24733938.2020.1822540.

Sheehan, W.B., **Tribolet, R.,** Novak, A., Spurrs, R., Watsford, M., & Fransen, J. (2020), Simplifying the complexity of assessing physical performance in professional Australian Football, *Science and Medicine in Football*, DOI: 10.1080/24733938.2020.1745264.

Sheehan, W.B., **Tribolet, R.,** Novak, A., Fransen, J. & Watsford, M. (2021), An assessment of physical and spatiotemporal behaviour during different phases of matchplay in professional Australian football, *Journal of Sports Sciences*, DOI: 10.1080/02640414.2021.1928408.

Sheehan, W.B., **Tribolet, R.,** Watsford, M., Novak, A., Rennie, M.J. & Fransen, J. (2021), Tactical analysis of individual and team behaviour in professional Australian football: Original investigation, Science and Medicine in Football, DOI: 10.1080/24733938.2021.1923792.

Fransen, J., **Tribolet, R.,** Sheehan, W.B., McBride, I., Novak, A.R. & Watsford, M.L. (2021), Cooperative passing network features are associated with successful match outcomes in the Australian Football League, *International Journal of Performance Analysis in Sport,* DOI: doi.org/10.1177/17479541211052760.

Conference proceedings and abstracts

Tribolet, R., Sheehan, W.B. Novak, A.R., Rennie, M.J., Watsford, M.L. & Fransen, J. (2021, November 26-27). Assessing player adaptability in team sport: A quasi-experimental study in professional Australian football players, Presented at the Australasian Skill Acquisition Network Conference.

Statement of Contribution by Others

This thesis details original research conducted by the candidate at the Sydney Swans Football Club while enrolled in the Faculty of Health at the University of Technology Sydney. The thesis includes research articles of which I am the lead author and was primarily responsible for the conception and design of the research, ethical approval to conduct the research, data collection, analysis and interpretation, manuscript preparation, and correspondence with journals.

Where explicitly acknowledged in each experimental chapter, a number of individuals have contributed to the research presented in this thesis.

- Dr. Job Fransen: Study design, data analysis, interpretation and manuscript review
- Assoc Prof Mark Watsford Study design, data interpretation & manuscript review
- Dr. Andrew Novak: Data analysis and interpretation, & manuscript review
- Will Sheehan Data interpretation & manuscript review
- Michael Rennie Data interpretation & manuscript review

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Date: ……………………………

COVID-19 Impacts on the Research

COVID-19 had a significant impact on my ability to design research studies and collect data related to this thesis and subsequently, execute research studies. A number of limitations arising from COVID-19 have affected this, including:

- An inability to access research participants as a result of government restrictions. Additionally, my embedded position in an Australian Football League (AFL) club meant further restrictions were placed on which staff had face-to-face contact with the playing group when government restrictions did begin to ease
- An inability to collect data for a whole season as a result of government and AFL restrictions
- An inability to liaise and discuss potential research study designs and their implications with key personnel in the AFL organisation due to government and AFL restrictions

Collectively, the restrictions implemented by government resulted in an inability to access research participants and collect data for a whole season. Additionally, the relationship with the industry partner was subsequently affected as a result of disrupted communication. Although not tangible, it had an impact on the 'buy in' from key stakeholders (e.g. coaching group) upon resumption of normal training. This also had an impact on the overall impact and outcomes of this PhD thesis.

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Thesis Abstract

Australian football (AF) is a dynamic and complex team evasion sport, which demands high levels of team and individual skilfulness. From an ecological dynamics perspective, AF performance is a complex system characterised by dynamic interactions between the players and the environment. These interactions provide collective opportunities for action through shared affordances and consequently, players' decisions and actions are influenced by many different sources of information. Coaches' manipulate and implement different activities in practice, attempting to change or reinforce certain behaviours and to ultimately have this behaviour transfer to match-play. In practice, coaches' typically rely on experiential knowledge (intuition, 'gut feel') to design practice, typically without using empirical information. There has been little evidence supporting the use of objective data to aid decision making systems for practice design in AF and therefore the sequence of studies presented in this thesis aimed to provide insights into this important area of inquiry.

Study One revealed that coaches' changed the frequency of practice types across pre- and in-season, in addition to the duration of the practice type activity. Furthermore, coaches' implemented more training-form activities during pre-season than in-season. *Study Two* demonstrated that feedback intervention frequency and practice time along with the interaction between both were associated with the amount of augmented feedback provided by coaches', explaining 65% of the variance. *Study Three* explored the factors and constraints explaining Connectedness, a particular cooperative passing network variable associated with successful AF performance. The results demonstrated that the time in the small-sided game (SSGs) activity and the number of shots at goal explained 65% of the variance in Connectedness scores. These findings provide possible applications about how constraints can be manipulated to elicit favourable cooperative behaviours. *Study Four* showed goals were scored more frequently with less passing actions per minute during match simulation than during competitive games. Furthermore, the receiving and distributing passing networks during simulations were more centralised (reliance on fewer key individuals), with less turnovers and tackles per minute compared to match-play. Such differences have implications on skill transfer to competitive environments. *Study Five* investigated individual level changes in individual and integrative levels of behaviour across six conditions (SSGs, match simulation and AFL match-play), suggesting no or negligible changes for integrative measures across changes in condition. Individual level behaviours demonstrated varied responses across changing conditions.

Overall, the findings of this thesis can enhance current practice design in team sport settings and guide future empirical research.

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List of Abbreviations

AF	Australian football
AFL	Australian Football League
AFLW	Australian Football League Women's
AIC	Akaike information criterion
β	beta
χ^2	Chi square value
CI	Confidence interval
CNS	central nervous system
d	Cohen's d effect size
df	Degrees of freedom
DST	Dynamical systems theory
ED	Ecological dynamics
GPS	Global positioning systems
HB	Handball
IPT	Information processing theories
JASP	Jeffrey's amazing statistics program
KPI	Key performance indicator
MANOVA	Multivariate analysis of variance
m^2	Metres squared
mins	Minutes
N	Number of
η^2	Partial eta squared
r	Pearson correlation
Q-Q	Quantile-quantile
SD	Standard deviation of the mean
SSGs	Small-sided games

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Chapter 1 | Introduction

Background

Performance in team sport is underpinned by the players' and team interacting with their environment (Davids et al., 2003). Here, the environment helps shape decisions and actions made by the performers. For example, a soccer player may recognise an opposition player in dangerous space near the goals and come off their opposition player to defend the other player. In response, a teammate may then identify this occurring and subsequently cover the previous defender's opposition player. The players' must dynamically interact to achieve a common task goal of preventing the opposition team scoring. As a result, the changes in information in the players' environment influence the actions players make. These behaviours can be considered in light of the Ecological Dynamics (ED) framework. ED is an established multidisciplinary framework that integrates perspectives and insight from dynamical systems theory (Clark, 1995; Kugler et al., 1980) and ecological psychology (Gibson, 1979). The integration of these two theories assists practitioners and researchers in sport to explain how coordinated behaviour in players and teams emerges as a result of the performer-environment relationship. As such, the ED approach presents as an interesting avenue to observe, explain and develop collective behaviour in sport (Duarte et al., 2013).

In team sport, ED shows that the perception of relevant information helps players self-organise into functional coordinative patterns that aim to overcome the opposition (Davids et al., 2003; Pinder et al., 2011). However, whilst competition is a valuable source of learning and development, coaches' manipulate the practice environment in attempts to optimise match day performances by the players' and team. Here, ED forms the foundation of several coaching and pedagogical approaches, such as the constraints-led approach, where characteristics of the individual, environment and task interact and are altered to elicit functional coordinated behaviour (Davids et al., 2008; Handford et al., 1997). The constraints-led approach is a practical method to implement the ED framework into practice design. According to the constraints-led approach, skilled behaviour emerges through the interaction of individual, environmental and task constraints (Clark, 1995; Newell, 1986). Here, coaches' aim to design practice environments that represent competition and enhance the transfer of skill. The transfer of skill likely comes from the similarity of information between practice and competition that the players' and teams use to make decisions. This has been termed 'representative learning design'.

Representative learning design emphasises action fidelity, i.e., maintaining the relationship between actions in competition and emulating that in practice environments, and functionality i.e., the information to make decisions is similar between competition and practice (Pinder et al., 2011). To help optimise action fidelity and functionality, coaches' and practitioners' should aim to manipulate constraints that sample the constraints players' and team interact with during competition. For example, a coach can make the field size smaller to increase the amount of defensive pressure on players' passing in an association football small-sided game. Here, differences in constraints between practice and competition may compromise skill transfer and affect the players' and team's ability to perform behaviours acquired during practice to competition. For example, Greenwood and colleagues (2016) investigated the impact the presence of an umpire has on cricket bowling run-up patterns. These authors demonstrated that action fidelity is impacted when key ecological constraints are omitted such as an umpire, creating non-representative practice conditions. Thus, it is important that the constraints sampled during practice represent competition. Whilst Greenwood and colleagues (2016) demonstrate how omitting key constraints impact behaviour, recent research has investigated how movement patterns can be improved by using the constraints-led approach. For example, Verhoeff and colleagues (2020) provide exercises to improve key components of the power clean (weightlifting movement). Specifically, they detail an analysis of areas that performers' may make mistakes in and how constraints can be implemented for the performers' to find their own solution i.e. self-organise into an effective solution. Moreover, two training methods, one designed to encourage self-organisation (differential learning and the constraints-led approach) and the other being a traditional prescriptive instructional approach, were compared when aiming to optimise baseball batting performance (Gray, 2020). The author determined the self-organisation methods and in particular, the constraints-led approach, showed greater improvements in post-tests as well as retention tests one month later (Gray, 2020). Here, the constraints-led approach is considered as a "guided" exploration of movement solutions to the constraints presented to the performer. Thus, it is important to note how the omission or inclusion of constraints can help encourage targeted behaviours and how a carefully designed practice environment can enhance skill transfer to competition.

Australian Football (AF) is an intense, intermittent team sport where players' require physical prowess along with high levels of skilfulness (Gray & Jenkins, 2010; Johnston et al., 2018). Players' within teams must cooperate effectively to use a variety of tactical strategies to score points and prevent the opposition from scoring points (Alexander et al., 2021). The tactics for each team will differ depending on player availability, coaching philosophy, the opposition team and contextual factors, such as the match venue or the weather. Within competitive AF matches, players' and teams' perceive (shared) opportunities for action which guide decision-making and subsequent action (Sheehan et al., 2021). Here, relevant sources of information help players' and teams' elicit functional states of behaviour to help achieve the task goal(s). Subsequently, the challenge for coaches' and practitioners' is the process of emulating these key sources of information that guide action in matches, to the design of effective practice environments. One potential method to measure and monitor whether this is occurring during practice is to rely on the foundational principles outlined in the constraints-led approach, such as using an interaction of constraints to influence skilled behaviour, coupling perception with action to maintain key informational sources and acknowledging the complex systems characteristics exhibited by sports teams, to name a few. For example, Brown and colleagues (2020) identified that the frequency and interaction of constraints during AF practice differs considerably to Australian Football League (AFL) matches. Specifically, the time in possession of the ball was larger in practice and the pressure players were influenced by when disposing possession was substantially lower in practice compared to competitive matches. Whilst representative learning design advocates for practice to continually emulate the constraints players' and teams' interact with during competition to help optimise skill transfer, further research is required to assess what coaches' currently implement in relation to skill acquisition literature. Furthermore, the practice environments implemented by coaches are typically designed on intuition, 'gut feel' and prior playing experience, but not on the results of empirical study (Greenwood et al., 2012; Lyle & Cushion, 2010). Consequently, the addition of empirical knowledge and objective data can help compliment the experiential knowledge the coaches' possess.

Currently, skill acquisition research in AF is limited. A structured empirical investigation into practice design, which integrates experiential knowledge from coaches, would benefit skill acquisition outcomes and provide unique insight into skill acquisition in team sport and AF specifically. Moreover, using the constraints-led approach in addition to an integration of skill and tactical measures would help increase the efficacy of practice by enhancing its representativeness to competitive matchplay and increasing the awareness of where levels of representativeness may be lower in specific practice activities. Indeed, the most beneficial approach to improving skill acquisition outcomes is to integrate experiential and empirical knowledge together (Renshaw et al., 2019; Woods et al., 2021), which is the ultimate aim of this thesis.

Research Question

Despite recent research focussing on how constraints influence player behaviour in AF, there are few studies conducting skill acquisition research monitoring player behaviours as a result of coach manipulations made to practice environments *in situ*. Currently, the available research has provided a broad understanding of ED principles and how they relate to gameplay in AF. Moreover, research has provided recommendations on how specific constraints such as time in possession or the type of pressure encountered when disposing the ball, may be manipulated to improve representative learning design (Browne et al., 2019; Browne et al., 2020; Teune et al., 2021). Whilst these studies provide a greater knowledge on how constraints influence player behaviours during practice and competitive matches, there is limited evidence observing and capturing the naturalistic behaviour of coaches' in relation to practice design using the constraints-led approach. Furthermore, measuring and integrating the behaviour of players' and teams' in response to manipulations in constraints can help identify whether such manipulations are beneficial for team behaviour in comparison to competitive matches. To date, no research has investigated how interacting constraints influence individual player and collective team behaviour.

Contemporary research has also compared interacting constraints within different activities during practice (Browne et al., 2020). These comparisons help inform practice design and help identify which activities are more or less representative of AFL matches. Whilst these studies have assessed interacting constraints when player's dispose of the ball, there has been no integration of collective team level comparisons between practice activities and competitive matches. Research into this area would help provide a detailed insight into what team measures differ between practice and competition and how coaches' may be able to use the constraints-led approach to manipulate practice to optimise its representativeness. Collectively, this thesis aims to address these questions and provide thorough empirical research to help inform the coaches knowledge in professional AF.

Consequently, the generation of five research questions sought to address the aims of this thesis. The research questions asked were:

1) How do coaches currently design practice across a season and what value do they place on different practice types?
2) Which factors explain the duration of augmented feedback coaches provide to the team during practice?
3) Which factors can coaches manipulate during practice using the constraints-led approach to influence favourable collective tactical behaviour metrics?
4) Which differences exist (if any) between the most representative form of practice i.e. match simulation, and competitive Australian Football League matches?
5) In which way do professional Australian football players change their cooperative and individual behaviours when space per player (m^2) is manipulated during practice?

Research Objectives

A series of studies have been conducted to address these research questions. *Study One* investigated the value coaches' place on certain practice types and activity forms by observing changes in practice throughout a full AFL season. *Study Two* examined how often coaches' provide augmented feedback during different practice types and activity forms. As such, *Study One* and *Study Two* provide a *status quo* in terms of coaches' implementations of practice design and augmented feedback. *Study Three* monitored the changes in constraints coaches' manipulate within one small-sided game and assesses the subsequent tactical behaviours exhibited by the team. The findings of *Study Three* helped provide tangible constraints that coaches' can manipulate to elicit higher or lower cooperative passing network values (specifically, network connectedness). *Study Four* assessed the difference between match simulation and competitive AFL matches across tactical passing network metrics, skill metrics and task constraints. The findings of *Study Four* provided insight into the differences between the 'most' representative practice activity i.e., match simulation, and competitive matches, and across a range of variables. Coaches and practitioners can use the results from *Study Four* to understand the value of match simulation and to aid the near skill transfer from match simulation to competition. *Study Five* investigated individual and integrative levels of behaviour under varying task constraints and demands. The results of *Study Five* indicated no or negligible changes to integrative level measures and varying responses across conditions for individual level behaviours. These findings highlight the (in)stability of individual and integrative level behaviours across changing constraints. Coaches' may use these results to help guide practice design in Australian football. A schematic representation of the thesis is represented in Figure 1.1.1.

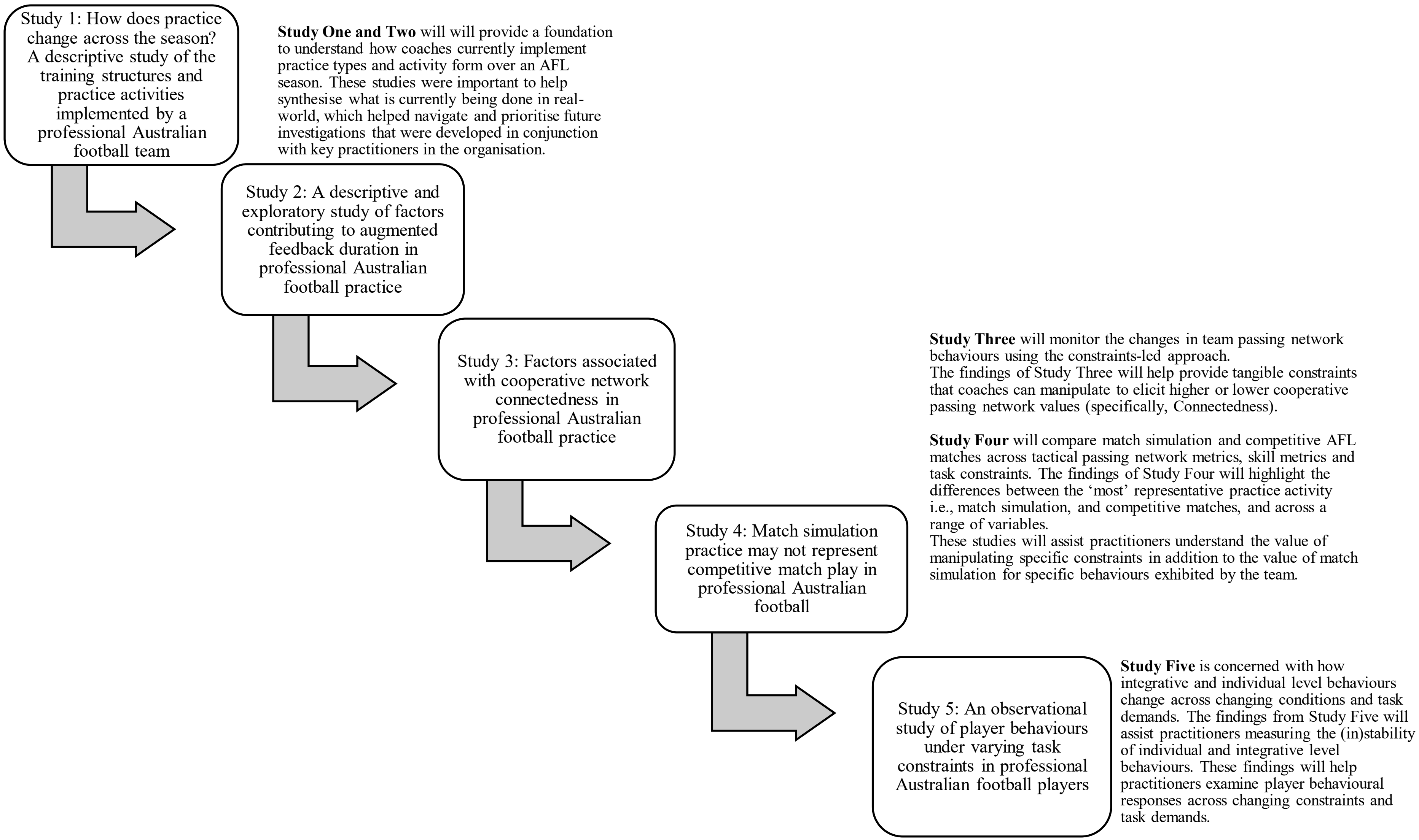

Figure 1.1.1: Schematic representation of the thesis.

Study One – How does practice change across the season? A descriptive study of the training structures and practice activities implemented by a professional Australian football team

Purpose: To examine how coaches' implement different practice types and activity forms over a full AFL season and subsequently show that engagement in different practice types can be objectively monitored to provide valuable information about practice design.

Significance: This observational study established how coaches' currently value different types of practice across the season and whether this changes across pre- and in-season periods. Specifically, the study quantified the exposure (time and frequency) to certain types of practice. The findings will help provide insight on how coaches' design practice and will help to guide future investigative research within the organisation.

Study Two – A descriptive and exploratory study of factors contributing to augmented feedback duration in professional Australian football practice

Purpose: To explore which factors are associated with the terminal augmented feedback coaches' provide during practice to the whole team.

Significance: Research has yet to investigate the factors that contribute to augmented feedback coaches' provide. Whilst intuition suggests coaches implement feedback based on factors such as the practice type, time of season, the duration of the practice activity, to name a few, no evidence exists to create informed strategies. This exploratory study assessed the factors which contribute to augmented feedback to help optimise its delivery during practice.

Study Three – Factors associated with cooperative network connectedness in professional Australian football practice

Purpose: Using the constraints-led approach, *Study Three* aimed to investigate which constraints influence the cooperative passing network metric "Connectedness". Previous research has suggested higher Connectedness scores show a strong relationship with winning competitive AFL matches. Thus, team passing behaviours were observed during a commonly implemented small-sided game over the course of one AFL season and subsequently analysed to examine team cooperation.

Significance: Constraints such as space per player (m^2), field length and width, player numbers and time in the practice activity were used in the exploratory analyses. These findings assisted with the establishment of metrics that coaches' and practitioners' can manipulate, using the constraints-led approach, to enhance Connectedness scores. Additionally, these results can assist performance analysts when notating specific metrics during practice activities.

Study Four – Match simulation practice may not represent competitive match play in professional Australian football

Purpose: To evaluate the similarity of match simulation in practice to competitive AFL matches. The analyses aimed to assess whether match simulation adequately samples the task constraints, skill and tactical behaviours of competition.

Significance: Whilst existing research has commenced the assessment of the differences between match simulation and competitive matches, this study extends on previous investigations by incorporating cooperative passing network metrics and collective skill metrics in the analyses. This study aids in the understanding of whether match simulation effectively samples both individual and cooperative behaviours observed in competitive matches. These results will have implications for practice design in team sport.

Study Five – An observational study of player behaviours under varying task constraints in professional Australian football players

Purpose: Skilled behaviour can be considered as the ability to perform skills under a variety of constraints. This study will examine how individual skill behaviours are different between six different game conditions (small-sided games, match simulation and competitive AFL matches). This study aims to examine the degree to which players adapt individual and cooperative behaviour to changes in task constraints across commonly used small-sided games, match simulation practices and competitive games.

Significance: The findings from this study can be used to provide coaches' insights into how their practice design could elicit certain particular player behaviours. Moreover, the results will help coaches, performance analysts and sport scientists monitor how individual and integrative levels of behaviour in individuals change as a result of task constraint manipulations to space per player and game type. This study will help consolidate a combination of experiential and empirical knowledge to guide practice design in AF using the constraints-led approach.

Limitations and delimitations

Whilst this thesis was embedded within a professional Australian football team and hence provides valuable insights into the practices and behaviours of expert coaches and players, some limitations must be considered. Only one professional AF team was analysed. Thus, limitations such as the coaching group, the calibre of the team studied and injuries within the team, to name a few, must be considered when interpreting the results. This also means that results obtained in this thesis cannot necessarily be generalised to other AFL teams or AFL players and coaches as a whole. Furthermore, given the practical constraints involved with practice observations, there was only one coder observing and notating practice. Whilst this researcher has over 300 hours experience and there were high-levels of agreement using intra-class correlation coefficients between washout periods when coding, this must be considered. Lastly, injuries in team sport are prevalent and must be considered in this thesis. Subsequent injuries may lead to players missing training sessions, specific activities or competitive matches, leading to data inconsistencies. The statistical approaches used mitigate some of the concerns with missing data, but it is important readers consider the implications of these limitations.

There are also some delimitations of the thesis to be considered. Firstly, the data was collected and analysed within a professional AFL team. Subsequently, this cohort may be classified as an expert sample within Australian football. Secondly, Australian football is an evasive and dynamic team sport with similarities to other team sports such as association football, hockey and basketball, to name a few. As such, there may be methods and findings from this thesis that apply to other team sports, even when findings in the sample used in this study cannot be generalized. Lastly, the thesis was directly linked and related to skill acquisition concepts whilst also integrating input from professional coaches. This strongly reflects the contemporary practices of skill acquisition specialists and performance analysts embedded within professional sport and makes the findings from this research thesis particularly relevant to them.

Summary

The studies in this thesis aim to provide an evaluation of how coaches' currently prescribe practice and how the constraints-led approach is used in professional AFL. Furthermore, this thesis aims to provide insight into the practice activities coaches value over a season, how constraints may influence collective behaviour metrics and how practice design can be evaluated from individual and integrative behaviour measures. The naturalistic approach used to collect data throughout this thesis ensures that the relevant questions being asked by the industry are approached with an empirical lens. Collectively, these studies offer enhanced understanding into how analysts, coaches and researchers can integrate experiential and empirical knowledge into practice design in team sport. Future research questions are presented and discussed.

Chapter 2 | Literature Review

2.0 Overview

The following chapter provides an overview of research on skilled behaviour in team sport. The first section comprises a narrative review that examines the Ecological Dynamics (ED) framework, its components (ecological psychology and dynamical systems theory) and how it applies to the study of team sport performance. The review then outlines how coaches' and practitioners' may use a pedagogical approach based on the ED framework, the constraints-led approach, to help facilitate how players' and teams' learn and develop skilled behaviour in team sport. The review evolves into a discussion on representative learning design using the constraints-led approach and what implications this approach has for coaches', practitioners' who work closely with coaches such as skill acquisition specialists, performance analysts and sports scientists. Next, the review applies principles and characteristics of ecological dynamics to Australian football (AF), a team sport characterised by high levels of complexity and skilled behaviour. Lastly, the review outlines how the constraints-led approach may be used to help inform practice design in Australian football. A summary with implications and current research problems is then presented and discussed. The purpose of the narrative review was to provide an overview of ecological dynamics and how it relates to practice design in team sport, and in particular, AF. The aim was to provide information on practice design, and in particular, representative learning design and ecological dynamics. Current evidence in AF research is then presented and future avenues for research are outlined.

2.1 Theoretical bases of skilled behaviour in team sport

Within team sport, players on the same team form a unique and dynamic interaction to achieve a common outcome and/or task goal (Silva, Garganta, Araújo, Davids & Aguiar, 2013). For example, members' of a football team exert defensive pressure as a cohesive unit, in order to prevent the opposition team from scoring. The ability to coordinate and behave synergistically with teammates is of paramount importance to a team's success (Silva et al., 2013). However, team behaviour is a complex phenomenon, influenced by a myriad of factors such as the team's experience and expertise, the contextual circumstances and the task goal, and therefore its conceptualisation is not well understood in the research literature. Research has attempted to further the understanding of the complexities of collective behaviour in sport, particularly by investigating how members of sports teams coordinate their actions to achieve a common goal (Ometto et al., 2018).

Traditionally, understanding team coordination involved the idea of group cognition, which was based on shared, internalised knowledge among all team members (Silva et al., 2013). This idea premised the team having a mental representation responsible for regulating their in-game behaviour (Silva et al. 2013). This was founded on information processing theory (IPT), a theory influenced by computer processing analogies that coincided with rapid advancements in technological capacities. In IPT, the role of central structures in movement control are modelled on electronic and mechanical storage devices to represent how information is represented in the Central Nervous System (CNS). According to IPTs, movement control is a result of the performer moving through discrete cognitive stages that involve perception, information processing and movement execution (Keele and Posner, 1968; Schmidt and Wrisberg, 2000). As such, IPT emphasises the role played by the CNS to produce consistent and reliable movements. However, these theories can be criticised on the basis that the storage and processing capacities of the CNS are limited, and therefore the exclusive use of IPT to understand the vast complexities related to interacting with dynamic environments is questionable. Indeed, Clark (1995) emphasises that the reliance purely on stored and retrieved representations of behaviour in humans' is not a feasible explanation for the way humans' interact with their environments using motor skills, due to the complexity of the organism and the dynamic nature of performance environments. For example, it is unlikely that an individual acts in a 'what if' fashion when counterattacking, where the perception of an opposition player's position, the processing of that information, and the execution of a counterattack are solely the result of a mental representation. After all, successful sports athletes are adaptable, and likely possess the ability to perceive an opposition player's position before transitioning into a counterattack, while minimising the amount of cognitive processing required under the immense time pressures related to competition.

There are, however, alternative views that help explain the complexities of collective behaviour in sports teams, which do not overemphasise shared memory representations. For example, a team's behaviours can be considered from an ED perspective. This theoretical framework borrows concepts from the *Brunswikian* (Brunswik, 1952; 1956) or *Gibsonian* (Gibson, 1979) view of ecological psychology (i.e. the study of the interdependencies of humans and their environment) and dynamical systems theory's perspectives on how humans' solve vastly complex *degrees of freedom problems* (Bernstein, 1967) by exploiting the self-organisational tendencies of the human body when adapting our coordination patterns to changing environmental circumstances (Kelso 1981, 1984; Newell, 1986; among many others). Given the dynamic and ever-changing nature in which athletes perceive and act, and that athletes themselves are but agents acting independently as members of a collective unit in sports teams, the ED approach has been presented as an interesting avenue to observe, explain and develop collective behaviour in sport (Duarte et al., 2013). The unique and unifying contributions from ecological psychology and dynamical systems theory within the ED framework provides a basis for the understanding of concepts such as non-linearity, self-organisation, attractors and stability, self-emergent behaviour, perception-action coupling, affordances and interacting constraints within the confines of team sport (Clark 1995; Davids, Button & Bennett 2008). As such, this framework will be used throughout this thesis to underpin the measurement and development of collective behaviour by emphasising the emergence of coordinative, patterned relationships between and within performers in team sports.

2.2 The Ecological Dynamics framework applied to team sport

The ED framework is predicated on the relationship between the individual and their environment and has the potential to better explain behaviour in team sport compared to traditional theories that neglect principles of human behaviour. Within these principles, there are many concepts, both from dynamical systems theory (e.g. self-organisation) and ecological psychology (e.g. direct perception), that help explain how and why human behaviour in team sport occurs. It then becomes relevant because it allows practitioners' to explain how individuals within teams, and teams themselves act with such expertise, even though their behaviours are potentially influenced by an enormous number of factors. This review will attempt to explain how these concepts are applicable for assessing team sport training and how it relates to developing expertise in team sport.

From the dynamical systems perspective, a sports team exhibits coordination and control tendencies, aimed at efficiently achieving a task goal. For example, basketball teams use attacking and defensive strategies, with players in different field positions executing predetermined offensive or defensive roles, in order to outscore their opponent. Each performer is a complex neurobiological system that can be considered an independent but interacting degree of freedom, acting within a larger system (i.e. the team unit). Bernstein (1967) proposed this idea of *degrees of freedom* to capture the complexity of human movement. After all, from the day humans are born we are accustomed to acquiring motor skills that are refined over a lifetime to allow efficient and coordinated action when moving about in our environments. However, Bernstein was concerned with how humans' achieve such levels of control when interacting with their environment, despite the vast complexity or *degrees of freedom* involved in regulating movement. For example, the human body consists of several hundreds of degrees of freedom (e.g. joints, muscles etc), which need to be coordinated to produce purposeful movement, often described as 'Bernstein's degrees of freedom problem'. However, through experience and practice, humans' develop the ability to form functional and efficient coordinative linkages, which in turn limit the number of *degrees of freedom* that need to be controlled in the production of purposeful action. In other words, humans' learn to overcome the complexity related to produce purposeful human motor behaviour by 'solving the *degrees of freedom problem*'.

In team sport, and when taking into account the complexity of coordinated team behaviour, these same coupled degrees of freedom are formed through player interactions and are manifested through coordinative structures (e.g. defensive or offensive *shape*, collective actions when regaining possession after a turnover, etc.), which can dissipate and emerge due to the potential for non-linearity in behaviour (Kugler et al., 1980). The emergence and dissipation of coordinative structures, according to dynamical systems theory, is influenced by the boundaries in which the system acts. These boundaries are commonly referred to as constraints (Clark 1995). For example, the strength of an opposition team is a constraint that influences the emergence of defensive coordinative structures in a soccer team, where stronger oppositions make a team's defence sit further back to absorb offensive pressure. Another example is the size of the field and subsequent space a soccer practice drill takes place in, which constrains movement behaviours like the type of skills performed (short passes) and running velocities (high accelerations). Newell (1986) described that not only the acquisition, but the development of movement skill and behaviour is a result of the complex interaction of three types of constraints: individual/organismic, task, and environmental (Figure 2.2.1).

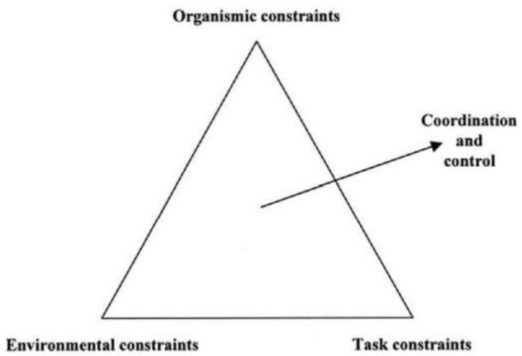

Figure 2.2.1: Newell's model of interacting constraints (Newell, 1986).

Another crucial concept in dynamical systems theory is self-organisation. Complex systems that consist of independent and interacting components, like a sports team, are governed by principles of non-linearity and spontaneous organisation and patterning (Clark 1995). Applied to sports teams this means that when a team self-organises, it seeks to achieve an efficient and stable state of coordination (i.e. an attractor state) that can resist external perturbations. For example, if a turnover occurs in soccer, the defending team will self-organise into a formation and structure where a goal is difficult to achieve for the opposition. However, if the self-organised defensive structure is not sufficiently stable, it may be easily perturbed by the attacking teams' manoeuvres. Therefore, many teams train these defensive structures during practice, to allow a stable patterned relationship to emerge within the team, which can then be replicated in the context of competitive play. Specifically, Figure 2.2.2 alludes to this. The regions in Figure 2.2.2 where this occur is at the bifurcation points (curved lines). For example, when defenders are slow to react and the space to their nearest teammate is large, the solution to prevent the opposition from scoring is difficult to organise into (green arrow and circle). Through specific practice and experience, teams attune to specific information to improve their organisational solution to a turnover. Therefore, the possible problems and different contexts a turnover occurs in during match-play are able to be successfully overcome through a stable defensive structure that is adaptable to different spacings to teammates and different reaction times to turnovers (blue arrows and circles), preventing the opposition from scoring.

Thus, to create stable attractors as a result of practice, practitioners' must be aware that there are numerous potential solutions that can emerge within a team's structure and patterning. In order to 'push' or 'nudge' the behaviour of a team towards a more effective attractor in the perceptual-motor workspace (i.e. all the potential solutions the team can organise into), practitioners' and coaches' can manipulate control parameters (i.e. constraints that alter the behaviour of the system towards a new attractor) which in turn influence the order parameters (i.e. the systems organisation and behaviour) of the system. This process is described in Figure 2.2.2. In practice, coaches' may manipulate the task constraints that form the boundaries for behaviour. For example, they may increase or decrease the defensive pressure on a team during a modified game by increasing or decreasing the available place per player, in order to manipulate the attacking and defensive behaviour of each team. For example, minimising the available space per player within a modified game will likely result in structured defence and increased contact for the defensive team, while the attacking team will need to move the ball quickly in order to stretch the defence and create scoring opportunities.

Interestingly, such a system, whose coordinative structures are dynamic, generally needs little or no explicit direction (e.g. by coaches') since its organisation is mainly governed by dynamical systems laws (Kugler et al., 1980). Therefore, through the manipulation of learning environments, coaches' manipulate components of the performance environment (i.e. the interaction of constraints) to implicitly produce skilled behaviour that leads to beneficial system (re)organisation that transfers to match-play.

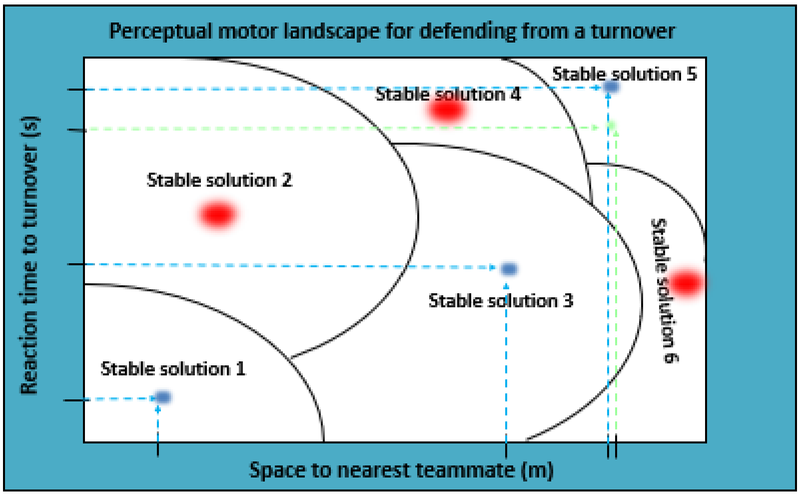

Figure 2.2.2: A schematic adapted from Davids and colleagues (2012) depicting the relation of two constraints forming a control parameter of the system within the teams perceptual-motor landscape. With different combinations of space to the nearest teammate(s) and reaction time(s) to the turnover, stable solutions emerge and disappear.

Similar to dynamical systems theory, ecological psychology provides useful concepts related to collective behaviour in team sport. Ecological psychology details that actions and behaviours require coordination between a) the organism and its relevant components, and b) the environment and the information it provides. For example, Gibson (1979) proposed his theory of direct perception, in which it was argued that humans' identify and use invariant sources of information in their perceptual array by moving about in their environment. As a result, they can use environmental information as opportunities for action, without the need for substantive cognitive processing. For example, a player can see that a teammate is in a favourable goal scoring opportunity and pass to them. This decision may take less than half a second to make. The concept of direct perception argues that this player did not have to calculate the angle and velocity of their kick, where they needed to put their ankle in relation to their knee and hip when they contact the ball etc. The environment provides the player with enough information to invite this decision without significant cognitive input from the performer (Farrow et al., 2013). This theory gave way to the concept of perception-action coupling to describe the concepts related to direct perception (Anson, Elliot & Davids, 2005; Handford et al., 1997). Gibson's theory stands in stark contrast to the IPTs discussed earlier, which argues that indirect, rather than direct perception, where the performer needs to make sense of information before action on it (i.e. the perception, processing, action cycle) is responsible for perceptual-motor control. Even though concepts from both theories can be integrated (Anson, Elliott & Davids, 2005), the ecological approach better accounts for the way athletes move about in and interact with highly dynamic performance environments.

In ecological psychology, the cyclical relationship between perception and action in the system and the environment it behaves in, also called perception-action or information-movement coupling is of considerable interest. In this cycle, information can constrain action, and action can constrain information perception, which ultimately influences system behaviour (Fajen et al., 2008; Turvey & Shaw, 1999). For example, the tactical instructions from a coach prior to specific practice activities influences how the team and players' behave, which in turn influences the information available to the team that can be acted upon. Previous research has shown teams' receiving different instructions (offensive, defensive or no focal points) behaved differently to one another in association football small-sided games (Batista et al., 2019). Another reason why concepts derived from ecological psychology apply to team sport is because of its relationship to open systems (Handford et al., 1997). An open system is one that describes how neurobiological organisms have variable amounts of energy affecting them, whilst harnessing their own energy sources (Fajen et al., 2008). This causes energy to constantly flow in and out of these systems. For example, the collective behaviour of a team of track cyclists is influenced by perceptual information obtained from feedback from a coach, which in turn forces the cycling team to speed up or slow down by using internal energy sources stored in the cyclists' muscles. As such, the cycling team can be considered an open system, where energy flows freely through the system. Interestingly for those concerned with sports performance, through practice and experience, an organism learns how to exploit the energy and information in the environment to guide action (Davids et al., 2003; Fajen et al., 2008). This exploitation of informational invariants forms the basis of Gibson's (1979) theory of affordances. Affordances are information sources in the environment that provide opportunities for action, through direct perception. This means that by perceiving affordances as invitations for action, the cognitive processing load on the performer decreases significantly. For example, a large amount of space between the defensive line and the goal may afford the attacking player information to run into that space in order to get into a favourable position to score. Once this gap in the defensive line is perceived, it can be acted upon immediately without requiring much cognitive reflection. Anecdotal evidence for the direct way in which experts make decisions exists in correspondence with many coaches and players, who argue they 'intuitively' make decisions, and cannot always verbalise how or why they made these decisions. A particularly interesting anecdote comes from Malcolm Gladwell (2005, p. 49) about how former expert tennis player and coach Vic Braden can predict double faults in tennis serves before they occur:

'*Something in the way the tennis players hold themselves, or the way they toss the ball, or the fluidity of their motion triggers something in his unconscious. He instinctively picks up the "giss" of a double fault. [...] But here's the catch: much to Braden's frustration, he simply cannot figure out how he knows'* (Gladwell 2005, p. 49).

In team sport, information that regulates collective behaviour is shared (Silva et al., 2013). These shared affordances invite actions that are performed collectively. For example, highly trained volleyball teams easily recognise opportunities to attack from the front or back court based on information gathered from the position of their teammates and the opposition (Afonso et al., 2012). Whilst information is of course used at an individual level within team sports (e.g. a goalkeeper may choose to set up a quick counterattack thanks to a highly accurate and powerful throw upon catching the ball directly from a corner kick), information that can be used by all players' as part of the team collectively is crucial for functional coordination patterns to emerge at a team level. Indeed, a sporting team can be trained to become perceptually attuned to shared affordances, which strengthens an attractor state within the teams perceptual-motor workspace. For example, by playing a 6v5 (attack versus defence) small-sided game, the defenders are outnumbered and therefore success in this game is achieved by defending a zone of the field rather than an opposition player. When repeating this action frequently, defenders' become attuned to the perceptual information that is available when using zonal defence, without the need to cognitively overload them with instructions and/or tactical guidelines. In team sport, common affordances are the positioning of teammates and opposition and their motion directions, velocities and changes, and location within the field of play, to name a few (Passos et al., 2008). These shared affordances help stabilise a team's collective behaviour in order to help them achieve task goals such as collectively organising attacking or defending structures (Figure 2.2.2). An effective evaluation of which attractor is 'more' optimal introduces the synergistic roles played by skill acquisition and performance analysis, which will be described later.

Undoubtedly, integrating these concepts from ecological psychology and dynamical systems theory into something practitioners' can use to prepare athletes for competition is difficult. This is further complicated by a lack of understanding around these concepts outside of academic research and by the lack of academic research on how they are directly related to improving team performance and behaviours. Therefore, an integrated framework that combines the application of dynamical systems theory and ecological psychology concepts to team sport is the constraints-led approach. Although the constraints-led approach is not a novel approach to skill acquisition, nor is it reserved only for team sports, its application to measure, understand and train collective behaviour makes it an excellent framework for researchers' and practitioners' interested in collective behaviour of team sports teams and players (Davids, Araujo, Shuttleworth & Button, 2003; Newell 1986). It is therefore the aim of this thesis to investigate the fundamental theoretical concepts discussed above whilst providing applications to team sport practices using the constraints-led approach. Ultimately, this thesis aims to provide applications for team sport practitioners', coaches' and skill acquisition staff members' on how these concepts can be applied and integrated to design learning environments and ultimately improve team performance. Each study in this thesis will be discussed considering key concepts to interpret behaviour in team sport. In summary, Table 2.2.1 describes the main ED concepts and how they relate to team sport.

Table 2.2.1: Some central tenets of the Ecological Dynamics framework and how they relate to team sport

Theory	Concepts	Examples
Dynamical systems theory	*Degrees of freedom* – independent but interacting components (players) that form functional coupling for goal-directed behaviour (Bernstein, 1967)	Players' on the same team get in positions to effectively receive possession of the ball implicitly (i.e. non-verbal sharing of information)
	Self-organisation – spontaneous periods of adjustment or adaptation of system components (Clark, 1995)	After a turnover, the opposition will implicitly self-organise into a defensive structure based on information on who currently possesses the ball
	Constraints – boundaries or limits placed upon the system (Newell, 1986)	Field size, player numbers
	Non-linearity – changes in behaviour can be large and non-proportionate to the size of the change in constraints or the information they provide (Davids et al., 2012)	A small change in task rules can have a large change in cooperative network metrics
	Patterns – even though there is complexity in the system and each component within it, there is effective pattern formation (and all the potential solutions within it) (Clark, 1995)	Teams ability to contract in defence to prevent the opposition from scoring
	Attractors – behaviours that are stable and resistant to external perturbations (Handford et al., 1997)	Defensive structures that are stable and effective are less prone to goals against
Ecological psychology	*Perceptual-motor landscape* – an available 'repertoire' of stable solutions the team can perform	Being able to score a goal in AF through multiple passing channels (same outcome but different process to get there)
	Perception-action coupling – the cyclical relationship between perceiving information and acting on that information (Pinder et al., 2011)	Perceiving the opposition utilises their right foot more and positioning themselves to prevent effective use of that foot
	Shared affordances – the shared opportunities available for the team to utilise for collective action (Silva et al., 2013)	Within practice, attunement to a shared affordance (like when the ball is in the teams attacking half) could consist of opportunities surrounding how to effectively press up and reduce the space the opposition can use to exit effectively
Constraints-led approach	*Newell's model* – details the interaction between task, individual and environmental constraints that lead to behaviour (Newell, 1986)	A combination of individual (e.g. leg strength), environmental (e.g. score of the game or if it is raining) and task (e.g. effectively pass 40m to a teammate) constraints affect how the behaviour emerges and is performed
	Representative design – effectively recreating similar coupling between perception and action to those couplings that exist in the target environment e.g. match-play (Pinder et al., 2011)	Reducing the time allowed with possession before you make a pass in practice, or increasing the pressure from the opposition (as you would observe in competitive matches)
	Adaptability – being able to produce effective and functional movement organisation in different contexts and situations	Making an effective pass under different amounts of pressure and with less time

The ED framework provides insight into the behaviour individuals and teams exhibit in relation to their performance environment. This section has described how ED has important characteristics, such as direct perception, non-linearity of behaviours, degrees of freedom, to name a few, that relate and help explain behaviour in team sport. As such, the theoretical importance of ED is significant. However, to optimise the integration of its key components and characteristics to understanding and improving behaviour in team sport, a pedagogical approach is required to help practitioners' and coaches' implement these key principles. Furthermore, empirical research is required to validate the relevance and applicability of ecological dynamics in team sport. Nonetheless, the constraints-led approach conveys ED principles in a way coaches' and practitioners' can better understand. The next section will describe the constraints-led approach, followed by its application to practice design in team sport.

2.3 The constraints-led approach

The constraints-led approach describes how skilled behaviour emerges through the interaction of three constraints: individual/organismic, environmental and task (Newell 1986; Figure 2.3.1). These three constraints limit, set and/or influence the boundaries the system behaves within (Clark 1995). The individual constraints refer to those properties embodied in the person, for example, an individual's persons height, arm length, decision-making ability, resilience etc. The environmental constraints involve the physical environment (e.g. humidity, temperature, rain) and sociocultural environment (e.g. culture and attitude in a room towards diet). The task constraints refer to the actual task at hand and directly relate to the goal that is to be achieved (Araújo et al., 2006). For example, different behaviours emerge when observing the task of kicking a soccer ball compared to kicking a rugby ball. From an ecological dynamics perspective, movements and behaviours emerge from the interaction of constraints (Davids et al., 2003; Handford et al., 1997). In sport for example, a player may be constrained to only passing to a certain number of players within 30m because their leg strength or kicking technique does not afford them the action to kick a further distance. In other words, their behaviour can only exist within the boundaries set by the individual constraint of leg strength or kicking technique. Conversely, if a field is oval in shape compared to a rectangular field during practice, the attackers would be constrained by the space available to play in and find it more difficult to progress the ball forward, whilst the defenders are afforded more opportunity to press and force a turnover. The shape and size of the field are considered a task constraint. It appears that task constraints are the most manipulatable constraints, given their short-term response outcome (compared to individual constraints), as they directly relate to the desired outcome.

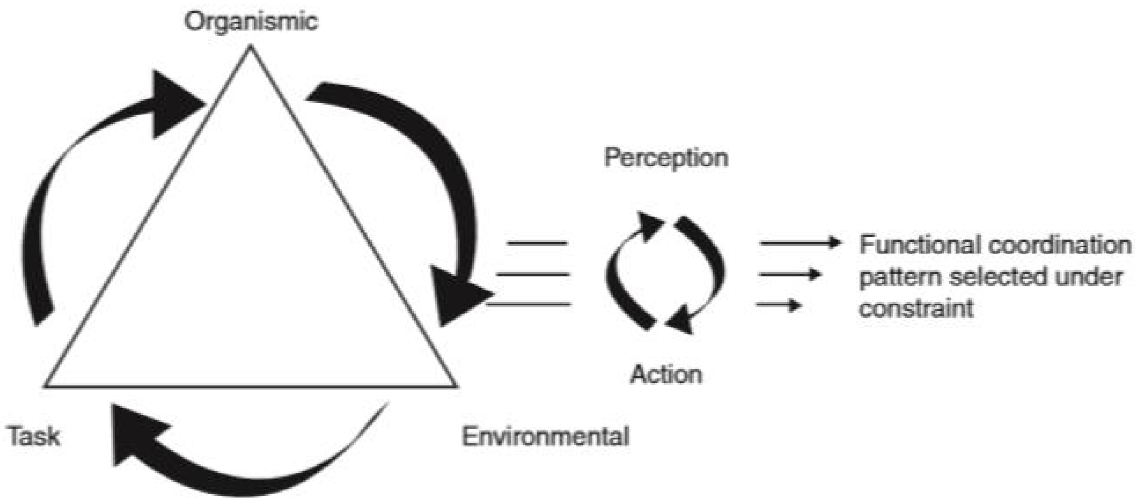

Figure 2.3.1: The cyclical relationship between perception and action producing functional behaviours under the interaction of constraints.

The process that provides purposeful and coordinated action in highly complex systems is called self-organisation. Self-organisation is a fundamental principle in dynamical systems where smaller components are governed by dynamical principles to produce organised and coordinated collective behaviour (Clarke, 1995). Self-organisation is not a random process, rather a spontaneous process that is also not controlled by an executive entity (previously, IPTs would suggest an executive entity would control and influence coordinated movement). Under the influence of specific sets of interacting constraints, the system will find an efficient and stable state of organisation. Conversely, less functional organisations are disregarded, resonating a Darwinian process of favouring more useful and relevant behaviours (Davids et al., 2003). For example, an individual player will possess an effective stable state when dribbling a soccer ball and beating players in a 3 versus 2 attacker/defender practice drill. In this context, the interaction of constraints potentially affords him/her more time and space to beat the opponents leading to reliable and functional behaviours over time (Davids et al., 2012; Handford et al., 1997). In match-play however, there is much more variability that can affect the players' organisation, which can be observed through the increased pressure and subsequent decrease in time, which affords less space and time. This may lead to dribbling behaviour that is perturbed by the defensive pressure and results in a loss of possession. Thus, specific attention must be paid to the interaction of constraints and how and why specific behaviours self-organise.

The dynamics of skill acquisition are more accurately considered using the constraints-led approach. Since individual and collective actions are influenced by the constraints placed on the system (Araújo et al., 2015; Clarke, 1995), it is important to understand that practice and experience under constraints creates a pattern. This pattern can stabilise and become stronger over time when it is practiced or experienced more and more (Davids et al., 2003; Kugler et al., 1980). For example, healthy adults, over time, develop a strong coordination pattern for walking. Conversely, toddlers, who are not afforded the same practice time, possess relatively weak and vulnerable walking coordination patterns (Clarke, 1995). Nonetheless, both the adult and toddler are capable of producing a walking pattern. The differentiating aspects are in the strength and efficiency of those patterns. If the pattern is strong, it can resist perturbations and variability (e.g. walking across different sized rocks). If the pattern is weak, it generally indicates that system reorganisation is required to overcome these constraints (i.e. more specific practice or experience is required). Thus, as behaviours emerge from interacting constraints, it ensures that changes in a pattern result from changes in one or more constraints (Clark, 1995).

A strong understanding of constraints can help coaches' and practitioners' best enhance the application of the constraints-led approach as a pedagogical coaching approach, where (an interaction of) constraints are manipulated to achieve specific performance or learning outcomes (Davids et al., 2003). The ultimate aim is to selectively manipulate constraints so specific behaviours and patterns emerge. By doing this, a performer explores a range of movement patterns and perceptual information. Resultantly, the performer becomes better attuned to identifying and using available affordances (Gray, 2018; Silva et al., 2013). For example, deliberately adding a barrier constraint that must be hit over in baseball hitting had increased effectiveness changing the batting technique compared to attentional cueing methods (Gray, 2018). Here, Gray (2018) suggests a greater degree of exploration from the athletes who were exposed to the constraints-led approach. Additionally, the findings highlight how coaches' can use the constraints-led approach to create targeted environments for these performers' to satisfy the unique combination of constraints imposed on them (Renshaw et al., 2010).

The process of self-organisation and pattern formation under the influence of constraints can be harnessed by coaches' who have an awareness of how constraints can be manipulated to produced targeted and specific behaviour. For example, research investigating pitch markings during 5-a-side association football small-sided game demonstrated that changes to the boundary pitch markings (full line, dashed line or a marker in each corner only) resulted in different movement behaviours (Countinho et al., 2020). Specifically, Countinho and colleagues (2020) determined more visible boundary markings (full line and dashed line) resulted in lower team dispersion (i.e. the team occupies less space on the field) compared to markers in the corners only. Coaches' may use this information for more targeted practice interventions through manipulating constraints to encourage such targeted behaviour, e.g. an attacking focus in a practice activity may only use corner markings to create a more expansive and wider team shape compared to full line markings. Ultimately, it depends on the goal and intention of what the coach and players' need to improve for successful performance in the sport. Nonetheless, targeted and systematic manipulations of constraints is encouraged to help optimise the pedagogical approach of targeting specific behaviours, so they self-organise and emerge organically using representative information in the practice activity.

Here, an understanding of how individual, environmental and task constraints shape emergent behaviour is necessary to translate practice to the context that action or behaviour is required in. Thus, understanding how constraints interact can provide information to coaches' on how to best structure practice. Consequently, the constraints-led approach is a practical, pedagogical framework embedded within Ecological Dynamics (ED). The constraints-led approach can help explain how skilled behaviour emerges in complex systems and how behaviour is influenced by the constraints placed upon the system. The constraints-led approach further helps provide coaches' with detail on how manipulations to an interaction of constraints can help alter or guide an individual or teams behaviour to optimise competitive performance (Otte et al., 2020; Woods et al., 2020a). The integration of the constraints-led approach with an enhanced understanding of ED would help coaches make informed decisions on how and why to make manipulations during practice to optimise the behaviour of an individual or the team.
Traditionally, the design of practice environments in sport is based on experience, emulation and historical precedence (Cushion, Armour, & Jones, 2003; Williams & Hodges, 2005), and its implementation in team sport is often the prerogative of the coach, who is, among other reasons, hired for their experience. However, experience within the sport may hinder the

application of evidence-based practice methods derived from motor learning or skill acquisition research (Ford, Yates & Williams, 2010). Therefore, an underlying framework, and the implementation of that framework under the guidance of skill acquisition specialists is often crucial to successful implementation. Using the constraints-led approach, an interaction of constraints that reflects what occurs during competitive matches may help improve the skill transfer from practice. Representative learning design aims to improve training and practice interventions and focuses on how processes of perception, cognition, decision-making and action can be influenced using the constraints-led approach.

2.4 Representative learning design using the constraints-led approach

In team sport, emergent coordination patterns become evident under the interaction of constraints, which emphasises coordination in these settings as a constant organisation and re-organisation process (Handford et al., 1997; Renshaw et al., 2019). Indeed, as effective coordination patterns are reinforced, less functional states of goal-directed behaviours can be discarded (Davids et al., 2003). Through this process of organisation and re-organisation through exposure to practice, system attractors become more stable and less vulnerable to perturbations over time, making their performance in a new context adaptable (i.e. transfer skills and behaviours to a new context and remain stable). This ability to transfer learning from practice to performance in a competitive context should be the aim of all practice (Pinder et al., 2011). However, not all practice is equal. That is, for behaviour to be transferrable from practice to performance contexts, perception-action couplings in training need to replicate those of competition contexts (Davids et al., 2003; Maloney et al., 2018). For example, for practice to be representative of competition, opposition players' and teammates' must run at similar speeds during practice than during competition, for players' to become attuned to the opportunities for action presented by fast moving opponents and teammates (Araújo et al., 2014; Fajen et al., 2008). As a result, players' will become accustomed to the perceptual information that is embedded in fast moving opposition players and teammates, ultimately encouraging decision-making behaviour and skill execution that is representative of that experienced during competitive play. Specifically, if the practice context is one focusing on transitioning from defence to attack, the speed of transition must be realistic to what is generally observed in matches. If the length of the field is reduced, and less ground needs to be covered by the players', they may run slower than what is required or observed when a similar transition occurs in a match. Slower running results in a slower flow of information and altered information-movement couplings when decisions are executed based on environmental information.

From an Ecological Dynamics (ED) perspective, the performance environment is abundant with constraints and affordances (i.e. opportunities for action) (Fajen et al., 2008). Since the underlying presumption of affordances is based on what the performer can utilise and achieve within the performance environment, Silva and colleagues (2013) suggest that shared affordances become the main avenue for action in coordinative team tasks during competitive performance. As such, the constraints and subsequent information provide possibilities for collective decision-making. For example, attacker-defender coordination tendencies in basketball change according to the relative position of the performers to the basket (Esteves et al., 2012). In rugby union, the time-to-contact between the attacker and defender may affect future pass possibilities and constrains the attacker-defender interaction (Correia, Araújo, Craig & Passos, 2011). These examples of affordance-based coordination demonstrate that players' explore the environment in search for relevant information that can be used to shape subsequent action. Additionally, if a defensive rebound is made by a basketball player and the team is encouraged to play quickly, teammates' may get on the outside of their opposition player so they can use the width of the court and open up the middle (as the opposition will 'follow' and mark them) for another teammate to run through. It is likely that such an understanding between teammates of where to be and when must largely be achieved through practice (Silva et al., 2013). Coaches' and practitioners' alike may term this as second nature, which can be described as the teams implicit understanding of positioning when perceiving shared information and subsequent opportunities for action. Consequently, this can lead to stronger patterning of behaviour and attractors that continue to develop with more specific practice and experience (Handford et al., 1997). Nonetheless, these behaviours must align to what the coach thinks is an effective method to win competitive matches. Consequently, it is useful for coaches' to work with skill acquisition specialists to help their program and align fundamental concepts from established frameworks into their daily practice.

Representative design is a concept first proposed by Brunswick (Brunswick, 1956) with the intention of being used to study psychological processes at the organism-environment relation (Pinder et al., 2011). These ideas align closely with the expert-performance approach (Ericsson & Smith, 1991; Williams, Fawver & Hodges, 2017) and Gibson's (1979) work on direct perception and affordances in the environment, emphasising the importance of designing experiments that incorporate the contexts to which the findings are intended to generalise to (i.e. the performance context). Although the assessment of how much of practice transfers to competition is difficult to measure considering the dynamic interaction between the performer and the environment, it is a necessary step to enhance the similarity of experiments to the performance context. In sport, this is exemplified through training interventions and practice drills. The aim of these interventions is to improve the players' performance in match-play by transferring the learnt skills from practice into the new context. In sports research, Pinder and colleagues (2011) propose representative learning design as a framework to assess and describe the functionality (i.e. functional coupling between perception and action processes) and action fidelity (i.e. simulating the performance context) of practice tasks and learning environments. This framework integrates principles of ecological psychology and dynamical systems theory to enhance the similarity of practice to match-play.

The representative learning design framework for improving training and practice interventions describes how processes of perception, cognition, decision-making and action underpin intentional movement behaviours in dynamic environments (Pinder et al., 2011; Turvey & Shaw, 1999). In collective skill acquisition settings like team sport, these subsequent actions are dynamic based upon the interacting constraints acting upon the team and how attuned the team is to the shared affordances available (Silva et al., 2013). For example, if a team is unaware of an opportunity (and the relevant perception of information and subsequent action) to effectively score from a turnover in basketball, is it because it wasn't practiced? If it was practiced, was it performed in an effective manner where players' and the team were perceiving representative information and acting in response (or anticipating) to that information? This notion emphasises the importance of the coach in deciding content included in practice. Further, it also shows the potential value of a skill acquisition specialist to help coaches' design practice which couples the relevant and most favourable action with the available information.

Traditionally, practice constitutes different implementations or variations that aim to replicate the sports competitive matches. Small-sided games (SSGs) are described as smaller versions of the actual match conditions, generally observed through altered playing numbers, size-reduced fields or modified rules and/or implements (Ometto et al., 2018). SSGs have been adopted largely to increase training participation, with the reduced numbers and field size offering alternative physiological stress compared to full match simulation or gameplay that effectively leads to adaptations relevant to the team sport being practiced (Hill-Haas et al., 2011). Additionally, collective behaviour and skill components can also be targeted in SSGs (Ometto et al., 2018), and can change depending on how the SSG is designed (Silva et al., 2014). These characteristics provide the platform for SSGs to replicate gameplay, and (ideally) achieve representative learning design in practice. Thus, key task constraints, such as the field length and width, the number of goals, or an outnumber in attack, can be manipulated to shape emergent behaviour and expose players' and teams' to common sources of information in the environment (Silva et al., 2013). An awareness of how manipulating task constraints can affect team and individual player behaviour is needed to optimally expose players to favourable shared affordances. Aligning the practice environment to favourable shared affordances is essential for translating practice to competitive matches. For example, if a practice context is designed to stabilise an effective ball movement pattern in soccer, the amount of space per player in the SSG must be similar to that experienced during a competitive game in order to effectively couple perception and action (Olthof, Frencken & Lemmink, 2019). The emergent behaviours' will be a result of the time and pressure put on each player as a consequence of the design of that specific environment.

The intention of SSGs is to expose players' to particular situations and environments that occur in competitive matches. Consequently, an enhanced learning process can occur, where the interaction of constraints permits emergent behaviours alike gameplay. Task constraints such as player numbers and field dimensions are the most commonly manipulated variables when designing SSGs (Ometto et al., 2018). When manipulating task constraints, collective and individual behaviours' change. For example, Silva and colleagues (2014) report effective playing space and team separateness increase in larger field dimensions. Additionally, skill level constrains emergent behaviours, with different behaviours' reported between national and regional level soccer players'. Furthermore, a numerical advantage in attack may lead to more predictable behaviour performed by each individual player, compared to a numerical disadvantage leading to more unpredictability in individual movement behaviour (Aguiar et al., 2015). Coaches' can harness findings like these to implement and manipulate practice to focus on particular behaviours.

It appears that knowledge of the constraints relevant to a team's performance environment can build an understanding of how to optimise the structure and design of learning environments for long-term learning and adaptation (Renshaw et al., 2019). Representative learning design incorporates manipulating practice to best represent competitive match-play. The implementation of this method aims to optimise and integrate ED concepts and principles (Pinder et al., 2011). Consequently, practitioners' can enhance the interactions and behaviours players' perform in practice to be more like matches. However, this type of approach requires a more detailed, evidence-based approach to understanding how manipulations to key constraints will affect individual and team behaviour. As such, monitoring the constraints coaches' implement and players' interact with is an effective way to understand how to best optimise practice design. Meaningful interactions from games can then be identified and implemented into practice. For example, Ireland and colleagues (2019) compared the frequency of task constraints for all disposals in Australian football (AF) game-scenario drills to competitive match-play. They reported game-based training drills significantly under-represented the pressure on the kicker and receiving player when compared to match-play. Additionally, match-play kicks executed in 0-1 seconds showed significant differences in frequency between game-scenario training and competition match-play. Understanding such constraint interactions allows coaches' and practitioners' to maximise skill transfer from practice to gameplay.

As a result, successful utilisation of representative learning design and the constraints-led approach in team sport requires an understanding of ED concepts and how they can guide practice design and increase the understanding of collective skill acquisition. For a specific example related to team sport, the next section will describe AF and why it can be classified as a complex system. Understanding the characteristics and traits that make it a complex system will help to elucidate why the constraints-led approach can be used effectively for practice design in AF.

2.5 Australian football is a complex system

Australian football (AF) is a dynamic evasion sport that involves two teams of 22 players (18 on the field at once) playing against each other to score goals, located at each end of the ground. The ground can vary in length (185m – 135m) and width (155m – 110m) (Figure 2.5.1). It involves phases of attack, defence, contested play and stoppages (ball goes out of play and is restarted by the umpire by either a centre bounce, ball up or throw in). The physical nature of the game exposes players' to intermittent high-speed running, frequent changes of direction and collisions (Gray & Jenkins, 2010; Johnston et al., 2018), which occur over four 20-minute quarters in the Australian Football League (AFL; the professional competition in Australia).

Players' also require high levels of skilfulness when passing the ball and shooting for goal, often using both hands and feet (Johnston et al., 2016). Furthermore, position specific roles require players' to perform more or less of certain physical activities and skill requirements, with the physical and technical activities of players' also changing according to the phase of play (Rennie et al. 2020). For example, contested phases of play involve less handballs than offensive phases of play. Whilst differences in key metrics could be similar across games and teams, with previous research determining key metrics related to winning in AFL across the 2013 and 2014 seasons (Robertson, Back & Bartlett, 2016), differences can originate from different tactics implemented by the coaching staff. These tactics may change according to the size of the ground, the opposition and their rank, which key personnel they have in their team, which key personnel they have in their own team etc. Consequently, players' decisions and actions are guided and influenced by many different sources of information before and during match-play. As such, the players' decisions and actions can change according to an interaction of the different variables, some of which will be outlined below.

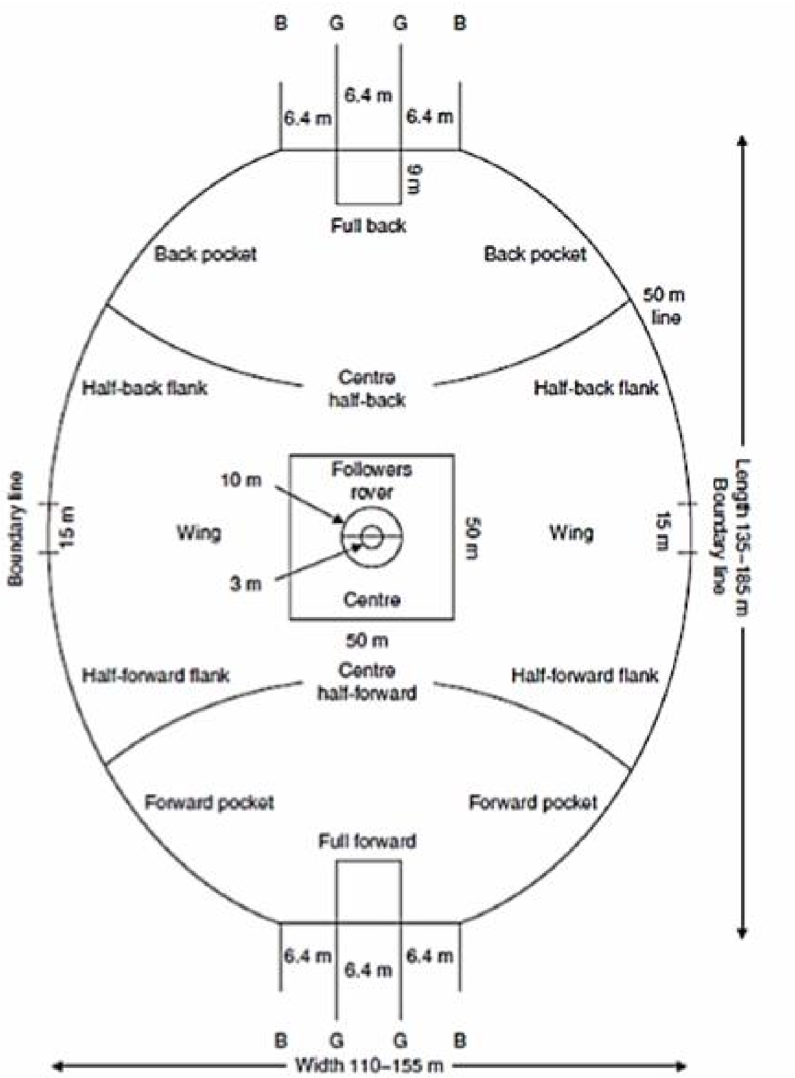

Figure 2.5.1: Typical player positions and typical field dimensions in Australian football (Taken from Gray & Jenkins, 2010).

From an Ecological Dynamics (ED) perspective, along with an underpinning of dynamical systems theory as described in a previous section, AF is a complex system characterised by dynamic interactions between the performers' (i.e. players') and the environment. These interactions, which include explicit or implicit exchanges of information such as ball movements, defensive running patterns, verbal communication, and even non-verbal exchanges of information, provide collective opportunities for action (i.e. shared affordances). These shared affordances allow stable or variable coordinative patterns to emerge or dissipate, depending on whether the players' can satisfy the relevant constraints in the environment. As such, it is the interacting constraints that create inter-dependent behaviours between players' on the same team (to produce effective and stable behaviours) and opposition players' (to perturb the stability of their behaviours). Consequently, the resultant behaviours in a complex system are the interaction between its components, as evidenced by behaviour in AF. For example, Sheehan and colleagues (2019) describe how cooperative networks (passing interactions between players on the same team) can be used to capture the dynamic and self-organising properties of AF. It also illustrates the independent but interacting components within the system. Additionally, Alexander and colleagues (2019) reported emergent spatiotemporal variables differing between phase of play in a match simulation practice context within professional AF players. The non-linear changes within the system (x-axis and y-axis centroid, length, width and surface area) demonstrate system self-organising properties that are based on dynamic sources of information that are used for exploitation. Thus, AF represents a complex system whose order arises from interactions between players (components of the system) and the environment to produce goal-directed behaviour.

Complex systems rely on principles that drive and influence the organisation of the components within the system, and is crucial for many fields including biology, neuroscience, thermodynamics and economics (Expert, Evans, Blondel & Lambiotte, 2011). It has origins in the mathematical and physical sciences to explain systems that change over time (Clarke 1995). In movement sciences, it was first introduced by Kugler and colleagues (1980). Since its inception in the movement sciences, the characteristics and principles of complex systems have evolved into understanding and explaining intricate complex systems and how they operate. With the underlying principles derived from dynamical systems theory, there are a number of essential elements that are present for AF to be classified as a complex system. Complex systems are characterised by independent and variable degrees of freedom, a multilevel structure, the potential for non-linearity in behaviour, capacity for stable and unstable patterned behaviour (short and long term), the ability of subsystem components to limit or influence the behaviour of others and self-organisation tendencies. Each of these exist in AF, making it a plausible case to examine.

Effective teams make the available degrees of freedom redundant by coupling them, creating more efficient movement and information sharing. This coupling reduces the complexity of the whole system so that each sub-component, or player, can participate in many different coordinative structures at different time points (Kay, 1988). For example, there are many transitions between phases of play resulting in different amounts of time spent in offence, defence, contested play and stoppages in AF (Rennie et al., 2020). One player can make an independent decision to participate in an offensive sequence of play, increasing the 'apparent' complexity of system organisation (plus one degree of freedom), but also has the potential to effectively couple with other player's (reducing the degrees of freedom of the system) and create an effective outcome, e.g. link up with another player out of a contested scenario and kick the ball forward to gain territory. The coupling of information sharing can be thought about through a specific example in cooperative network analysis (passing interactions between players). Fransen and colleagues (2021a) report that a one standard deviation increase in connectedness (more spread in passing/interacting between all players in the team/system) increases the teams odds of winning by 79.5%. The connectedness metric can be interpreted as reducing the degrees of freedom. The players' in an AF team effectively couple through ball movement and therefore create more effective goal scoring opportunities. Furthermore, it may also make the team more efficient, as they can effectively organise, utilise time and space more effectively and satisfy the interacting constraints through information sharing and coupling. Recent evidence reported by Sullivan and colleagues (2014) suggests such a notion exists in professional AF, with coaches' subjectively rating players' higher when they ran less in competitive matches, potentially alluding to greater efficacy in pattern recognition and decision-making. However, degrees of freedom are variable, indicating that player behaviours and decisions may be variable across different conditions in the environment, with contextual information an essential consideration when undertaking any such analysis.

Variability is useful in performance process instances, such as kicking technique or running patterns in the forward line, as it indicates the exploitation of individual and team degrees of freedom to create effective outcomes and demonstrates adaptation to the prevailing constraints placed upon the system. For example, useful variability in running patterns by a key forward permits flexibility in using or not using other degrees of freedom (e.g. use other player's to block or shepherd a path for them) to effectively mark the ball from a kick entering the inside 50 region. This compensatory variability mechanism is a key characteristic of expert players. Conversely, less skilled performers' may show as much or more variability, but it is not functional and hence not adaptable to the constraints placed on the system (Davids, Glazier, Araújo & Bartlett, 2003). For example, younger, less-skilled players' in the AFL may be unaware that running into space being occupied by a nearby teammate is not functional variability, as it prevents the other player from effectively utilising that space. This player has not effectively exploited the available degrees of freedom and as such, does not have complementary variability to help achieve effective outcomes such as an effective mark in a goal scoring opportunity location. Independent and variable degrees of freedom definitively underlie behaviour in AF. Consequently, it provides a powerful basis to understand how skilful behaviour and actions emerge, and how individuals compose independent yet interacting components in the system, with a powerful ability to influence one another through redundancy (e.g. not passing to a player when it is not needed) or exploitation (e.g. understanding that a stronger teammate may be a better target option when they are marked by a smaller opposition player).

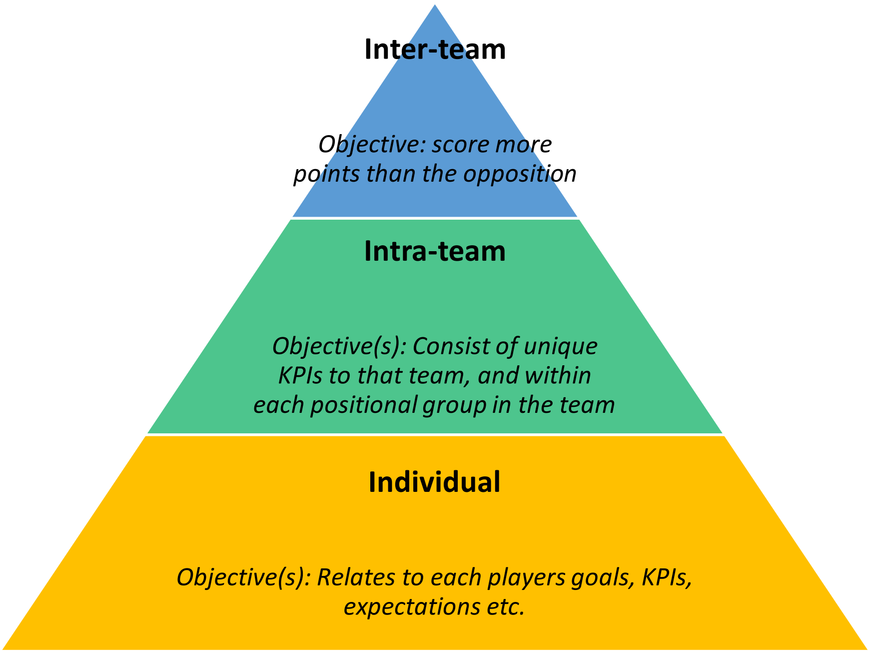

Figure 2.5.2: Multilevel structure of Australian football. KPI = Key performance indicator.

The availability and variability of independent yet interacting degrees of freedom within an AF team can be observed from a multilevel structure (Figure 2.5.2). The multilevel structure of the team provides a basis for effective coordination solutions to satisfy the interacting constraints placed on the system and its components. A consistent feature when developing analytical models of large-scale systems, alike to an AF team, is partitioning behaviour into modules or subsystems (Mahmoud 1977). Additionally, Mahmoud reports large multilevel systems adopt characteristics relating to interdependency of subcomponents (previously explained through the degrees of freedom problem) which serve functions, share resources, and are governed and influenced by shared goals/tasks and constraints. In AF, a multilevel structure exists that demonstrates shared goals and decision problems and helps clarify the communication of information and how such exchanges occur across system levels. Figure 2.5.2 shows a broad level structure of an AF system.

The hierarchical and multilevel arrangement of subsystems in AF provides an insight into how information sharing occurs, with each subsystem or level, consisting of different and unique goals to be achieved. At the top of the whole structure and system, one decision problem upon which the overall objective of the system depends is apparent in AF: to score more goals than the opposition and win. From there, each other subsystem will attempt to create organisation patterns and coordination solutions to achieve that goal. Naturally, the goals and decision-making processes of other subsystem levels to achieve the overall objective of winning become more complex, with each level attempting to solve unique problems directly relevant to their objectives and constraints placed upon the system. The model of multilevel structure and its partitioned 'subproblems' repeats itself over each level within the systems organisation. For example, inter-team goals consist of defeating the other team by scoring more goals and preventing the opposition from scoring. In order to score goals in AF, intra-team aims may consist of key performance indicators (KPIs) which provide a more granular insight such as inside 50 counts, kicking efficiency percentage, contested mark win rates, the number of uncontested marks etc. In order to achieve these key performance indicators, positional groups' within the team will have KPIs to meet. For midfielders', this may include contested ball wins, clearance wins, number of tackles etc. Finally, the individual player subsystem may be classed as the most complex because of the infinite number of decision problems a player must encounter and overcome in one game. For example, a player must decide where to stand, who to defend, to make body contact or not, run faster or slower, look around and scan when running etc, which can all occur within one passage of play. These problems and decisions encountered by players should be influenced and helped to be solved by the higher order problems, for example if they are a midfielder, what are the KPIs for midfield? If the aim is to win contested possessions, then will they be required to run faster at that specific time to get to the ball. As such, higher order inter-team problems then determine how that positional group or whole team behave to achieve their main objective of scoring more points than the opposition. Consequently, the problems at the base of the pyramid should be influenced and solved by other higher order problems and objectives.

Similar to other complex systems, AF subsystems interact through shared objectives and constraints. This nature of information sharing not only assumes interdependence amongst subsystems but provides evidence of subsystems having the ability to limit or influence the behaviour of others (Ribeiro, Silva, Duarte, Davids & Garganta, 2017). The emergence of coordinative behaviours in AF is based on the formation of inter-player synergies. These synergies can be described considering the degrees of freedom problem posed earlier, and how it is solved in AF. Teammates must couple the available degrees of freedom, becoming temporarily constrained to act as a single and coordinated unit (Kelso, 2012). Because the outcome of behaviour is largely determined by the underlying task to be achieved, objectives help determine the specification of shared affordances for coordinative behaviours. For example, if the defensive playing group aim to take 10 intercept marks, they will implicitly get into positions which may allow them to achieve this. In doing so, they are aiming to achieve a common goal by influencing each other's behaviour and actions. Specifically, one defender may leave their opponent in an attempt to achieve an intercept mark. This will force another defender to cover the opposition player. Thus, the individual system can influence other higher order subsystems. The key to effectively undertaking this lies in performing actions that contribute towards the achievement of goal-directed behaviour. Furthermore, if the midfield group is performing poorly and not achieving positional specific objectives such as obtaining an insufficient number of clearances and hence the team is losing territory, the defensive group may have to compensate and elevate their work rate by running more or using more body contact on the opposition to maintain an effective state of system organisation and prevent the opposition from scoring. Thus, the behaviours of a complex system such as an AF team, emerge from the interactions of system components/subsystems.

The potential for non-linearity in behaviour provides complex systems, such as an AF team and its subsystems, the power to adapt to changing and dynamic conditions. As each system can change (e.g. a player may choose to pass to one player and not another because of their position on the field) over time, the organisational state of the system is continuously influenced. The extent and magnitude of the influence on system behaviour is non-proportional to that decision or event. For example, the same error can occur in the game, but the location of the error and whether it is located on the defensive goal line, or in the middle of the field, can lead to significantly different changes in system organisation for each event. As such, there is often a non-linear response in behavioural change to a change in match-play conditions. Specifically, Alexander and colleagues (2019) reported that player positioning showed considerable variation during phases of play in a 15 versus 15 AF match simulation drill. As the nature of AF is dynamic, the trajectory of system behaviour cannot be linear as the fundamental ideology to complex systems is how to solve the degrees of freedom problem. That is, to produce purposeful movement, hundreds of degrees of freedom within each player and across players need to be functionally coupled. Effective coupling is achieved successfully by exploiting variability of each subsystem and its components. Considering the non-linear nature of coordination and gameplay in AF, configurations of organised behaviour emerge and dissipate in response to the continually evolving conditions. From this alone, adaptability and non-linearity in behaviour are related as behaviour that is linear is predictable; whereas adaptability infers an ability to maintain stable behaviour across different and changing conditions (Handford et al., 1997).

In connection with coordination and control problems in movement systems posed by Kugler and colleagues (1980), an awareness of non-linear and multilevel systems in AF provides a model of the organisation approach to complex systems. Specifically, this theory stands with the natural predisposition of complex systems to spontaneously organise subsystems to achieve a global coordination pattern. The constant transactions of information and energy between system subcomponents (i.e. players) allows spontaneous pattern formation to emerge through self-organisation. This process occurs due to transitions between organisational states as a result of satisfying dynamic constraints that are present in the environment. For example, an AF team must be able to successfully transition between an organisational state in attack and defence. If there are ~85 turnovers per game, teams must be able to continuously adapt and reorganise between phases of play. Additionally, it would be an inefficient method if players explicitly shouted at each other every time reorganisation was required. Thus, to favourably reduce and compress the dimensionality associated with the large number of degrees of freedom within players and within the team, the team and its components, that is, the players', use information in the environment such as the movement of opposition players', location of the ball, their position on the field, to spontaneously self-organise (Araújo et al., 2014). The hopeful notion is one that the team will self-organise into successful coordinative structures to either score or prevent the opposition from scoring. Such coordinative structures are assembled temporarily and flexibly, so that each subsystem and its components (e.g. one coordinative structure may use 4 players, whilst the next uses 7) can participate and contribute in many different coordinative structures across time (Kay, 1988). Individually, the coordinative structure may change so that a player may dispose of the ball using his/her non-dominant left foot, rather than his/her right foot.

Coordinative structures involve the temporary assemblage of components within and across each subsystem(s). To achieve an effective coordinative structure in AF requires efficient information exchange between system components (Kugler et al., 1980). However, as sources of information may be perceived and acted on differently according to the skill level and expertise of each player, there is a capacity for stable and unstable relationships within the complex system (Passos, Araújo & Davids, 2013). For example, is the team able to maintain possession when passing the ball closer towards the opposition goals. If they can, it provides some insight into the stability of that coordinative structure in that context (i.e. slow play ball movement, fast play ball movement). Conversely, if they are unable to move the ball effectively towards the opposition goals, it may demonstrate an unstable relationship between system components to produce an effective coordinative solution for that context (Handford et al., 1997). Whether the pattern is stable or unstable relies on the overall behaviours available to the team, which can be observed through their collective perceptual-motor workspace. For example, the team may possess many solutions in its repertoire to move the ball effectively. If the team has just one, they are very predictable and may be very easy to stop. If they have many, they are adaptable to different conditions and oppositions, and can effectively move the ball up the field. Performance in stable regions in the teams perceptual-motor workspace is easier to maintain across dynamic conditions in AF. Conversely, performance in unstable regions cannot be maintained and is transient (Araújo, et al., 2004). The ideal outcome would be to have effective solutions that are stable and therefore adaptable. Teams in the AFL can have a repertoire of effective and ineffective solutions that are a mix of stable and unstable patterns. For example, a team could be at the top of the ladder with effective and stable solutions, whilst you may also have a team at the bottom of the ladder with stable solutions, but they are ineffective, resulting in more losses. Here, the team at the top of the ladder may have a particular method of defending where they consistently pressure the opposition team into a turnover, so they regain possession and teams do not progress further up the field. Their defensive strategy and tactics are effective (they are able to regain possession) and stable (they defend this way against a variety of teams and attacking styles). Nonetheless, it is the interaction of components within the system and the variability they possess (at the individual level and team level) that provides a capacity within the complex system to demonstrate stable and unstable behaviours.

The nature of AF sees the emergence of patterns of behaviour in a dynamically evolving environment. It displays characteristics common across complex systems in neuroscience, biology, thermodynamics and economics. These commonalities emphasise the degrees of freedom problem, and how it can be solved through dimensional compression (i.e. a larger number of degrees of freedom are compressed into a smaller number of degrees of freedom to reduce the complexity of behaviour) in AF, the multilevel structure of AF (individual, intra-team and inter-team) and the ability of these subsystems to influence each other's behaviour. Additionally, AF demonstrates the potential for non-linearity in behaviour (and in performance and also learning), the capacity for stable and unstable behaviour and a complex systems ability to spontaneously self-organise and form a coordinative structure through an effective assemblage of its components (i.e. players), which can be temporary and/or flexible. These features of observing AF as a complex system provide a conceptual basis and a working method to explain behaviour. If practitioners' consider AF to be a complex system, it is governed by these complex system rules. If it is governed by these complex system rules and concepts related to ecological dynamics, the behaviour can be simplified and understood using the constraints-led approach. Utilising the constraints-led approach will assist with the translation of the conceptual ideas discussed herein, which can appear complicated to the coaches' and practitioners' it directly applies to. Effective translation will help coaches' design practice interventions that help players' transfer skills and behaviours to matches. Nonetheless, most research in AF has not integrated the constraints-led approach when examining practice and competitive matches. Where research has used the constraints-led approach, a significant focus has been placed on assessing the constraints when players' dispose the ball. Additionally, the lack of skill acquisition experts in professional AF organisations may indicate ineffective communication of this work with coaches' to something they can relate to. In part, this thesis aims to rectify this issue by providing novel findings to established concepts in skill acquisition. Moreover, it will attempt to translate the findings to industry experts and in doing so it is anticipated that skill acquisition will be more favourably viewed to benefit coaching practices and sporting organisations.

2.6 Overview of Skill Acquisition Research in Australian Football

2.6.1 The Ecological Dynamics framework applied to Australian Football

Ecological Dynamics (ED) has long been established as a framework to understand and assess individual and team behaviours in sport. A myriad of papers have theoretically posed its usefulness and applicability in human movement and sporting contexts (Clark, 1995; Davids et al., 1994; Davids et al., 2003a; Davids et al., 2003b; Handford et al., 1997; Kugler & Turvey, 1987; Turvey, 1990). Although it has increased rapidly over the last five years, ED research is Australian Football (AF) is relatively rare. One reason for this may have been the abundance of ED research in team sport showcasing the transferability of ED principles to other team sports (Davids et al., 2003a; Davids et al., 2003b; Handford et al., 1997; Silva et al., 2013). For example, key concepts such as self-organisation, changing patterns across time, perception-action coupling and constraints relate to things such as team stability, variability and transitions in the configurations of play. Nonetheless, AF may have more complexity than other team sports because of the large number of players' (18 per side on the field) and rolling rotations that can be used at any point during play (four interchange players). Here, the degrees of freedom are larger than most other sports such as association football, hockey, rugby league and rugby union.

The earliest recorded adoption of ED principles in AF was in 2013, where a researcher (Pill, 2013) applied dynamical systems theory to the forward press. The forward press is a tactic used by team's which involves the players' from the attacking team pressing forward into the forward half of the ground as the ball transitions into the teams forward 50m arc (Pill, 2013). The forward press is an example of constricting the amount of space and time the opposition has to pass the ball in order to increase the chance of turnovers closer to their own goal and increase the chance of scoring (Figure 2.6.1). Pill (2013) also described this constriction of space in relation to attacker-defender relationships. Whilst Pill (2013) goes on to describe how each sub-system has the ability to influence the organisation and effectiveness of the whole system, he provided the first relation of ED to AF in a succinct but non-empirical format. In 2014, Pill continued this work and further described the relationship between complex dynamics of gameplay in AF and the game sense coaching approach to learning skill. Here, he outlined why accounting for complexity and potential possibilities and scenarios player's encounter in competitive matches was important to replicate during practice. Pill suggested that a sensible and theory-informed method to use was the constraints-led approach. Additionally, whilst he did not use the language from ecological psychology, the performer-environment relationship was described along with how it was shaped and influenced by interacting constraints. Thus, these studies by Pill (2013, 2014) provide some of the first applications of ED components in AF. Tangible, but non-empirical examples, were provided throughout to showcase dynamical systems theory, game sense coaching, the constraints-led approach and the performer-environment relationship.

Recent research has observed an increased integration of ED principles into AF, with an added emphasis into the ecological psychology ontology. Woods and colleagues (2019a) provide information on how affordances emerge in the environment for AF players. Specifically, the authors reinforce the need for contemporary coaching and pedagogical domains to incorporate ED principles into their programmes.

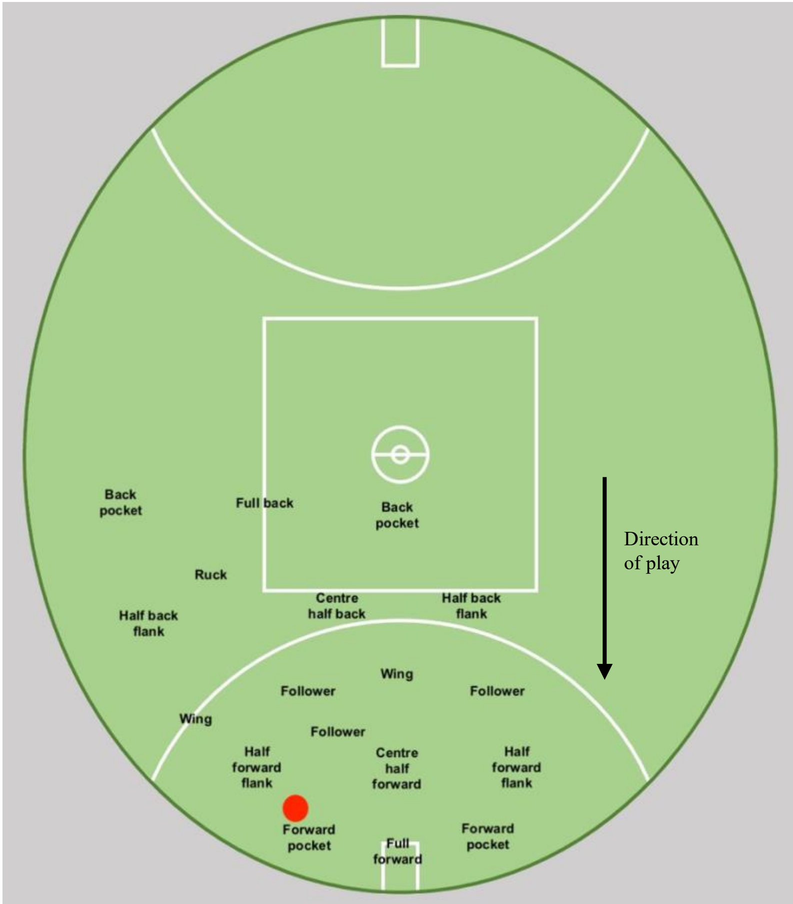

Figure 2.6.1: Altered positions during a forward press. The red dot represents the ball.

The authors then prescribe an AF small-sided game, in which principles such as perception-action coupling, affordances, degrees of freedom, to name a few, are applied. Furthermore, the context of each disposal (kick, handball) can also be notated for details such as the amount of time the player has in possession, the pressure they were under, or the effectiveness of the disposal, which are then compared to competitive matches. This approach helped to identify the constraints players' interact with when disposing the ball and provide a simple comparison between practice and competitive matches. The same principle and type of data collection and analysis was also performed by Woods, Jarvis & McKeown (2019b) and Robertson (2016). Whilst Woods and colleagues (2019a) detail how the approach can help inform practice design, it is by no means an extensive or exhaustive amount of data analysed. Unfortunately, case studies and case reports are common in AF and ED research. While these generate some level of evidence, they are ranked relatively low in the evidence hierarchy as findings from a specific case may not generalise to the wider population. As a result, there may be a lack of an empirical evidence on the application of the central principles of ED in skill acquisition to sport.

Features and characteristics of ED have been promoted in high performance sport, where performers manifest skilful and adaptable behaviour in highly dynamic contexts. For this reason, research has attempted to integrate these concepts across different facets of high-performance sport, and in particular, AF. Here, ongoing challenges and reservations such as the difference between performance and learning, the 'I-did-it-this-way-when-I-was a player philosophy' some coaches possess or the mechanistic, technique-based approach to skill learning can make it difficult for the integration of ED concepts. Whilst these reservations are justified due to the absence of empirical data to support many ED assertions, Woods and colleagues (2020a, 2020b) attempt to provide working models and further case studies to show how these concepts can work in real-life high-performance sport. For example, in an attempt to simplify the jargon presented in ED research, Woods and colleagues (2020a) aimed to provide a user-friendly framework to help practitioners interested in adopting a scientific approach to practice design (Figure 2.6.2).

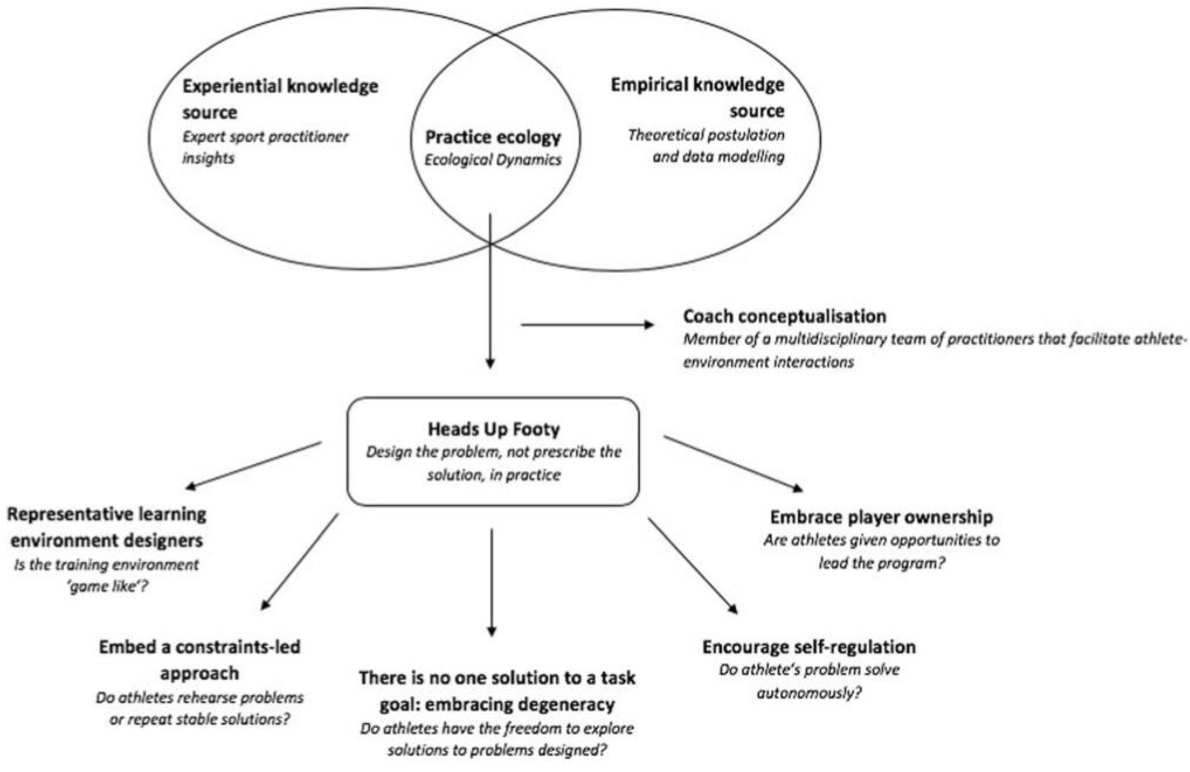

Figure 2.6.2: The 'heads up footy' framework. Taken from Woods and colleagues (2020a).

The aim of the framework is to support transference of key concepts to practitioners. The authors acknowledge the important integration of experiential (coaches, practitioners) and empirical (researchers, academics) knowledge sources to help optimise practice design. Whilst there is no thorough or investigative data presented through the manuscript, there are multiple examples called upon which showcase underlying ecological principles such as matching perception-action coupling from practice to matches through modifying constraints, assessing player and team degeneracy via specific task rules and improving player self-regulation through the use of questioning. Indeed, the authors conclude "we encourage the sport science community to promote the sharing and scientific publication of exemplars and/or case studies that afford opportunities to accept, reject or adapt practical approaches used by others" (pg. 10). Thus, current research exploring ED in AF illustrates what the framework is meant to imply, whereas true experiments and rigorous data collection tests a theory's implications (van Hezewijk, 1965). Consequently, the current scope of ED research in AF is largely theoretical and contains few and biased exemplars and case studies to showcase a glimpse of 'what it looks like in the real world'. Whilst these research papers discussed above may be somewhat useful, there is an apparent need for empirical data probing some of the assertions and principles set out by the ED framework in sport. Nonetheless, recent research has commenced the collation of empirical data to support decision making regarding practice design using the constraints-led approach in professional AF. These research papers are vital to help practitioners and coaches understand the differences between competitive and practice environments in order to maximise skill learning. The following section will detail what practice environments look like in AF and how a constraints-led approach can be used to collect empirical data in AF and as a result, improve the level of representativeness in AF practice.

2.6.2 Practice and constraint notations in AF

Human behaviour is regulated by a continuous process of perceiving and moving. As such, the environment provides opportunities for action i.e. affordances, as the athlete navigates the space they can move and interact with (Gibson, 1979; Maloney et al., 2018). Contemporary accounts of ED in life typically observe the performance of the individual or team in their performance environment and make a comparison to their practice environment. It is a simple but effective comparison permitting the researcher/ practitioner to assess the similarity between the environments, ultimately aiming to facilitate the transfer of skills from practice to competition (Maloney et al., 2018). For example, Greenwood and colleagues (2016) revealed that cricket bowlers adjust their run-up based on the absence or presence of the umpire. The removal of the informational constraint i.e. the umpire, resulted in altered movement patterns that were more variable compared to when the umpire was present. Hence, the information in the environment influenced how the performers moved and presented alternative opportunities for action. Importantly, the coaches and practitioners can help facilitate what information is more 'useful' and help athletes attune to these specific environmental features (Gibson, 1979).

In AF, researchers have used the constraints-led approach proposed by Newell (1986) as a way to explain changes in perceptual-motor behaviour that result from interacting constraints. Here, the assertion is that engaging with more practice that has increased similarity or representativeness of the performance environments optimises skill transfer (Davids et al., 2008). This is a simple approach to help guide scientific conclusions on the efficacy of practice environments for skill transfer. Robertson (2016) provided the first publicly available case study comparing the task constraints between practice and matches. Specifically, the frequency of specific task constraints such as time in possession, kicking distance, kicking target type, type of pressure, and type of kick were measured across pre-season training, in-season training and competitive matches. Furthermore, these constraints were compared between the AFL competition and the reserve grade competition (i.e. the Victorian Football League). Matches had a much higher percentage of kicks executed with less than two seconds of possession compared to pre- and in-season training, along with a higher proportion of kicks originating from receiving a handball. These two outcomes alone suggest there is a higher amount of pressure in competitive matches, meaning players must dispose of the ball quicker. Furthermore, there seems to be a quicker transition speed in AFL matches extrapolated from a much higher proportion of handball receives being performed. Consequently, practitioners and coaches can use these simple comparisons to increase practice specificity through task constraint manipulations. For example, a 2-second time in possession rule may be implemented by the coaches.

Similarly, Corbett and colleagues (2017) used similar data with the addition of physical measures. These authors aimed to develop an objective method to prescribe activities using their physical and skill characteristics whilst concurrently comparing these metrics to matches to assess their similarity. Of the five clusters they identified, not one was able to reach the levels of competitive matches for all physical and skill characteristics. For example, one cluster identified much higher physical outputs during match-play (metres per minute and high intensity running) which had much lower exposures to skill characteristics (kicks under no pressure, moving kicks, kicks executed in < 2 seconds). Whilst each cluster was not able to fully represent the physical and skill behaviours of competition, these clusters help provide an indication of what activities may be similar to each other and can subsequently assist practitioners when designing targeted practice. Indeed, Magill (2011) hypothesised that optimal skilled performance ensues after exposure to highly representative activities, with these activities having the highest transfer to performance. This is reinforced by expert performers themselves, with Baker and colleagues (2003) revealing that competition was rated as the most helpful form of training for the development of perceptual-motor and decision-making skills, whilst competition was also rated highly for developing skill execution and physical fitness. As maximising the representativeness of practice in professional sport is limited due to the large focus on recovery and optimising physical preparation, coaches' and practitioners' must consider operating along a representativeness continuum, with the most representative activities incorporating task constraints which can be modified to increase the specificity to matches.

Since the pioneering work of Robertson (2016), who instigated the observation of the constraints under which player's dispose of the ball, several research groups have used similar approaches while incorporating slightly different analyses and broader athlete cohorts. Research has assessed kicking and handball disposals to compare between game-scenario drills in training (pre- and in-season combined) and competitive matches (Ireland et al., 2019). These authors reported similar findings to Robertson (2016). For kicking disposals specifically, 0-1 seconds time in possession was more frequently observed in competitive matches, as were kicks travelling greater than 40m, physical pressure when disposing the ball, the proximity of the opposition in the 0-5m range and the prior disposal type coming from a groundball or 'crumb' (i.e. gathering the ball in the air off the body/hands of another player) (Figure 2.6.3). The authors presented large effect size differences for all of these metrics, with the exception of prior disposal type being a groundball or crumb ($d = 0.78$). In contrast to kicking, training revealed a much larger frequency of handballs performed in the 0-1, 1-2, 2-3 and 3-4 second ranges. Additionally, handballs in training were typically performed under more pressure and under closer proximity to opposition players compared to competitive matches. Consequently, kicks were executed significantly faster in games compared to training, whereas handballs were executed significantly faster in training compared to games. These findings help coaches' and practitioners' obtain objective data on the exposure to specific constraints a player or the team is having. It can then assist with targeted interventions to improve the representativeness of practice.

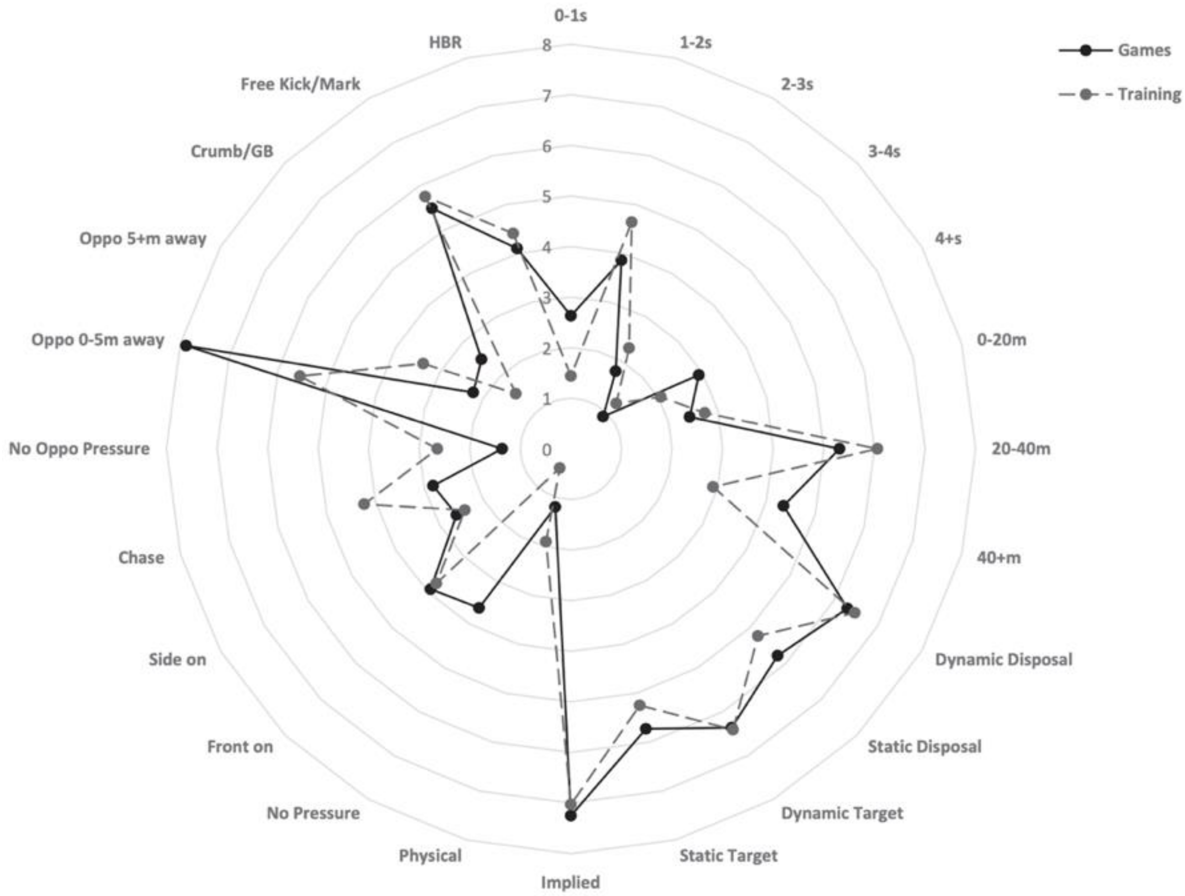

Figure 2.6.3: Skill constraint disparities (frequency per 120 minutes) between practice and competitive matches. Taken from Ireland and colleagues (2019).

Identifying the constraints that act on player behaviour during practice is useful to achieve desirable levels of representativeness during practice. However, it is typically a concomitant interaction of multiple constraints under which skilful behaviour self-emerge (Newell, 1986). For example, a player may typically have less than two seconds time in possession before disposing of the ball, however they may also be under physical pressure and attempting to kick the ball greater than 40m. To help address the complex interaction of constraints, research by Browne et al (2019) and Robertson et al (2019) took into account the most commonly occurring sets of constraints. These studies help provide detail around the relationships of important constraints that influence disposals in AF, ensuring the multivariate context is taken into account. As a result, the practitioner can generate insights into how players action capabilities adapt under certain conditions and interacting constraints. For example, Robertson and colleagues' (2019) analyses determined that a lower amount of time was consistently influential across the constraint interaction matrices or rules. Specifically, a time in possession of less than two seconds occurs in four out of five constraint interaction rules in addition to negatively influencing kick outcome in competitive matches. Although these findings only relate to data collected from competitive AFL matches, the findings warrant increased targeted interventions during practice that aim to improve player performances under these constraint interactions.

The predominant challenge to optimise practice resides in how coaches design it. Whilst this has largely been based on coaches subjective opinions, measuring interacting constraints across multiple contexts has provided useful indications and assessments of how representative the practice activity is. Recently, research has compared constraint interactions and their frequencies in small-sided games, match simulation and competitive AFL matches (Browne et al., 2020). These researchers aimed to understand disposal sequences and the extent to which disposals are dependent on the preceding disposals. It was reported that disposal sequences differ between small-sided games, match simulations and competitive matches. Specifically, match simulations were more representative of competition compared to small-sided games, as indicated by disposal types and the types of pressure players interacted with. Moreover, the frequency of effective third disposals in the sequence were higher in small-sided games compared to match simulations and competitive matches. Here, assessing the disposal sequence and disposal effectiveness may help uncover information surrounding the continuation of play and how more or less effective disposals in a sequence can alter the perception of affordances across different timescales. Nonetheless, further consideration must be given to specific activities where the group-level task constraints, such as player numbers (e.g. 9v8), field size or different task rules (e.g. score by taking a mark in a particular zone on the field) would likely significantly alter these results. This requires research to integrate what the intention and purpose of the activity is as identified by the coaches and how practitioners can assess the intention to report whether it has been achieved or not.

To address this, Teune and colleagues (2021) documented a combination of three environmental (area per player, number of players and team outnumber) and two task (activity objective i.e. possession or scoring based and disposal limitations i.e. kicks, handballs or both permitted) constraints across AF practice activities. Regression models indicated these five constraints explained 68% of the variance in disposal frequency but only 22% in disposal proficiency. These results indicate the capability of these models to predict, to some extent, the disposal frequency of players in practice activities, but not disposal proficiency. This may be useful when coaches and practitioners are planning practice activities, aligning activities with a skill periodisation framework for advanced periodisation of skill learning (Farrow & Robertson, 2017). Nonetheless, altering team outnumbers or manipulating space per player did not influence disposal proficiency in this study, which is in disagreement with previous research in state-based AF players (Fleay et al., 2017). Teune and colleagues (2021) speculated that these differences between their results and the literature may be explained by the skill level of the sample being assessed. Future research may build on this by incorporating increased specificity of activity intentions (rather than just possession or scoring).

Whilst assessing AFL competition and training data reveals key constraint interactions that may influence players' skilled behaviours, practitioners and coaches working within or across different competition tiers i.e. state-level, may have different findings to research in the professional league. To address this, Browne and colleagues (2019) assessed constraint interactions when disposing of ball possession across three competition tiers of AF. Specifically, the authors compared Under-18, state-level and AFL competitions. The expansion of data analyses across three competition tiers demonstrated the AFL competition yielded an interaction of more difficult constraints. For example, players had to execute short kicks with 0-2 seconds of possession to a 'covered' teammate i.e. a teammate who has a defender on them, or a leading teammate i.e. a teammate who is running towards them wanting to receive the kick. Comparatively, U18 and state level competitions displayed greater variation across the seven shared interaction matrices/rules. Based on levels of confidence, the consensus was that AFL players executed skills more proficiently than state level players who executed skills in a superior manner than U18 players. This finding is intuitive, however, further provides some specificity as to which aspects of practice could be manipulated to help optimise development in each competition tier. Nonetheless, whilst these approaches and manuscripts provide great insight and the results suggest a general consensus into how constraints interact when players dispose of possession, each analysis yields similar results. So much so that there now seems to be a saturation of research that makes these comparisons of constraints and contextual features when players dispose possession (Robertson, 2016; Corbett et al., 2017; Woods et al., 2019b; Ireland et al., 2019; Browne et al., 2019; Robertson et al., 2019).

These approaches are now commonplace in professional AF. They provide accurate comparisons between practice constraints and competitive match constraints. However, an area that is yet to receive detailed attention is the structure and monitoring of practice. The amount of time coaches prescribe to specific activities remains an important but untouched aspect of skill acquisition and performance preparation. Previous research looking at physical performance reported differing training loads according to the type of training performed (Moreira et al., 2015). Specifically, pre-season activities recorded higher physical training load and session duration compared to in-season activities. The activities monitored were very broad and included games, combat activities, fitness, football and others. The authors also mentioned the large array of pre-season sessions was likely due to the wide variety of different training modes to meet the physical demands e.g. acceleration, deceleration, repeat-sprint ability, strength, power etc of AF. A similar extrapolation seems appropriate for individual and team skill and tactical preparation. Nonetheless, it is currently unknown how more specific practice activities change over a season. Farrow and Robertson (2017) proposed a skill acquisition periodisation framework and proposed guidelines to help researchers periodise and evaluate skill learning. Whilst it is based upon traditional physical periodisation models and generally lacks empirical data to support its notions, it provides some utility and guidance for practitioners. Nonetheless, future research should look to validate the guidelines set out in this framework.

The majority of the research evaluating constraint interactions during practice and comparing them to matches consistently report differences between each context. Specifically, it seems that time in possession, disposal type, pressure from opposition, disposal effectiveness and disposal sequences remain different in practice compared to competitive AFL matches. Whilst it seems a consensus on why this is the case is generally demonstrated i.e. different levels of representativeness during practice are implemented by the coaches, future research must challenge existing frameworks to consider whether pedagogical frameworks such as ED align with what is currently implemented by domain experts in the real world. Questions surrounding the highest level of representative practice required for players or teams to perform in competition or whether coaches compromise skill development if they do not implement ED principles are yet to be answered and require attention. The studies in this sub-section demonstrate consistent differences and potentially inadequate levels of representativeness of constraints in some aspects of practice but not others. Ultimately, the coaching group should determine the level of representativeness they are content with. Practitioners, such as performance or data analysts, sport scientists and coaches, and researchers play an important role regarding representative learning design during practice. Whilst the current research has largely focused on how disposals are affected under different interacting constraints, there is further research that has examined collective behaviour in AF teams during practice and competitive matches. Furthermore, there has been an improved integration of technical and tactical measures of skill and behaviour to assess match outcomes in AF. Consequently, the next section will detail how observations into collective team behaviour can help inform objective interpretations of team tactics. Consequently, this information can assist practitioners and coaches in their evaluation of practice interventions to improve skill transfer and further design practice using the constraints-led approach.

2.6.3 Investigations of performance indicators and behaviour in AF

The inception of large datasets and enhanced technologies has led to increased potential to help determine important indicators of performance and quantify collective behaviour in team sport (Gudmundsson & Horton, 2017; Silva et al., 2013). Key performance outcomes can help identify events or indicators that attempt to explain successful competitive outcomes. The adoption of technology, such as Global Positioning Systems (GPS) and improved data capture systems, and increased availability to researchers of the resulting data has resulted in a proliferation of research assessing performance indicators and collective behaviour investigations in team sport (Low et al., 2019) and more recently, AF (Alexander et al., 2019a, 2019b, 2021; Fahey-Gilmour et al., 2019; Fransen et al., 2021a; Sheehan et al., 2019; 2020; 2021a, 2021b). Performance indicators can help explain outcomes by segregating the whole performance into smaller components and analysing each in context of each other. Whilst they are reductionist by nature, performance indicators should complement a multidimensional approach to assess performance. Nonetheless, these sorts of indicators demonstrate what happened, however they do not consider how or why. To supplement this, information on collective behaviour can help uncover global patterns and interactions amongst the players' and team to help provide more precise and objective information on team tactics. With the evolution of analytical methods to appraise these aspects, such measures are now considered an important component in team sports (Clemente et al., 2018; Low et al., 2019). Consequently, assessing performance in team sport and AF should incorporate performance indicators with measures of collective behaviour. This section describes the research in each of these areas as it relates to AF.

Performance indicators can provide useful information to inform tactical strategies for competitive matches, however, they also provide guidance on areas that should be prioritised during practice (Robertson et al., 2016). The earliest analysis of performance indicators in AF was undertaken by Stewart and colleagues (2007) who reported influential statistics that contribute to a scoring margin across competitive matches from the 2002-2006 AFL seasons. The variables deemed most important in terms of their influence on game winning margins were inside 50s, all kicks in general play, short and long kicks and ground ball gets (gathering the ball). When creating a player evaluation to score margin model, the authors detailed key variables included a bounce whilst running, kicks that travelled more than 40m, centre bounce clearances and all kicks in general play. A key caveat to this research identified by Robertson and colleagues (2016) was the use of performance indicators in their absolute forms i.e. count values for a given match. Here, Robertson et al. improved the previous research by using relative values i.e. subtracting an opponents reported value from that of the team in question. The model outcomes and interpretations improved as the input values are relative to the opposing teams influence and account for between match changes that may randomly alter their effect e.g. weather, style of the game. Robertson and colleagues (2016) were able to correctly classify ~80% of match outcomes across the 2013 and 2014 AFL seasons using only two indicators: kicks and goal conversion. Other indicators such as inside 50's and contested possession were also useful in model classification. The agreement between these two manuscripts demonstrates the importance of kicks and inside 50's on match outcome. Considering the difference in time (and potentially era's and styles of play) from the respective seasons analysed, the results may indicate the timelessness of these metrics relative to competitive match outcomes.

Recently, Woods and colleagues (2017) investigated the temporal trends of key performance indicators across the 2001 to 2015 AFL seasons. The authors report differing counts of possession types and indicators of game style (marks, effective disposals, uncontested possessions, handballs) across different time periods from 2001 to 2015. This demonstrates that performance indicators can be transient depending on the coaching styles and tactics deemed to be most important to contribute to successful match outcomes. Other contextual factors, such as travelling for matches, the number of days break between matches, having an older or younger team and accounting for opposition strength have all shown trivial to large effects on match outcomes in the AFL (Fahey-Gilmour et al., 2019; Lazarus et al., 2017; Robertson & Joyce, 2018). Thus, performance indicators provide useful information for practitioners and researchers in regard to assessing performance in AF. However, such analysis has two main limitations: 1) they only describe what happened as opposed to how or why it occurred, meaning that the results may not have a great potential to be modified during training; and 2) performance indicators have shown considerable variability across time. This second point makes the addition of collective behavioural measures appealing when analysing match outcomes as they account for the dynamic nature of performance, as reflected by ED principles (Silva et al., 2013) and may also show greater levels of consistency across time (Fransen et al., 2021a). As such, collective tactical analyses can assist with the provision of a greater level of detail to team performance.

The capacity of tactical analyses to provide enhanced insight is captured by assessing the interactions amongst teammates and understanding how teams and individuals manage time and space through their movements (Duarte, et al., 2012; Passos, et al., 2009). As described in the previous sections, the movement patterns of players and teams emerge under an interaction of constraints in dynamic environments where players adapt to the positioning of their opponents, teammates and the ball (Duarte et al., 2013). Whilst performance indicators have provided useful information about the evolution of AF, such as increased possession-based strategies (Woods et al., 2017) and an increased adoption of defensive tactics (Pill, 2013), spatiotemporal tactical analyses can extend this analysis and provide further information. For example, Alexander and colleagues (2019a) investigated the influence of match phase and field position on team behaviour in one competitive AFL match for one team. The authors reported differences in the teams positional length, positional width and surface area in each phase of play (offence, defence and contest), with phase of play having a larger influence compared to field position (defensive 50, defensive midfield, attacking midfield, forward 50). Moreover, players compress the available space and move closer to their own goal when the ball was in their defensive half (creating higher density in their defensive 50 to reduce the space and options the opposition can pass and lead to) and pressed higher up the field when the ball was in their forward half.

Sheehan and colleagues (2021b) used newly derived spatiotemporal and physical metrics to examine the influence of match phase on physical and spatiotemporal movement behaviour. These novel metrics indicated that set shots, goal resets and stoppages can be characterised by superior dispersive coordination (i.e. the total space the team is occupying on the field in addition to the spread or contraction of the entire team relative to the teams centre/centroid) and multidirectional synchrony (i.e. the average position of all players in the team in the lengthways and widthways of the field) compared to offence, defence and contested phases of play. The superior values for set shots, goal resets and stoppages are likely reflective of game rules (e.g. position set ups during a centre bounce stoppage require a higher dispersion of players across the whole field) and a slowing of the speed of gameplay (i.e. players taking a set shot are given 30 seconds to do so). These spatiotemporal metrics incorporate common spatiotemporal metrics such as surface area and stretch index for dispersive coordination and lateral and longitudinal centroid synchrony for multidirectional synchrony (Sheehan et al., 2021b). Whilst stoppages (throw ins, ball ups and centre bounces are each types of stoppages where umpires reset play) are unique to AF in the way that players are actively re-positioning themselves during this 'break' in play, the findings regarding offence and defence are similar to previous research in association football (Clemente et al., 2018; Vilar et al., 2013). More recent research in AF has examined team numerical advantages across match phases (offence, defence and stoppages) and field positions (same as above) (Alexander et al., 2021). Numerical advantages were associated with greater likelihoods of gaining possession from clearances or scoring from inside 50's. Consequently, explorative collective behavioural analyses can help provide objectivity to team tactics and greatly compliment performance indicators. Consequently, practitioners can uncover spatiotemporal differences in competitive matches to help inform representative practice design and manipulate specific constraints to afford the team and players different opportunities. Readers are directed to Low et al. (2019) for further reading on specific outcomes from constraint manipulation in association football.

An additional component of collective behaviour analyses incorporates physical exchanges of information. These analyses have been common in the social sciences, examining things such as friendships, social interactions and email exchanges in workplaces, to name a few (Sparrow et al. 2001). These analyses provide detail on the connections and relationships amongst components in the complex system. Given the ability to capture complex and collaborative behaviours, social network analysis has been proposed as a useful method to capture collective behaviour in team sport (Passos et al., 2011; Silva et al., 2013). These networks can be used to represent passing or shooting interactions as a method to demonstrate how the players and team connect and cooperate. For example, Braham and Small (2018) modelled passes between players and play shots at goal as weighted, directed edges. A visualisation is presented in Figure 2.6.4.

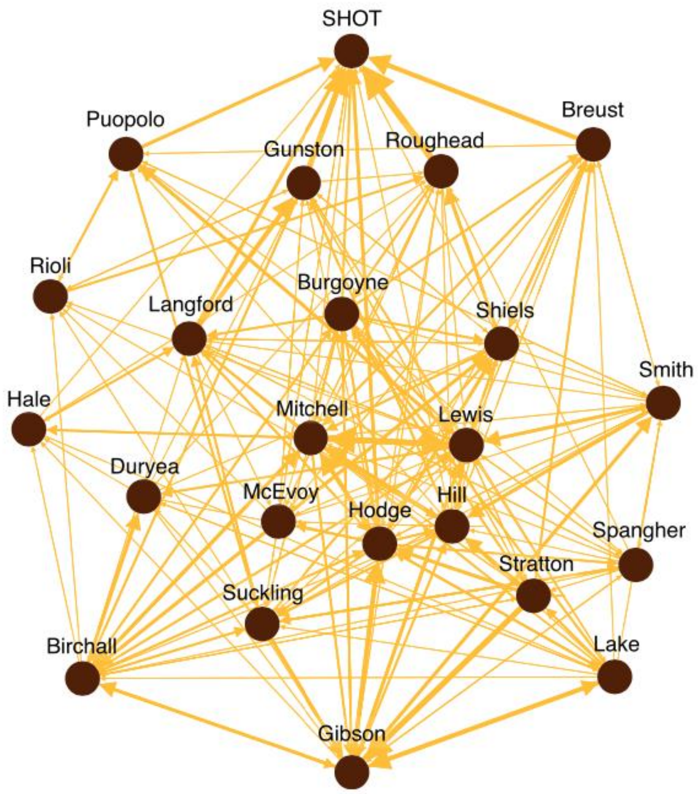

Figure 2.6.4: Player passing and shot network for Hawthorn Football Club during the 2014 grand final (Taken from Braham & Small, 2018).

These authors reported a method to quantitatively characterise team's passing strategies and styles. They detailed that successful teams have better connected networks and a more even distribution of passes between the players. Young and colleagues (2019) further reported differences between winning and losing teams across the 2009-2016 AFL seasons for cooperative passing network analyses. Specifically, edge count and edge density were higher in winning matches, whilst average path length was lower. This suggests that winning teams make more effective passes and have a higher number of passing connections amongst the team, whilst simultaneously having a lower number of passes per possession chain. That is, more players are involved in a more 'direct to goal' passing strategy. At a more microscopic level, specific passing chains can also be observed. For example, low network density and high entropy i.e. higher unpredictability in passing network, led to successful outcomes from kick in possession chains (Taylor et al., 2020). It is evident that cooperative passing networks are related to successful outcomes in team sports and AF in particular, however, there is a myriad of network metrics that researchers or practitioners could consider for inclusion in their analyses.

The emerging field of research has a range of variables which appear to have been largely selected as a matter of convenience using subjective methodology (e.g. inside 50s, kicks, handballs, disposals, clearances, metres gained; Robertson et al., 2015; Woods et al., 2017; Young et al., 2020), as opposed to more rigorous, objective methods. Whilst the metrics have shown utility in previous team sport research, the wide array of potential metrics to 'choose' from means that the analysis may determine different experimental findings as it only shows part of the picture. To combat these concerns, Sheehan and colleagues (2019) performed a principal component analysis on cooperative passing metrics in AF match-play. This type of analysis reduced the number of variables into three 'team-related' and two 'individual-related' components. The relationship the team metrics have to performance in the AFL was recently confirmed by Fransen and colleagues (2021a) who reported a 79.5% increase in the likelihood of winning an AFL match when there is a one standard deviation increase in one of the cooperative principal component scores, Connectedness. As detailed by Sheehan and colleagues (pg. 5, 2019), connectedness is comprised of multiple metrics where higher connectedness values *"signify that most players connect bi-directionally (network density) and are easily reachable for others (team in- and out-closeness centrality). Additionally, the negative contribution of team betweenness centrality indicates that lower scores benefit overall connectedness. A lower team betweenness centrality score signifies that most players within the network can connect with one another without relying on a linking individual*." Indeed, the simplified metric broadly showcases how well-connected networks are associated with positive outcomes in AF.

Collectively, network measures have established their value and importance in AF match outcomes. Furthermore, the inclusion of passing network metrics in analyses of match outcomes provide more information compared to purely conventional AF statistics (e.g. disposals, inside 50s etc), ultimately improving model outcomes and enhancing the generalisability of these metrics across teams. Here, Young and colleagues (2020) combined technical and tactical (passing networks) metrics to assess match outcomes in the AFL. Whilst the authors found comparable classification rates of winning and losing games to previous literature (Fahey-Gilmour et al., 2019; Robertson et al., 2016; Young et al., 2019), the seven passing network metrics represented ~55% of total weightings in the model, suggesting an important contribution even with a lower number of variables compared to technical indicators (45).

Nonetheless, whilst providing useful information corroborating findings in association football (Grund, 2012; Mendes et al., 2018) and basketball (Fewell et al., 2012), the current state of research speculates on how to achieve favourable outcomes in these metrics i.e. coach tactics or manipulating practice strategies. Research in association football has reported using the constraints-led approach to affecting cooperative passing network behaviours. Specifically, reduced playing space increases the interaction amongst players' within the network (Moreira et al., 2019). Players who were physically closer were more easily reachable using less complicated passing movements, resulting in a higher frequency of interactions between a greater proportion of players. Considering the potential value of being able to track the constraint manipulations made during practice and assess cooperative passing networks, it is surprising that it is yet to be investigated in AF practice. Additionally, coaches' interact with the players' and team and may further constrain behaviours during practice using feedback or instruction. Therefore, it is important to recognise the role of coaches' during practice as increased amounts of constraints such as feedback or instruction may influence a players or teams ability to retain information during practice and may ultimately affect competitive performance. Thus, the next section of the review will consider the current evidence examining coach behaviours in AF. An understanding of this will help determine how coaches currently behave in competition and practice, and how research can help provide a deeper understanding of empirical and experiential knowledge to improve skill transfer and improve the use of motor learning concepts such as feedback provision.

2.6.4 Documenting coach behaviours in AF

The development of expertise is complex (Baker et al., 2003; Ericsson et al., 1993). In team sport, coaches are a crucial link between measured behaviours (metrics used in performance analysis) and practice design. Practice is developed and monitored by coaches so it can be used to develop behaviours beneficial to winning competitive matches. As such, holistic perspectives on skill acquisition science in sport should consider the coach as an important component of skill learning. Coaches interaction with the players and team is an important component in the training and competitive environments (Cushion, Armour & Jones, 2006), in addition to the social and cultural dynamics of the environment (Amorose, 2007). Nonetheless, many elements of coaching, including feedback provided to the players or team, remain largely guided by tradition and emulation (Williams & Hodges, 2005). This is the common 'I did it this way when I played' type of approach. This has been termed the 'apprenticeship of observation' (Cushion et al., 2003, pg. 217) which results in coaches adopting a style that is heavily influenced by the approach they were exposed to as an athlete. Consequently, there has been a misalignment between the coaching frameworks proposed to best optimise skill acquisition and motor learning and development in the literature, and what occurs in the real world (Ford, Yates & Williams, 2010).

The recent interest in understanding coaching behaviours has grown as coaches' and coaching groups have become larger and played a larger role in performance preparation with regard to skill acquisition and development. The actions of coaches' significantly impact the cognitions and behaviours players and teams exhibit, influencing how they may learn and develop skills (Amorose, 2007; Cushion, 2010). It is important to note that every action and behaviour a player performs provides task-intrinsic feedback; feedback that is developed by the player when they perform the task and is continuously and concurrently available during a movement (Anderson et al., 2019). A critical question coaches must consider here is whether augmented feedback i.e. additional feedback on the performance of the task, is necessary and whether it further helps facilitate skill learning in the player or team. An effective use of augmented feedback is context dependent, pending a number of factors such as when it is provided, how it is provided and what component of the behaviour is feedback provided on (Anderson et al., 2019; Magill 1994). For example, a coach may provide augmented feedback during the performance of a defensive practice activity in association football. In the activity, players receive task-intrinsic feedback and may also receive augmented feedback in the form of a coach speaking to them. Here, players are more likely to use the coaches feedback over task-intrinsic feedback, even if the augmented feedback may be incorrect. It is an easier form of feedback to utilise to alter movement behaviours (Anderson et al., 2019). Whilst a significant portion of coaching behaviour literature has been performed in association football (Cushion, 2010; Cushion et al., 2012; Ford et al., 2010; Partington et al., 2015), AF has seen a recent focus of research on this aspect of performance and skill learning.

In AF, pedagogical frameworks have been considered when probing AF coaches about their experience implementing feedback (Pill, 2015). Here, the researcher (Pill, 2015) examined what factors influenced the two studied AF coaches decisions when implementing game sense coaching (game sense coaching advocates a hands-off approach to learning where the coaches facilitate learning via questioning and probing players after a game-type activity is performed). Whilst a largely theoretical perspective, Pill (2015) highlighted the importance ongoing interactions between coaches are in developing how they provide feedback and how providing feedback is contextual depending on characteristics such as when it is given and to whom it is given, to try to optimise skill learning. In light of this finding, it is important to recognise coaching, and in particular, providing verbal feedback, likely alters during practice compared to competitive matches. One of the main reasons this may be the case is based on the goals of each context. Mason and colleagues (2020) allude to one of these reasons being the relationship between time and performance outcome responses. For example, Mason and colleagues (2020a) reported higher levels of prescriptive feedback than descriptive feedback during a competitive AFL match. Empirically, prescriptive feedback attains a behavioural response quicker than descriptive feedback as the player/team are ‘told’ what to do, rather than to ‘think’ what to do (Anderson et al., 2019), removing cognitive processing times in the former feedback type. Contextual constraints such as the limited time to perform in competitive matches may mean this approach is more beneficial to performance (short term focus), but not learning (long term focus). Moreover, this research further reported that over 60 messages of verbal feedback are provided to players in a competitive AFL match (Mason et al., 2020a). Whilst this number is relatively low per player (~3 messages per player), coaches’ are logistically limited to how much feedback they can provide during an AFL match. During practice however, coaches’ may liberally provide feedback as often as they like and desire to. Consequently, it seems investigating verbal feedback as a constraint on skill learning and performance preparation in AF is significantly context dependent. To date, no investigations into verbal feedback have been examined in practice settings in AF.

Investigations in sports such as association football (Cushion et al., 2013; Partington & Cushion, 2011), boxing (Halperin et al., 2016) and basketball (Bloom, Crumpton & Anderson, 1999) have provided some background into the knowledge of coaches regarding how feedback is used and integrated in sports across practice and competitive matches. Indeed, Tinning (1982) contends that observing the instructive behaviours of coaches provides information on variables that help determine effectiveness within such instructive behaviours. A significant breadth of research exists in the observation of men’s youth soccer coaches. For example, Cushion and Jones (2001) observed the behaviour of top-level English premier league coaches’. These authors’ determined that the observed coaches pre-dominantly use instruction, praise and silence during practice sessions. Whilst feedback differs to instruction, the systematic observation of coach behaviours helps establish how coaches may use different interactions with the players or team to influence behaviour change. Furthermore, Partington and Cushion (2011) reported youth soccer coaches' provide high levels of prescriptive instruction during both training- and playing-form activities. Further qualitative assessments of these coaches revealed that the coaches had low self-awareness of their behaviours during practice, indicating a misalignment between intent and the actual behaviours they exhibited during practice (Partington & Cushion, 2011). Consequently, an assessment of the feedback coaches provide may help reveal information on coaches behaviour during practice and provide insight into which practice activities they intervene to provide feedback in.

In professional level association football coaches, Potrac and colleagues (2007) demonstrated that pre-, concurrent- and post-instruction (i.e. feedback) interactions represented 54% of all recorded interactions with the players during practice. The authors speculate that these behaviours seem to align largely with what a coach 'should do', based on previously playing and coaching and associated socialisation experiences in their respective sport (Portac et al., 2007). Moreover, increased instruction or feedback may be provided because coaches do not want to be perceived as lacking knowledge or expertise. In amateur youth volleyball however, coaches show much lower rates of pre-, concurrent- and post-instruction during practice compared to professional football coaches (36% versus 54%; Isabel et al., 2008). As a result, the context and recipients of coach interactions during practice is an important concern researchers must be aware of when observing coach behaviours.

Critically however, the frequency and content of the feedback provided to players can have an influence on future dependency on feedback for performance. In essence, augmented feedback is provided to guide the learner towards successful completion of the task goal (Anderson et al., 2019). A potential negative consequence of providing feedback to complete the task goal is that learners/performers become dependent on the informational support and neglect task-intrinsic feedback, such that performance suffers when augmented feedback isn't available (Anderson et al., 2019; Wulf et al., 2002). This is often the case in sport, where coaches can liberally provide feedback during practice, but not during competition. This situation, whereby augmented feedback guides the performer while simultaneously potentially creating a dependency is known as the guidance hypothesis (Salmoni et al., 1984). Thus, the provision of augmented feedback by coaches has implications for performance and may lead to inferior learning and poorer performance in competitive environments. Whilst research has identified strategies to discourage a performers dependency on feedback (e.g. scheduling feedback, a bandwidth approach, performer-requested provision of feedback etc; Anderson et al., 2019;

Wulf & Lewthwaite, 2016), it is important to identify how much feedback coaches are providing and in which activities during practice it is being provided.

Recently, an examination into AF coach behaviours regarding feedback provision was reported (Mason et al., 2020b). The authors assessed professional AF coaches beliefs, knowledge and approaches to providing, receiving and evaluating feedback. The results aligned with broad-level conceptual beliefs on feedback, namely that feedback is used as a tool to improve performance, build player confidence, monitor player progress and as a tool to evaluate their own performance (Mason et al., 2020b). Indeed, coaches seem to acknowledge the importance of feedback for both the coach and the player, with one coach suggesting feedback is necessary to provide to players for learning but can also be used to improve their coaching practice. Consequently, professional AF coaches consider verbal feedback to be an important area for optimising skill learning for players and the team. Whilst this study has helped provide information on coach beliefs on verbal feedback, future research is required to assess how coaches implement verbal feedback during practice, and how this may change pending on contextual factors such as the activity type or the time of the season. As a result, it seems examining verbal feedback provided by coaches during practice may prompt and illuminate areas of coaching that may further benefit from a higher level of integration of empirical evidence from motor learning and skill acquisition literature.

2.7 Summary and Research Problems

Ecological Dynamics (ED) is a viable and robust framework to explain behaviour in complex systems like a team sport (Davids et al., 2003; Handford et al., 1997). Yet, this approach often presents with a lack of application with practitioners due to its complexity and scientific jargon. Nonetheless, the constraints-led approach appears to be an effective method to apply ED and its concepts in the human-centred environment of sport. Whilst it provides value for enhancing the representativeness of practice to matches, there is a distinct need for more work to be performed in analysing how global complex behaviours can be best transferred to match-play. For example, it is important to determine the type of cooperative network beneficial for winning competitive matches and whether this network can be modified through the use of appropriate training. Furthermore, it is important to investigate how coaches can manipulate training to influence complex system behaviour and 'push' its behaviour towards something more optimal. Indeed, such research aims to provide insightful information regarding how complex systems operate and emerge in professional Australian football (AF) practice. Moreover, this process aims to improve the scientific process of practice design and integrate current coaching expertise with empirical skill acquisition knowledge.

Performance in team sport, and indeed AF specifically, is complex and multifactorial. AF exhibits key characteristics of a complex system, making it possible to describe its behaviours in the context of the ED framework. Particularly, features such as multiple independent and variable degrees of freedom, potential for non-linearity in behaviour, capacity for stable and unstable behaviour, a multi-level structure where subsystem components can limit or influence another and self-organisation tendencies all comprise components of a complex system that can be observed in AF. Consequently, the practice environment and its design can be difficult to evaluate due to the broad range of activities performed and the breadth of intentions of these activities.

Traditionally, to determine the efficacy of practice, coaches use subjective opinions based on their experience playing and coaching. Whilst valuable, the complex and dynamic interactions of practice make it difficult to understand the behaviour and how and why it occurred in the environment. Additionally, evaluating player and team behaviour and comprehending whether it is similar and if it will beneficially transfer to match-play is even more difficult to determine. As such, objectively monitoring the practice environment, and how the constraints implemented by coaches change behaviour, would be useful to assist coaches to design practice contexts that are more representative of match-play. Unfortunately, to-date there is little research that has described complex behaviour in professional AF (Alexander et al., 2019; Sheehan et al., 2019; Woods et al., 2019a), with an abundance of possibilities to potentially be unlocked from the undertaking of such investigations.

Whilst recent advances in the integration of skill acquisition and performance analysis have assisted with the further improvement of the quantification of constraints and skilled performance, very few research publications to-date have assessed AF practice context in professional players (Alexander et al., 2019; Browne et al., 2019, 2020; Corbett et al., 2017; Ireland et al., 2019; Robertson 2016; Woods et al., 2019b), with a large focus on the prevalence of constraints when disposing (handball or kick) the ball. The research has differed in terms of the cohorts assessed, the level of competition played, and the type of disposal performed but it has generated a consensus across these characteristics that practice remains different to competition matches in AF. Nonetheless, whilst such research has quickly influenced practice, it remains a focus to understand how task constraints implemented by coaches influence collective behaviour during practice. Additional research focusing on performance indicators in AF may also provide useful information when assessing performance. Research has shown variation in metrics that are important for winning Australian Football League matches: inside 50 kicks, general play kicks, groundballs and scoring rates have shown consistent differences when teams win competitive matches (Robertson et al., 2016; Stewart et al., 2007). However, indicators that are important for winning matches have also changed over seasons (Woods et al., 2017). Practitioners must then account for performance indicators not fully describing how or why things are occurring and also that these indicators typically vary in importance over time. Thus, their use for practice design and their overall trainability may be questionable, making the integration of tactical metrics appealing to integrate as they better account for the inherent variability in performance.

Young and colleagues (2020) combined technical and tactical measures to assess match outcomes and found an important contribution from a smaller number of tactical measures relative to the technical measures in explaining match outcomes, where the authors reported similar classification rates of winning and losing matches to other research in AF (Fahey-Gilmour et al., 2018; Robertson et al., 2016; Young et al., 2019). Thus, an integration of technical and tactical metrics would be useful when assessing performance in AF, which would also apply to assessments of practice design and determining their efficacy. Nonetheless, designing valid and representative assessments during practice in professional team sport, which incorporate technical and tactical measures to assess their efficacy, is difficult. This is partially due to the nature of skill and the environment, and also due to resources and player availability. Thus, there remains opportunities to continue to refine training practices in professional AF team performance through ED and the constraints-led approach. Specific research problems that exist include:

- No research has examined how coaches implement practice activities over a full season and what implications this has for skill learning and representative practice.
- Recent research has examined the augmented feedback provided during competitive AFL matches, but no research has examined augmented feedback provision during

practice and investigated such feedback provision across things such as practice types, time of season and playing- and training-form.

- There is an overwhelming prevalence of assessing how constraints interact when players dispose of the ball. No research has assessed task constraints that may also influence individual and team behaviour, such as field length or field width.
- A comparison of the behaviours exhibited by players during practice that is considered to be representative of game play and competitive matches is useful to understand to which extent coaches in a professional team design representative practice.
- Whilst tactical metrics (e.g. passing networks and spatiotemporal metrics) have shown a higher propensity for trainability in association football, no research has examined how tactical metrics may be trained or influenced in AF using the constraints-led approach
- Overall, the theoretical principles of ED such as athletes perceiving and using affordances to inform action, behaviour spontaneously self-organising under the interaction of constraints, a multi-level structure within the complex system that has the ability to influence other components and levels, the potential for non-linearity in behaviour and it's development, to name a few, require further empirical examinations to ensure the concepts of the framework can be continuously applied and redirected in sport in general, and in AF specifically.

Consequently, an integration of understanding between empirical knowledge and experiential knowledge would help optimise how practice is evaluated in relation to individual and team behaviour. Further, an improved integration would assist practice design in relation to its level of representativeness and how this may be improved using the constraints-led approach.

Chapter 3 | Research Overview

As a result of synthesising the current Ecological Dynamics (ED) framework in team sport with the constraints-led approach, considerations to the current framework are proposed that substantiates the current thesis' studies (Figure 3.1.1). Within these considerations (Figure 3.1.1), the solutions of system organisation states are available, and discoverable, within the teams potential movement solutions (dark grey area on the left). These organisational states are defined by the interaction of constraints, i.e. task, individual and environmental, that provide shared affordances, or collective opportunities, for collective action, similar to how perception-action coupling affects behaviour in individuals. The potential movement solutions within the landscape are defined by the change in number and type of collective opportunities for action. As a result, system i.e. team, behaviours emerge and organise into certain patterns and stable states of behaviour over time, as a result of practice and experience e.g. competition. Within the resultant behaviours, control parameters (i.e. constraints that can move the system through different organisational states) affect the order parameters (i.e. the organisation of the system). This process results in dynamic processes of stability or organisation, and instability or reorganisation, of the systems behaviours. With an enhanced understanding of behaviour in complex systems, such as Australian football (AF), practitioners and analysts can observe behaviour and assess if it is stable after coaches manipulate certain control parameters (e.g. change in the practice activities width may lead to system reorganisation). Practitioners and coaches can then determine if the behaviour within a certain practice drill is stable and effective (consistent behaviour with increased transfer to match performance), or stable and ineffective (consistent behaviour with less transfer).

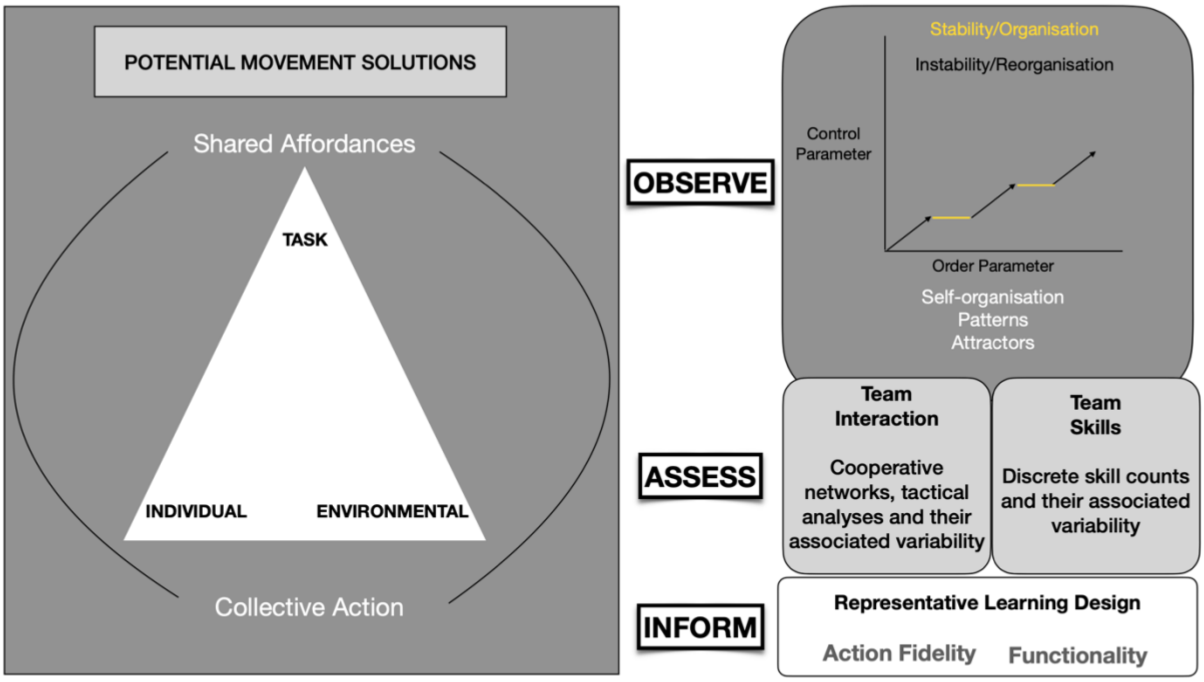

Figure 3.1.1: The current framework with considerations that integrate concepts from ecological dynamics and experiential knowledge from coaches and practitioners to help implement and evaluate the constraints-led approach to practice in team sport.

This thesis consists of a series of studies with the collective aims of synthesising current evidence and frameworks to enhance the efficacy of the activities coaches implement in practice, analysing complex behaviour in practice, whilst also evaluating behaviour to enhance representative learning design (Figure 3.1.2). Understanding ED as a guiding framework permitted data collection to occur in a naturalistic context, where coach behaviour could be investigated largely without any researcher intervention.

A primary aim of the research undertaken in this thesis was to enhance the application and integration of results in professional sport as the research questions were developed in conjunction with practitioners at the highest level of sport (coaches of a professional AF team).

Consequently, the generation of five research questions sought to address the aims of this thesis. The research questions asked were:

1) How do coaches currently design practice across a season and what value do they place on different practice types?
2) Which factors explain the duration of augmented feedback coaches provide to the team during practice?

3) Which factors can coaches manipulate during practice using the constraints-led approach to influence favourable collective tactical behaviour metrics?
4) Which differences exist (if any) between the most representative form of practice i.e. match simulation, and competitive Australian Football League matches?
5) In which way do professional Australian football players change their cooperative and individual behaviours when space per player (m^2) is manipulated during practice?

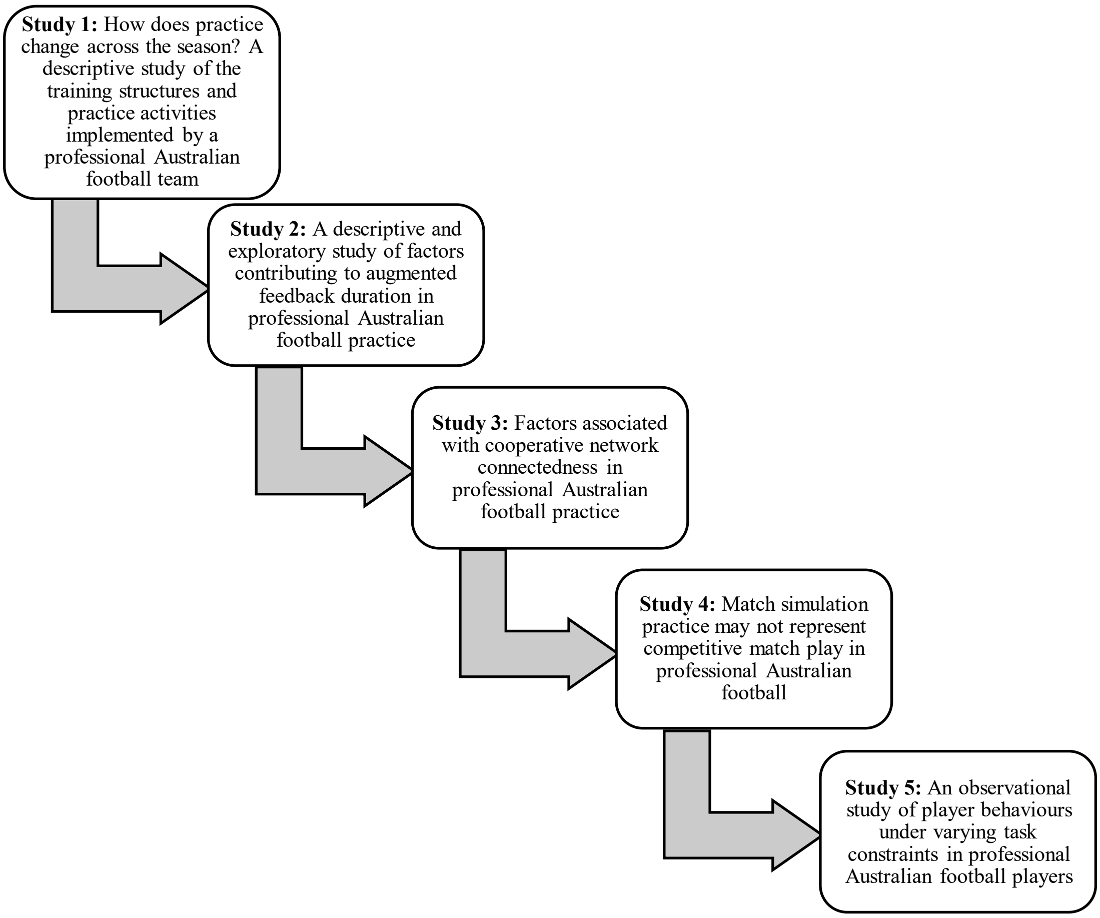

Figure 3.1.2: Integration of studies.

The descriptive and observational studies comprise a significant portion of the thesis. However, they represent an importance in shaping the observational study with a manipulation component, which was developed in conjunction with the coaches' based on the findings and results from the first four studies. The descriptive studies aim to describe what is currently being performed in professional AF practice in a naturalistic context, whilst the fifth study aims to improve how such practice can be evaluated and performed.

Chapter 4 | How does practice change across the season? A descriptive study of the training structures and practice activities implemented by a professional Australian football team

As per the published article:

Tribolet, R., Sheehan, W.B. Novak, A.R., Watsford, M.L. & Fransen, J. (2021), How does practice change across the season? A descriptive study of the training structures and practice activities implemented by a professional Australian football team, *International Journal of Sports Science and Coaching, DOI:* 10.1177/17479541211019829.

4.1 Abstract

There is limited research investigating objective practice monitoring in team sports. This observational study examined the practice activities used by eight professional coaches across 72 different practice sessions in one season within a professional Australian football team. This study aimed to evaluate the extent to which these practice types differed from those shown to facilitate skill acquisition in team sports. Across the whole season (pre-season and in-season), coaches implemented seven practice types which were categorised into training-form and playing-form. Practice type frequencies were different between pre- and in-season (χ^2=109.6, p<0.001). Significant differences were reported for practice type duration between pre-season and in-season (p=0.023, d=-0.17), where in-season activities were longer. Coaches implemented a higher percentage of practice time to playing-form activities in-season (62.0±25.4) compared to pre-season (52.4±19.8) [95%CI: -2.35:21.4]. Coaches were more likely to alter the frequency of practice types, rather than the exposure time. Players performed more training-form activities during pre-season than in-season (χ^2=30.8, p<0.001). There were no differences in playing-form activities between pre- and in-season. This study provides insights into the practice activities implemented by professional Australian football coaches and discusses the extent to which they represent best practice in the context of skill acquisition.

4.2 Introduction

Experts exhibit superior execution, perceptual-motor proficiency and information processing abilities with respect to skill in team sports (Farrow & Baker, 2008; Williams & Hodges, 2004). The amount of time spent in practice has historically been associated with the above characteristics e.g. Ericsson and colleagues (1993) hypothesised improvements in skill were primarily related to the amount of time spent in deliberate practice. However, contemporary research suggests that the development of skilled performance is more complex. Recent research has demonstrated a range of constraints that impact skill development and proficiency. For example, although Baker and Cobley (2013) note the differences between individual proficiency when performing a skill may originate from the relationship between the amount of practice and performance, it is the type of practice (i.e. high validity or highly representative environments and the information available within them) that can further differentiate expert performers from non-experts (Farrow et al., 2013; Kahneman & Klein, 2009). Different practice environments in team sport led to different behaviours emerging (Silva et al., 2014). Thus, the consequence of the interaction of the constraints imposed on the skill is fundamental to how skill emerges and develops (Newell, 1985). Consequently, an awareness of the specific environments implemented for skill acquisition and expertise development is useful for practice design. In part, this will enhance coaches' awareness for skill acquisition and development and its usefulness for future refinement of practice design.

According to the constraints-led approach to skill acquisition, skilled behaviour emerges through the interaction of individual, environmental and task constraints (Davids, Araújo, Shuttleworth & Button, 2003; Davids, Button & Bennett, 2008). Due to the complexity of team sport performance, performers interact and adapt to an array of interacting constraints to collectively achieve a common goal (Davids, Araújo, Shuttleworth & Button, 2003; Handford, Davids, Bennett & Button, 1997). Consequently, coaches aim to design practice that represents the performance contexts and the information sources that are present during competition (Pinder, Davids, Renshaw & Araújo, 2011). Task constraints are commonly implemented by coaches (Ometto et al., 2018), and involve changing the field size, the number of players, or task goals, to name a few. Coaches often manipulate task constraints during practice to elicit specific behaviours from their performers. Nonetheless, these constraints may not always be manipulated deliberately, and in reality, are often the result of ad-hoc implementations by coaches (e.g. the players are not sufficiently pressured, so the surface area in a small-sided game is adapted during training). It is this exposure to specific practice contexts that allows performers to adapt their behaviour to the environmental information more effectively over time. This concept is referred to as perceptual attunement and is commonly associated with expertise in human movement (Araújo, Davids & Hristovski, 2006; Gibson 1979). This mutuality between the performer and the performance environment is adequately described in the ecological dynamics approach to skill acquisition in team sport (Araújo, Davids & Hristovski, 2006; Davids, Araújo, Vilar, Renshaw & Pinder, 2013). To effectively train collective and individual behaviour in team sports, exposure to practice contexts that replicate the coupling of perception and action is needed. Interestingly, the specific practice activities implemented by coaches throughout the season at the professional or amateur level has yet to be documented in the scientific literature.

A common approach within team sports training is to increase specificity as competition approaches (Bompa, 1999; Impellizeri, Rampinini & Marcora, 2005). In the Australian Football League (AFL), particular attention is payed to periodisation and the specific activities players perform across pre-season and in-season. For example, Moreira and colleagues (2015) reported higher physical training loads for all training activities during the pre-season compared to in-season. The emphasis for practitioners is to physically 'peak' the players for the competitive in-season period, which is commonplace amongst physical performance programs in the AFL (Moreira et al., 2015; Robertson & Joyce, 2018). Consequently, practitioners and coaches must simultaneously prepare players physically, but also skilfully and tactically. The subsequent structure of practice and how much time is spent practicing certain activities then becomes a considerable concern. Importantly, when and how this shift in practice occurs often demonstrates a different collective focus for teams and likely reveals the value coaches place on physical, skill or tactical development throughout the season. Guided by physiology periodisation, Farrow and Robertson (2017) and Otte and colleagues (2019) provided conceptual frameworks for skill acquisition development in team sport and skill development for 'specialist' coaches, respectively. Both frameworks consider traditional coaching features that can be observed to indicate skill acquisition periodisation, such as the progression of practice (e.g. less to more representative practice), incorporating more specific practice closer to competition and how to overload the organisation of the team and individuals. Whilst these frameworks propose guidelines for skill acquisition periodisation, no literature exists to determine whether coaches implement such guidelines.

It is generally coaches relying on their experience, expertise and philosophies when designing and implementing practice. Hence, it would be beneficial to notate and measure the types and duration of practice coaches implement to help enhance our understanding of how much value coaches place on specific types of practice and when this changes throughout the season. There is currently an absence of research illustrating the types of practices professional teams perform in a full season across any sport.

The Australian Football League (AFL) is the professional competition of Australian Football (AF) that involves 18 competing teams based around Australia. The complex nature is demonstrated through dynamic environments and emergent patterns of behaviour (Alexander, Spencer, Mara & Robertson, 2018; Sheehan et al., 2019). Moreover, coordinative team behaviour in AF is predicated on functional behaviours based on the spatiotemporal relations between performers, as they continuously adapt to their teammates and the opposition's movements (Silva et al., 2016). This exemplifies that AF players perceptually attune to relevant sources of information in games and take advantage of shared affordances, i.e. collective opportunities for action (Silva, Garganta, Araújo, Davids & Aguiar, 2013) to produce actions that increase the team's likelihood of winning. As such, representative sources of information and action should be reflected in practice contexts through representative learning design (Pinder et al., 2011). In association football, research investigating practice activities implemented by youth soccer coaches has shown more time is spent practicing 'less relevant' activities, such as those with easier or less decision-making elements, part-task practice routines or simplified elements of tactical play (Ford et al., 2010; Partington & Cushion, 2011). There is no research examining the practice activities of professional association football players. Recent research in professional AF highlights the discord between the constraints encountered in training environments and competitive matches. These studies provide clarity for practitioners aiding practice design. For example, Ireland and colleagues (2019) described conflicting temporal and situational constraints when disposing possession in competitive matches compared to practice. Specifically, defensive pressure applied to kicking disposals was significantly higher in matches compared to practice contexts. Similarly, Browne and colleagues (2020) compared the frequency and interaction of constraints across match simulation, small-sided games and competitive matches. The authors reported disparity between each context, especially in regard to the disposal type i.e. kick or handball, and the proceeding disposal effectiveness. Here, the sequence of an effective third disposal was lower in matches and match simulations compared to the observed small-sided games. Thus, understanding and implementing representative learning design is crucial and can assist coaches to provide practice environments that are more likely to increase the transfer of practice to game performance (Farrow et al., 2013; Pinder et al., 2011).

To date, no studies have documented the practice activities that professional AFL teams perform throughout a complete season. This study aimed to describe the practice activities implemented by AF coaches throughout a competitive season, with an emphasis on quantifying the exposure (time and frequency) to certain types of practice. It was hypothesised that coaches would implement a higher proportion of more representative activities, termed playing-form activities, during the in-season phase. Additionally, it was hypothesised that coaches would employ a higher proportion of less representative activities, termed training-form practices, in the pre-season compared to in-season.

4.3 Methods

Participants

One professional AF club agreed to be involved in the research. Specifically, the coaching group and head of performance agreed for this research to be executed. The team consisted of 48 male professional Australian footballers (age: 23.28±4.35 years) and they participated in their normal training across one entire season. The pre-season phase lasted four months from November to March, whilst the in-season phase lasted six months from March to September. The eight senior and development coaches within the professional club had an average of 6.8±6.5 years of AFL coaching experience, in addition to an average of 11.5±5.1 years of playing professional level AF. Training occurred without intervention from researchers. Ethics approval was obtained for this study from the University's ethics committee.

Practice activities

In total, 37 pre-season and 35 in-season training sessions were recorded across the data collection period, resulting in an entire sample of 72 sessions. The data for each training session was collected at the team level. Practice sessions were planned by the coaching group in conjunction with physical performance staff to determine player availability (which players can participate in which drills). The club utilises a long-term planning framework to guide practice design, while also accommodating for variation based on player availability e.g. if less players were available than expected, then an activity tended to be conducted with slightly smaller field dimensions. For each field session, details of practice activities were recorded, and activities were filmed. Filming was captured using a combination of handheld and remote video cameras (Axis Q6128-E Network, Axis, Lund, Sweden and Canon Legria HFG30, Canon, Tokyo, Japan). One was placed perpendicular to the direction of play at the side-line, and the other behind the goals. Both cameras were placed at elevated positions. Training footage was manually coded for time spent in each practice and one investigator notated the start and finish of each practice.

All practice types were categorised into one of seven classifications by the coaching staff: fundamentals, fitness, skills, breakdown, transition, line specific and match simulation (Table 4.3.1). These practices were classified by the research team as either training-form or playing-form, as per the methods of Ford and colleagues (2010). Training-form practice types were performed in isolation or in small groups. They generally involved simplified practices (Edwards 2010) and are repetitive in nature. Playing-form practice categories have a game-related focus and emphasise certain phases in a game (i.e. stoppages) or relate to transitioning between certain phases (e.g. attack to defence). This practice includes position-specific set ups and break downs. All practice sessions were annotated by the same experienced observer, who had annotated more than 200 hours of AF training and match-play. Coding reliability was assessed using an intra-class correlation coefficient (3, k; Koo & Li, 2016).

Table 4.3.1: Training activity categories and their definitions

Practice Activity	Definition
Training-form	
Fundamentals	Drills that focus on kicking, handballing, marking, tackling technique and handwork. Generally performed in small groups that are repetitive and blocked and have unopposed skill repetition.
Fitness	Activities aimed at improving game-related fitness qualities (e.g. aerobic capacity, repeat speed ability etc).
Skills	Consists of various practices. They largely involve ball movement (cone to cone), chaotic handball practices with outnumbered situations (e.g. 4v3), goal kicking and crumbing. Tend to re-enact isolated game incidents.
Playing-form	
Breakdown	Part-practice activities that involve a certain phase of game play. E.g. stoppages or exiting the defensive 50. Generally, these practices have limited/reduced opposition.
Transition	Activities such as small-sided games that aim to simulate the continual adaptation between attack, contested play and defence seen in match-play.

Line-specific	Practices that are run by each line coach and are positional and craft specific. For example, midfielders may work on the centre bounce clearance whereas defenders and forwards may work on 1 on 1 marking contests.
Match Simulation	Involves representative game play/simulation. This involved anywhere between 13-18 players on each team

Data analysis

The time spent in each practice activity type was calculated over the whole season, and separately for pre-season and in-season phases. Practice activity was analysed as both frequencies and as percentages of total time. Firstly, cross-tabulations and chi-square tests of independence (χ^2) used the frequency of events to investigate the relationship between practice categorisations (practice activities and practice forms) and season phases (pre- and in-season). Chi-square tests of independence were used to help compare the distribution of practice activities between the pre- and in-season periods to assess how the frequency of the activity implemented by coaches differed between each period. Secondly, the time in each practice activity type between pre-season and in-season was compared using a paired samples t-test. Practice activity proportions were expressed as a percentage of total time spent in practice by dividing the time spent in the activity by the total time spent in practice for the whole season and then for pre- and in-season individually, and then multiplying this number by 100. Additionally, comparing the duration of time spent in playing-form activities from pre-season to in-season was analysed using a paired samples t-test. The data was normalised by calculating the percentage of session duration players spent in playing-form activities to prevent violating the statistical assumption of independence. Similar methods normalising playing-form activities have been used previously (Ford, Yates & Williams, 2010; Roca & Williams, 2020). Effect size statistics were used to quantify the magnitude of difference between the groups, with interpretation of magnitudes being <0.19=trivial, 0.2–0.49=small, 0.5–0.79=moderate, >0.8=large (Cohen, 1988). The alpha level for significance was set at $p<0.05$. All statistical analyses were conducted using JASP Team (Version 0.11.1, 2019).

4.4 Results

The intra-class correlation coefficients between test 1 and test 2 demonstrated excellent reliability ($r = 0.97–0.99$) for the annotations of practice types and time spent in each practice type.

Practice type and practice form frequencies

Table 4.4.1 demonstrates the chi-square contributions for each practice type and practice activity form. The chi-square test of independence comparing in-season practice type frequencies to pre-season practice type frequencies demonstrated significantly different frequency distributions in different phases of the season (χ^2=109.6, p<0.001). Table 4.4.1 presents the observed and expected counts for each practice type and shows the contribution to the final chi-squared value. The large chi-square value is largely caused by not performing any fitness sessions in-season, moving to a very low amount of fundamentals in-season and an increased number of line specific practice drills in-season. Pre-season included more breakdown (+8), fitness (+63), fundamentals (+105), skill (+14) and transition (+10) type practice. Higher amounts of line specific (+14) and match simulation (+4) practice types were performed in-season. Furthermore, the chi-square test of independence demonstrated a significant difference between training-form and playing-form activities when comparing pre- and in-season frequencies (χ^2=30.8, p<0.001). Table 4.4.1 presents the observed and expected counts for each practice form and their respective contribution to the final chi-squared value. There was no change in the frequency of playing-form activities between pre- and in-season. However, the relative contribution to chi-square values is caused by a large difference in the frequency of training-form practice between pre- and in-season. Training-form practice was performed more frequently during pre-season (+182). Playing-form practice frequency was equal between pre- and in-season (82).

Table 4.4.1: Cross tabulations and chi-square contributions for each practice type and practice form.

Practice Activity and Form	Season Phase	Observed Counts	Expected Counts	Sums	Squared Difference (Observed-Expected)	Chi squared contribution
Breakdown	Pre-season	23	25.5	38	6	0.24
	In-season	15	12.5			0.48
Fitness	Pre-season	63	42.2	63	432.8	10.26
	In-season	0	20.8			20.80
Fundamentals	Pre-season	117	86.4	129	936.3	10.84
	In-season	12	42.6			21.98
Line Specific	Pre-season	13	26.8	40	190.2	7.10
	In-season	27	13.2			14.40
Match Simulation	Pre-season	19	28.1	42	8	2.96
	In-season	23	13.9			6.01
Skill	Pre-season	97	120.6	180	555.1	4.60
	In-season	83	59.4			9.34
Transition	Pre-season	27	29.5	44	6.1	0.21
	In-season	17	14.5			0.42
					Total χ^2	109.6

Training-Form	Pre-season	277	249.2	372	775.2	3.1
	In-season	95	122.8			6.3
Playing-Form	Pre-season	82	109.8	164	775.2	7.1
	In-season	82	54.2			14.3
					Total χ^2	30.8

χ^2=chi-square value.

Practice activity duration

The average practice activity time for a drill in pre-season was 7.0±0.8 mins. While the average practice activity time in-season was 8.0±0.4 mins. There was a significant difference between practice activity duration between pre-season and in-season (t (177) = -2.286, p=0.023, d=-0.17 [95% CI: -0.319- -0.023]). Subsequently, the in-season phase had longer practice activity durations with lower variation.

Time-use analyses

Table 4.4.2 outlines the time spent in each practice type separated by season phase. Figure 4.4.1 illustrates the proportion of time (in addition to the proportion of frequencies, i.e. how often the practice activity was implemented relative to the total number of practice activities performed) in each practice activity between pre- and in-season. Since practice activity time differed across pre-season and in-season, a paired samples t-test was used to determine the difference in percentage of session duration spent in playing-form activities. The average percentage of time spent in playing-form activities for pre-season was 52.4±19.8, whilst for in-season it was 62.0±25.4. The difference in proportions between pre-season and in-season was non-significant (t = (27) -1.641, p=0.112, d=-0.31 [95% CI: -0.687-0.072). Across the whole season, a higher proportion of time was spent in training-form activities compared to playing-form activities. In pre-season, a higher proportion of training time was spent in training-form compared to playing-form activities, whilst a higher amount of time was spent in playing-form activities in-season, compared to training-form activities.

The descriptive data shows that across the whole season, the proportion of time in training was the largest for skill, followed by match simulation, fundamentals, transition, line specific, fitness and breakdown. In pre-season, skill type practices composed the largest proportion of training, followed by fundamentals, fitness, transition, breakdown, match simulation and line specific. The greatest proportion of training in-season was spent in skill, followed by match simulation, line specific, transition, breakdown and fundamentals. All of the relevant proportions (in percentages) are reported in Table 4.4.2.

Table 4.4.2: Practice types and the total time and proportion spent in each, according to whole season, pre-season and in-season.

	Practice Type	Average Duration (mins)	N	Total Time in Practice Type (mins)
Whole Season	**Training-form**	**5.9 ± 2.8**	**372**	**2207**
	Playing-form	**12.9 ± 5.1**	**164**	**2114**
	Breakdown	10.9 ± 5.5	38	414
	Fitness	6.8 ± 4.0	63	431
	Fundamentals	4.4 ± 2.1	129	569
	Line Specific	12.1 ± 4.0	40	485
	Match Simulation	15.8 ± 3.4	42	664
	Skill	6.7 ± 2.2	180	1207
	Transition	12.2 ± 5.7	44	551
Pre-Season	**Training-form**	**5.8 ± 3.0**	**277**	**1609**
	Playing-form	**14.8 ± 4.6**	**82**	**1220**
	Breakdown	13.5 ± 4.9	23	310
	Fitness	6.8 ± 4.0	63	431
	Fundamentals	4.2 ± 2.1	117	495
	Line Specific	15.0 ± 4.0	13	194
	Match Simulation	15.8 ± 4.2	19	301
	Skill	7.0 ± 2.3	97	683
	Transition	15.0 ± 5.1	27	415
In-Season	**Training-form**	**6.3 ± 2.0**	**95**	**598**
	Playing-form	**10.9 ± 4.7**	**82**	**894**
	Breakdown	7.0 ± 3.9	15	104
	Fitness	0 ± 0	0	0
	Fundamentals	6.1 ± 1.4	12	74
	Line Specific	10.8 ± 3.2	27	291
	Match Simulation	15.8 ± 2.8	23	363
	Skill	6.3 ± 2.0	83	524
	Transition	8.0 ± 3.7	17	136

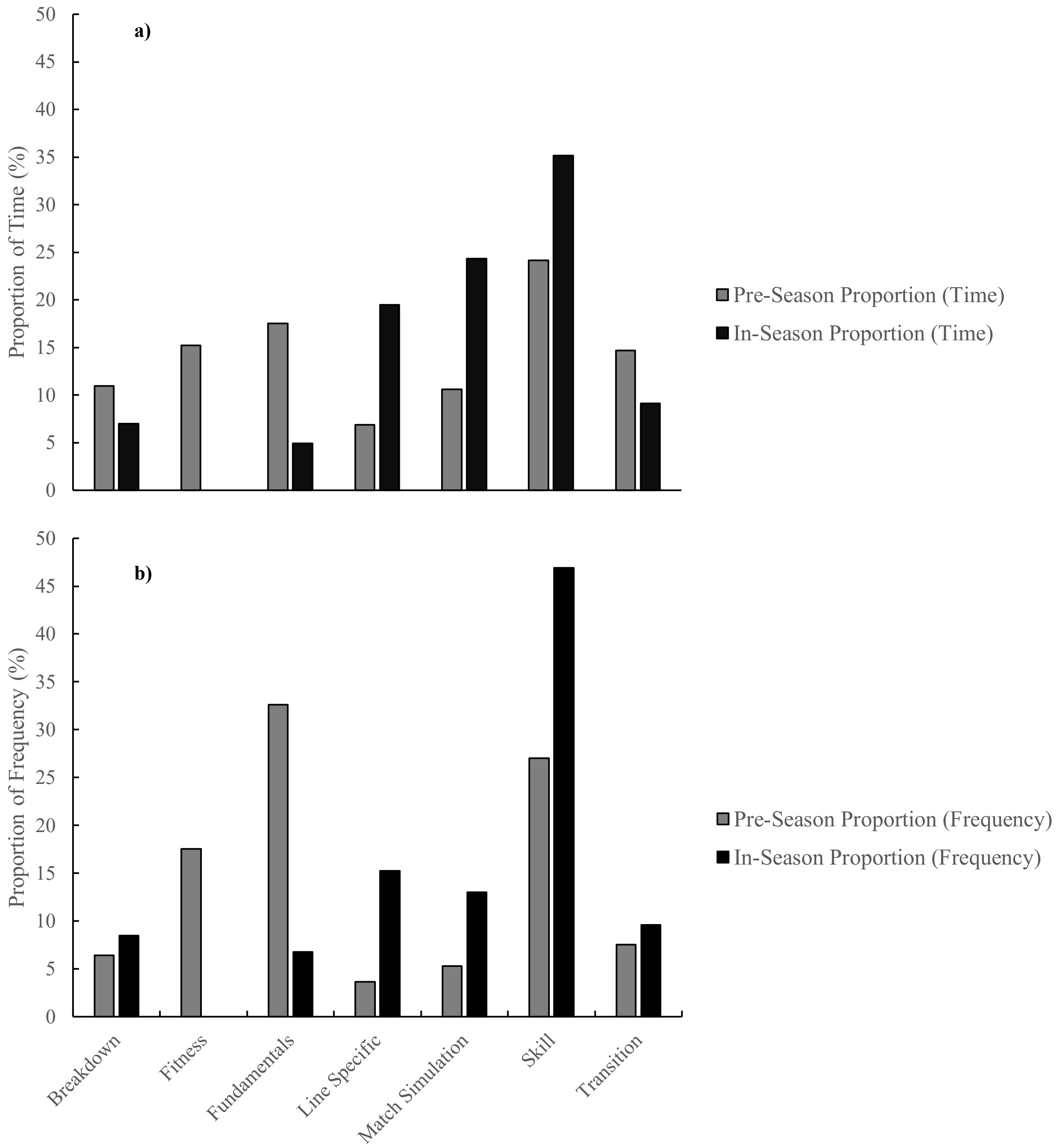

Figure 4.4.1: Proportion of practice types for time (a) and frequency (b) between pre- and in-season.

4.5 Discussion

This descriptive study examined the practice contexts that coaches implemented in a professional AF team with a view to facilitating optimal skill acquisition principles. Practice type frequencies between pre-season and in-season were different. The difference largely originated from no specific fitness drills being performed in-season, a low amount of fundamental practice types being performed in-season and an increase in line specific practice in-season. Moreover, coaches more frequently implemented training-form practice during pre-season than in-season. The significant chi-square indicates larger contributions from the observed playing-form frequencies compared to what was expected for both in-season and pre-season. There were no differences detected between in-season and pre-season for playing-form practice frequency (82 each). There was a significant difference between practice type duration between pre-season and in-season, with drills typically being of longer duration in-season. Furthermore, the mean percentage of time spent in playing-form in-season (62.0 ± 25.4) did not significantly differ compared to pre-season (52.4 ± 19.8). Collectively, these results suggest that coaches prefer to implement higher exposures, via frequency, to more practice types rather than a longer exposure to a specific, and smaller amount of practice types. For example, within one training week the coaches may implement 12 different variations of these practice classifications, with each lasting 6 minutes in duration. This would be in contrast to the coaches implementing 6 practice drills lasting 12 minutes each. The variation and differences within each practice type between pre- and in-season could also reflect variations between the intensity of these training activities. There are several conceivable reasons for these outcomes including the requirement to meet the physical requirements determined by physical performance staff, the implicit provision of more opportunities to expose players to the same problem in different contexts, or providing the coaches a platform to observe, refine and correct performance more often.

The highest pre-season proportions of training were skill (24.2%), fundamentals (17.5%) and fitness (15.2%) practice types. In contrast, in-season training time proportions were skill (35.1%), match simulation (24.3%) and line specific (19.5%) practice types. These results clearly demonstrate that coaches replace fundamentals and fitness with match simulations as they move to in-season training. This alludes to the specificity of practice hypothesis (Proteau, 1992). Coaches seem to implement more representative practice with reduced available time for training in-season. The match simulation may be implemented as it provides players with the ability to use more appropriate information from the environment to support actions (Pinder et al., 2011), showcasing to coaches whether the collective and individual perceptual and motor processes are desirable and align with specific tactics and outcomes they are wanting to observe. From an ecological view, it aims to create shared affordances and for the players to become attuned to these shared affordances that would also be present in competitive matches. The collective and cyclical relationship between shared affordances and shared action exposes players to behaviours, constraints and information that can be observed in match-play (Silva et al., 2013). Hence, match simulation may provide the most representative and manipulatable degree of perception-action coupling that can seemingly be achieved in practice. Specific constraints, like space (m^2) per player, using a scoreboard and assigning specific criteria to be met and achieved during match simulation, can be manipulated to optimise collective adaptations during practice.

Skill type practice was the most frequently performed in both the pre- and in-season phases. Moreover, the tendency for an increase of training tie proportion performing skill type practice in-season compared to pre-season (+10.9%) indicates that coaches appear to implement more general training-form practice in-season for these types of activity (i.e. skill type practice). Interestingly, this misaligns with skill periodisation ideas proposed previously (Otte et al., 2019; Robertson & Farrow, 2017). Furthermore, these conclusions are based on the total practice time and the number of times skill type practice was performed (i.e. not on the average practice duration time). This is important to consider, as it indicates that skill type activities were performed more frequently but for lower durations. Interestingly, in-situ skill periodisation is not as complicated as that proposed in the models and is largely implemented ad-hoc. Nonetheless, the large proportion of time spent performing skill type activities suggests coaches are primarily concerned with improving their athletes' skill proficiency. According to the literature, this approach to training may not be the best approach to achieve that goal (Pinder et al., 2011; Proteau, 1992). This practice type largely involved isolated game incidents that removed a continuation of play. Accordingly, this practice type may remove key perception and action responses for subsequent phases of play. For skill to improve and transfer to competitive match-play to occur, highly representative environments, where performer-environment interactions represent those experienced during game play, are needed (Pinder et al., 2011). Here, we advocate increased opportunity for skill acquisition specialists in professional sport to play a key role in continually developing expertise. As Steel and colleagues (2014) describe, "skill acquisition specialists are sport scientists who examine the theories, principles and processes of motor and perceptual learning". Thus, a complementary role between coaches, who make decisions based on experiential knowledge, and skill acquisition specialists, who make decisions based on both empirical and experiential knowledge can lead to beneficial outcomes for practice design, feedback and instruction. Furthermore, the complementary role skill acquisition specialists can play ensures the continual development of perceptual-motor learning based on scientific principles. A good example of how the cross-disciplinary nature of a skill acquisition specialist can help improve practice design has been documented by Ireland and colleagues (2019). These authors reported that kicking disposal constraints relating to space and time were underrepresented during practice compared to professional AF matches. For expert performers to improve skill, informational sources used to regulate behaviour need to be very specific (Farrow et al., 2013) and as such, it is likely that until coaches use and develop practice activities that truly resemble conditions from match-play, skill proficiency will not be optimised, or will remain at a level below that required for successful performance in competition. A simple method to enhance skill development in experts is to perform the skill at speeds similar to game play so the performers can process relevant information and execute skills at the required pace (Reimer et al., 2006). However, rather than mimicking actual game-play pace, coaches often choose to train skilled behaviour and decision making at a proportional pace of that experienced during competition (e.g. match simulation run-throughs at 60% of maximal velocity).

Similar to previous research assessing coaching and youth practice contexts in elite association football (Ford, Yates & Williams, 2010; Roca & Ford, 2020; Williams & Hodges, 2005), these findings indicate an insignificant difference, but higher proportion of time in-season vs pre-season is spent performing playing-form activities. Moreover, the greatest contributor to the chi-squared value (χ^2=30.8) assessing the practice form activity frequencies was the difference between expected and observed frequencies of playing form activities in-season. That is, the frequency of playing-form activities in-season was much larger than expected. This may indicate an increased and implicit awareness of representative practice from coaches, or an enhanced understanding of transferable practice due to their experience and philosophies. Additionally, these results may highlight the multidimensionality of practice design concerns for professional coaches. For example, other factors such as training load management e.g. reduce the number of defenders to reduce the number of change of direction efforts, the players and teams experience, the number of days between competitive games in-season e.g. less days between games means more time is focussed on recovery and not training, meaning the most relevant activities must be performed, or the upcoming opposition e.g. positional requirements across different phases of play. Nonetheless, playing-form activities are deemed more relevant as they generally contain more specific informational sources such as pressure from defenders, spacing and game speed. However, these proportions differed in pre-season for the current data i.e. training-form encompassed 56.9% of total training time. A conservative view may suggest slightly decreasing the proportion of training-form activities, whilst slightly increasing playing-form activities (Ford, Yates & Williams, 2005). This may be an ambitious suggestion in practice, but this approach considers that expert performers are systematically characterised by enhanced domain-specific perceptual-cognitive abilities such as enhanced scanning and pattern recognition, anticipation and decision making (Williams Fawver & Hodges, 2017) whilst measures of basic visual and cognitive function (i.e. domain-general skills) do not differ (Voss, Kramer, Basak, Prakash & Roberts, 2010). Thus, expert performers, as showcased here through a professional AF team, require consistent exposure to specific training to enhance adaptations related to their domain-specific expertise. Consequently, an integrated approach to increase playing-form practice types would be recommended across the whole season. Nonetheless, the overall proportion of training-form to playing-form was very similar (51.1% and 48.9%, respectively) over the whole season. Regular assessments and continued monitoring by performance analysts can provide feedback to coaches and assist their quest to optimise practice contexts.

Fundamental type practice constituted 13.2% (pre-season: 17.5%, in-season: 5%) of total training time across the whole season. These training-form practices incorporate basic variations of closed skill performances (e.g. groundballs, handballing, kicking, marking, tackling and handwork). The performance of the skill is generally completed in a decontextualized manner where skill execution is independent of the context it is required in. As such, it may not provide the specific information that experts use to regulate match behaviour and decision-making or may lack processing requirements that develop domain-specific skill (Farrow, Baker & MacMahon, 2008). This practice type also requires little cognitive attention as the athletes tend to be extremely proficient at the movement solutions. Additionally, because team sport experts differ to non-experts regarding pattern recognition, automatic movement control, anticipation and coping with constraints (Farrow, Baker & MacMahon, 2013), repeated exposures to simple closed skill performances are less representative of the domain-specific exercises required for experts to learn and keep improving. Although it can be utilised as a ‘get hands on the footy’ exercise, from a skill acquisition perspective for experts, it likely offers very little. For example, Farrow and colleagues (2008) reported higher cognitive complexity (and thus, engagement) in open type skill contexts. Thus, closed skill practice contexts likely do not cognitively engage the players and do not challenge the players. It appears that the utility of such exercises and practice contexts for expert performers is not warranted and time could be better utilised engaging in other practice types.

Whilst this was the first study to report on practice types and contexts implemented by expert coaches in a professional AF team, some limitations must be considered. Specifically, the data was collected from one professional AF team and therefore may lack generalizability to other professional AF teams' programs or more broadly to other team sports. However, the methodology presented in this study may be useful for other researchers and practitioners to adopt and investigate their own practice environments. Additionally, as these results are clearly preliminary and rely somewhat on the descriptive information on each practice type, future research is required to strengthen the interpretation and extrapolation to more teams and indeed different sporting contexts. This will assist researchers and practitioners understand how expert performers can continue to develop and refine their performance, whilst further understanding where research efforts are required. Nonetheless, the longitudinal collection over one full season using professional athletes presented here strengthens the interpretation of the data and the ecological validity.

4.6 Conclusion

This study provided information on the training structures and practice contexts that coaches implement in a professional AF team. There were seven practice types the coaches implemented throughout the season which were different between pre- and in-season phases. Skill practice was most prominent throughout the whole season but was performed more frequently in pre-season compared to in-season. This signifies the value coaches place on developing skill proficiency in professional AF players before competitive matches begin. Coaches also tended to emphasise training-form activities in the pre-season and playing-form activities in-season. This likely reflects coaches' willingness to implement practice that transfers into competitive play by providing activities with more representative learning design in-season. While these coaches' practices generally correspond with scientific knowledge surrounding optimal practice design, some training activities, including the large proportion of time spent performing closed-natured skills, and practices performed unopposed, may indicate the opportunity for skill acquisition specialists to aid in optimising practice design. Skill acquisition specialists can play an important complementary role to help coaches design practice and provide feedback and instruction. Additionally, they can implement pedagogical frameworks across an organisation through evidence-based practice. The information from this study can be used to monitor the type of practice being performed and used to determine the duration and exposures to certain practice types. Collectively, future research and daily practice in sport may warrant these analyses to be used alongside the constraints-led approach and in conjunction with collective behavioural measures to determine behavioural responses to practice in Australian football.

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4.7 References

Alexander, J.P., Spencer, B., Mara, J.K. & Robertson, S. (2019), Collective team behaviour of Australian rules football during phases of match play, *Journal of Sports Sciences*, 37(3), 237-243.

Araújo, D., Davids, K. & Hristovski, R. (2006), The ecological dynamics of decision making in sport, *Psychology of Sport and Exercise*, 7(6), 653-676.

Baker, J., Côté, J. & Abernethy, B. (2003), Learning from the experts: Practice activities of expert decision makers in sport, *Research Quarterly for Exercise and Sport*, 74(3), 342-347.

Bompa ,T.O. (1999), Periodization Training: Theory and Methodology, (4th ed.). Champaign, IL: Human Kinetics.

Browne, P.R., Woods, C.T., Sweeting, A.J. & Robertson, S. (2020), Applications of a working framework for the measurement of representative learning design in Australian football, *PLoS One*, 15(11).

Cohen, J. (1988). Statistical power analysis for the behavioural sciences (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

Côté, J., Baker, J., & Abernethy, B. (2007). Practice and play in the development of sport expertise. In G. Tenenbaum & R. C. Eklund (Eds.), *Handbook of sport psychology* (p. 184–202; 3rd Ed.). John Wiley & Sons Inc.

Davids, K., Araújo, D., Shuttleworth, R. & Button, C. (2003), Acquiring skill in sport: A constraints-led perspective, *International Journal of Computer Science in Sport*, 3(3), 31-39.

Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of skill acquisition: A constraints-led approach.* Champaign, IL: Human Kinetics.

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

Edwards, W.H. (2010). Motor Learning and Control: From Theory to Practice, Wadsworth, OH: Cengage Learning.

Farrow, D., Pyne, D.B. & Gabbett, T. (2008), Skill and physiological demands of open and closed training drills in Australian football, *International Journal of Sports Science and Coaching*, 3(4), 485-495.

Farrow, D., Baker, J. & MacMahon, C. (2013), *Developing sport expertise: Researchers and coaches put theory into practice*, London: Routledge.

Ford, P.R., Yates, I. & Williams, A.M. (2010), An analysis of practice activities and instructional behaviours used by youth soccer coaches during practice: Exploring the link between science and application, *Journal of Sports Sciences*, 28(5), 483-495.

Gibson, J.J. (1979), *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.

Handford, C., Davids, K., Bennett, S. & Button, C. (1997), Skill acquisition in sport: Some applications of an evolving practice ecology, *Journal of Sports Sciences*, 15(6), 621-640.

Helsen, W.F., Starkes, J.L., & Hodges, N.J. (1998), Team sports and the theory of deliberate practice, *Journal of Sport and Exercise Psychology*, 20, 12-34.

Impellizeri, F.M., Rampinini, E. & Marcora, S.M. (2005), Physiological assessment of aerobic training in soccer, *Journal of Sports Sciences,* 23(6), 583-592.

Ireland, D., Dawson, B., Peeling, P. Lester, L., Heasman, J. & Rogalski, B. (2019), Do we train how we play? Investigating skill patterns in Australian football, *Science and Medicine in Football,* 3(4), 265-274.

JASP Team (2020). JASP (Version 0.13.1)[Computer software].

Kahneman, D. & Klein, G. (2009), Conditions for Intuitive Expertise: A failure to disagree, *American Psychologist*, 64(6), 515-526.

Koo, T.K. & Li, M.Y. (2016), A guidelines of selecting and reporting intraclass correlation coefficients for reliability research, *Journal of Chiropractic Medicine*, 15, 155-163.

Kugler, P.N., Kelso, S.J.A. & Turvey, M.T. (1980), On the concept of coordinative structures as dissipative structures: I. Theoretical lines of convergence, *Advances in Psychology*, 1, 3-47.

Moreira, A., Bilsborough, J.C., Sullivan, C.J., Ciancosi, M., Aoki, M.M. & Coutts, A.J. (2014), The training periodisation of professional Australian football players during an entire AFL season, *International Journal of Sports Physiology and Performance,* 10(5), 566-571.

Newell, K.M., Morris, L.R. & Scully, D.M. (1985), Augmented information and the acquisition of skill in physical activity, *Exercise and Sport Sciences Reviews*, 13, 235-261.

Newell, K. M. (1986). Constraints on the development of coordination. In M. G. Wade, & H. T. A. Whiting (Eds.). Motor development in children: aspects of coordination and control (pp. 341–360). Dordrecht, The Netherlands: Martinus Nijhoff.

Pinder, R.A., Davids, K., Renshaw, I. & Araújo, D. (2011), Representative learning design and functionality of research and practice in sport, *Journal of Sport and Exercise Psychology*, 33, 146-155.

Proteau, L. (1992). On the specificity of learning and the role of visual information for movement control. In L. Proteau & D. Elliott (Eds.), *Vision and motor Control* (pp. 67- 103). Amsterdam: North Holland.

Renshaw, I., Chow, J.Y., Davids, K. & Hammond, J. (2010), A constraints-led perspective to understanding skill acquisition and game play: a basis for integration of motor learning theory and physical education praxis? *Physical Education and Sport Pedagogy*, 15(2), 117-137.

Robertson S, Joyce D. Evaluating strategic periodisation in team sport, *J Sport Sci* 2018; 36(3): 279-285.

Roca, A. & Ford, P.R. (2020), Decision-making practice during coaching sessions in elite youth football across European countries, *Science and Medicine in football*, DOI: 10.1080/24733938.2020.1755051.

Sheehan, W.B., Tribolet, R., Watsford, M.L., Novak., A.R., Rennie, M.J. & Fransen, J. (2019), Using cooperative networks to analyse behaviour in professional Australian football, *Journal of Science and Medicine in Sport*, DOI.org/10.1016/j.jsams.2019.09.012.

Silva, P., Garganta, J., Araújo, D., Davids, K. & Aguiar, P. (2013), Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports, *Sports Medicine*, 43, 765-772.

Silva, P., Vilar, L., Davids, K., Araújo, D. Garganta, J. (2016), Sports teams as complex adaptive systems: manipulating player numbers shapes behaviours during football small-sided games, *SpringerPlus*, 5, 1-10.

Steel, K.A., Harris, B., Baxter, D., King, M. & Ellam, E. (2014), Coaches, athletes, skill acquisition specialists: A case of misrecognition, *International Journal of Sports Science and Coaching*, 9(2), 376-378.

Williams, A.M. & Hodges, N.J. (2005), Practice, instruction and skill acquisition in soccer: Challenging tradition, *Journal of Sports Sciences*, 23(6), 637-650.

Voss, M.W., Kramer, A.F., Basak, C., Prakash, R.S., & Roberts, B. (2010), Are expert athletes' 'expert' in the cognitive laboratory? A meta-analytic review of cognition and sport expertise, *Applied Cognitive Psychology, 24*(6), 812–826.

Chapter 5 | A descriptive and exploratory study of factors contributing to augmented feedback duration in professional Australian football practice

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5.1 Abstract

Augmented feedback supplements or replaces task-intrinsic feedback and is common in team sports, however, no studies have reported on augmented feedback provision in professional Australian Football (AF) practice. This study investigated the effects of practice characteristics (feedback intervention frequency, practice time, practice type, season phase, practice activity form and competitive match result) on the duration of feedback provided by professional AF coaches. Two linear mixed-effects models were constructed. The first examined the collective associations between these practice characteristics and feedback durations while the second model investigated the associations between the same practice characteristics and previous match result. Results showed the feedback intervention frequency, practice time and a practice time*feedback intervention frequency interaction explained 65% of feedback duration whenever feedback was provided. Additionally, practice time, feedback intervention frequency, a practice time*match result inter- action and a match result*feedback intervention frequency interaction explained 99% of feedback duration in-season. Important factors that were hypothesised to affect feedback durations in AF such as practice type, practice activity form or season phase did not contribute any explanatory power. This study provides information on how professional AF coaches provide augmented feedback in-situ and provides opportunities for skill acquisition specialists to aid coaches when delivering augmented feedback.

5.2 Introduction

Skilled performance in team sports is the result of many hours of high-quality practice by the performer (Côté, Baker & Abernethy, 2007; Newell, Morris & Scully, 1985). Such practice involves interaction with the environment, teammates and coaches (Anderson et al., 2019). The performer-coach relationship has been of interest to sport performance researchers for several decades (Gilbert & Trudel, 2004; Rangeon et al., 2009). Côté and Gilbert (2009) reviewed this relationship by integrating a coach's knowledge and athlete outcomes in specific contexts. Thus, understanding coach-athlete interactions forms an important part of the training process. One of the most common interactions between players and coaches is augmented feedback, i.e. all feedback that supplements or replaces task-intrinsic feedback and comes in many forms such as verbal-, video- or bio-feedback (Magill 1994). This information aims to supplement athletes' intrinsic feedback, correct errors, refine performance by facilitating achievement of the behaviour or motivate the performer (Magill 1994; Magill & Anderson, 2014). Many elements of coaching, including the provision of augmented feedback, remain largely guided by precedence and emulation (Cushion, Armour, & Jones, 2003; Williams & Hodges, 2005). Hence, it is worthwhile to examine the current provision of augmented feedback used by coaches in a high-level team sport setting.

Augmented feedback is considered an important aspect of skill acquisition, and has been studied extensively (Adams, 1971; Newell et al., 1985; Magill & Anderson, 2014; Schmidt, 1982). Contemporary provision of augmented feedback in team sport is pervasive, and often viewed as a main role of the coach (Ford, Yates & Williams, 2010; Markland & Martinek, 1988). In team sports, performance environments have often been referred to as "messy learning environments", where decisions are made and actions are produced under considerable uncertainty (Causer & Williams, 2013). Consequently, the information presented to the individual or team is usually present from task performance, however the performer(s) have difficulties interpreting it to produce an optimal response or behaviour change. Therefore, the provision of augmented feedback is common in team sports, especially coaching feedback and video reviews (Groom & Nelson, 2013). There are many different types of augmented feedback that coaches can provide, which are characterised by the content (knowledge of results versus knowledge of performance) and timing (concurrent feedback and terminal feedback) (Anderson et al., 2019). Furthermore, knowledge of performance feedback is differentiated between descriptive i.e. simply describe the error(s) committed, and prescriptive feedback i.e.

detail on how to correct the error identified (Anderson et al., 2019). Moreover, concurrent feedback is presented during the performance of the activity, whereas terminal in contrast is provided after the performance attempt, and before the next attempt begins. In this study, we will notate terminal feedback across team sport practice.

Previously, studies have investigated the relationship between the content, frequency and/or timing of augmented feedback, and performance and learning in motor tasks. For example, Swinnen and colleagues (1990) investigated instantaneous versus delayed feedback for a simple motor task with delayed feedback demonstrating superiority for learning. Here, frequent and instant feedback seemed to reduce the performers ability to interpret task-intrinsic information to the detriment of long-term consolidation of learnt behaviour. Additionally, investigations into coach observations in association football have reported that coaches provide less prescriptive feedback during playing-form activities (these activities are the most similar to match-play because of their variability which has better long-term retention and learning (Ford et al., 2010) compared to training-form activities, which encompass traditional skill and technique practices, along with physical training). However, these coaches are unable to recognise that the feedback provided in these activities had more questioning, praise and more silence 'on-task' (Partington & Cushion, 2013). Coaches who are unable to recognise how much feed- back they provide during practice may benefit from systematic approaches to measure feedback. Furthermore, Halperin and colleagues (2016) revealed that winning and losing rounds in boxing lead to different feedback provisions by coaches. Specifically, coaches delivered the same number of feedback statements in winning and losing rounds but had less internal, less controlling and more positive feedback during winning bouts than losing bouts (Halperin et al., 2016). Interestingly, it seems the outcome of the performance may alter the strategies coaches use to provide augmented feedback to the performer and that performance results may influence augmented feedback delivery during performance and may influence its provision during practice.

It is useful for coaches to understand their feedback provision as increased amounts of augmented feedback can negatively affect an athletes ability to retain information (Anderson et al., 2019; Newell et al., 1985) and also affect their ability to use task-intrinsic feedback (as augmented feedback is the easier option to interpret, if available) (Magill & Anderson, 2014). Importantly, while augmented feedback is beneficial to learning motor tasks, it is often not available, or it is less frequent during later task performance i.e. competition. These implications can have an effect on performers becoming dependent on the augmented feedback (and neglecting task-intrinsic feedback in the process) so much so that it may negatively affect performance when the augmented feedback is not available (Anderson et al., 2019; Wulf et al., 2002). Consequently, the frequency and duration of augmented feedback can affect performance and learning outcomes.

The Australian Football League (AFL) is the professional competition of Australian Football (AF) that involves 18 teams. AF is a complex team sport (Johnston et al., 2018; Sheehan et al., 2019) with 18 players per side (16 players per side for the women's AFL competition, i.e. AFLW) playing on large field sizes that are oval in shape but can vary in length (175m–155m) and width (141m–110m) with the aim being to score goals located at each end of the field. Augmented feedback studies in AF are scarce (Madden, 1995; Walsh & Jureidini, 2016). Recently, Mason et al. (2020) reported professional coaches provided 10.9 coach-player instances and 4.6 coach-team instances of augmented feedback on average per quarter (elapsed time of about 28-30minutes per quarter) during AFL matches. Across the four studied coaches, this equates to ~44 instances of feedback across the 22 playing players per quarter. These results demonstrate the amount of information coaches can provide to individuals and comparatively show the reduced amount of interaction they have with the team. This highlights a fundamental difference when assessing the feedback coaches provide during practice and games. Contextually, coaches are not limited to intervene during practice as they are during competitive games which may see them liberally provide augmented feedback. Moreover, different practice activities, such as activities with more players on bigger fields which are more complex (i.e. messier learning environments), may warrant increased provisions of augmented feedback. In these contexts where the task complexity is increased due to increased player numbers or different spacings per player, it is potentially more difficult to generate and utilise task-intrinsic feedback as collective learning i.e. team sport performance, is multileveled (Magill, 1994; Newell et al., 1985), meaning using task-intrinsic feedback may become more difficult as the tasks complexity increases. For example, a coach may provide terminal descriptive feedback after a performance repetition has been performed by the team. The content may focus on the defensive shape of the team, but each player has a different role when it comes to the defensive shape depending on their position, their strengths, where their opponent is etc.

Consequently, messier learning environments may make learning too complicated at times, and may justify the inclusion of augmented feedback to help facilitate a players or teams ability to detect and correct errors (Anderson et al., 2019; Mason et al., 2020). Here, augmented feedback may be advantageous in comparison to task-intrinsic feedback, as it is more interpretable by the player or team. However, there must be a context dependent approach considering competitive matches rely on the players and team to self-organise into appropriate solutions without much coach input. Nonetheless, given the absence of published evidence in AF, it would be valuable to investigate the practical implementation of augmented feedback by AF coaches, and to determine whether this aligns with existing, evidence-based strategies in sport. Currently, we do not know the factors or context of when and the duration of terminal augmented feedback that coaches provide during practice. By understanding this, skill acquisition specialists can help determine what factors influence terminal augmented feedback duration within practice and can help optimise its delivery to maximise learning outcomes.

Accordingly, this study aimed to explore the factors associated with the duration of time coaches spend providing terminal feedback delivered to the whole team during each practice activity (i.e. after a performance attempt and before the next attempt begins). Factors such as the practice type, activity form, phase of the season, practice activity time, the number of feedback interventions and competitive match result were investigated. It was hypothesised that coaches would deliver increased terminal feedback durations to the team during more complex practice types. Moreover, terminal feedback duration delivered to the whole team was expected to be greater during pre-season than in-season. This was expected as coaches have more time at practice during the pre-season period. Coaches were also expected to provide more augmented feedback the week after a competitive match loss than a win due to wanting to feel an increased sense of controlling future outcomes in the next match.

5.3 Methods

Participants

One professional AF club consisting of 46 male professional Australian footballers (age: 23.28±4.35 years) participated in their normal training across one entire season from November to September. Eight senior and development coaches within the professional club also participated (6.8±6.5 years AFL coaching experience; 11.5±5.1 years playing AFL). The coaching staff designed and implemented the training with no intervention from the researchers to ensure ecological validity of the data collection. Approval was obtained for this study through the University's ethics committee.

Data collection

Collectively, 37 pre-season and 35 in-season training sessions were observed. This study observed terminal augmented feedback, where it was defined as occurring after a performance attempt was completed and before the next performance attempt begun, within the one activity. Feedback was recorded if a coach stopped the drill and addressed the whole team. For example, if the players dropped the footballs or stopped moving whilst the coach addressed the whole team, the time providing feedback begun. When the players started using the football or moving within the activity again, the time providing feedback was stopped. Feedback provided before the first performance attempt or after the last performance attempt of the activity was excluded as the focus was terminal feedback aimed at the collective team level. Here, feedback that was provided at the complete finish of the activity was not coded, only the feedback within the allotted time within the activity and after repetitions were performed. Coach feedback provided to individual players was not notated as it was too difficult to notate and not the purpose of the current manuscript. Whilst not intervening can be a contextually appropriate coach feedback strategy, the investigation focused on when coaches actively provided verbal feedback to the team. Each practice activity that had zero seconds of active coach feedback provided to the team, characterised by no active interaction, were notated accordingly i.e. zero seconds of feedback were notated.

The terminal feedback was coded into two categories. Firstly, the frequency was recorded by the total number of times coaches intervened. Secondly, the duration of interventions was the sum of time that coaches spent intervening. Both were then categorised according to each practice type as per the methods of Tribolet and colleagues (2021) with the exclusion of 'line specific' practice activities (this activity type was not notated, as described below). As per the methods of Ford and colleagues (2010) these practices were subdivided into training form and playing form. Training form practice is performed in isolation or in small groups and generally involves part-practice type drills (Edwards, 2010) that are repetitive. Comparatively, playing form practice categories have a game-related focus and commonly emphasises certain aspects that occur during a game such as stoppages (when play stops and is reset by the umpire via a ball up or throw in) or relate to transitioning between certain phases such as attack to defence. This activity form also includes line-specific (positional) setups. Problematically, feedback was constantly provided during the line-specific practice type and deemed too difficult to quantify and as such, terminal feedback in this position-specific practice was not analysed. Although relevant, verbal feedback is extremely difficult to quantify in this practice type as coaches may perform one repetition of the activity, then as the players reset for the next repetition, the coaches chat to the positional group e.g. the midfield or to an individual player. It is very hard to determine which they are doing. Therefore, notating these interactions across three different positional groups i.e. forwards, midfielders and defenders, was too difficult. Future research may focus on just this practice type as it contains a significant amount of player and coach interactions. Furthermore, conditioning drills were not analysed as they were beyond the scope of the research. Anecdotally, these practice activities are not about acquiring or improving a skill but improving the physical capacity of the athletes. In this practice type, the coaches would anecdotally typically provide motivational and encouraging feedback.

For each field session, training was filmed by placing elevated cameras perpendicular to the field and behind the goals. Training footage was coded using SportsCode (SportsTec Limited, version 9.4.1, Warriewood, Australia) with the lead investigator notating the information. To assess coding reliability, a random subset of data that comprised of pre-season and in-season practices consisting of 10 training sessions was observed a second time by the same coder after a three-month washout period.

Statistical analysis

Coding reliability was assessed using an intra-class correlation coefficient (3, k) (Koo & Li, 2016). This method of reliability testing is based on the consistency of coding. The intra- class correlation coefficients assessed the annotations of feedback durations and feedback frequency interventions across practice types. Prior to statistical analyses, assumptions of independence and collinearity ($r > 0.8$) were checked, and scatterplots and Cook's distance were used to determine potential influential data points. No collinearity was detected. The study design located units of analysis (each training session) nested in clusters of units (phase of the year). This form of analysis involves both fixed effects, defined as variables yielding a systematic influence on the dataset, and random effects, which have non-systematic influences on the dataset. Random factors were included in the model which enabled random deviations for each condition to the overall fixed intercept and fixed coefficients. The 95% confidence intervals were calculated to assess the precision of the estimates.

A 'step-up' model construction strategy was employed, similar to models previously used in team sport (Henderson et al., 2019). The process began with an "unconditional" model containing only a fixed intercept and the level 2 random factors (training session identifier and season phase). However, season phase did not explain any variance when comparing the first model iteration with training session identifier nested in season phase. Thus, it was removed from the random effects structure and did not contribute to further model construction. The model was then developed by adding each single level 1 independent variable as a fixed effect, with the exception of match result which was included in the second model assessing in-season explanatory factors. Variables were retained when they yielded better model fits (lower Akaike Information Criterion and significant Likelihood Ratio Test p value). Initially, linear mixed-effects models were constructed on the full data-set of 433 observations, including observations where the coaches did not provide any feedback time. After removal of influential datapoints using Cook's distance (4/n cut-off to identify points that influence the outcome of the regression), diagnostic plots of residuals indicated poor model fit for the data. Subsequently, 326 observations where coaches provided zero seconds of feedback (i.e. actively chose not to intervene) were removed. A full factorial model was subsequently constructed on 107 observations and deemed to appropriately fit the data. There were no influential datapoints based on the conservative Cook's distance threshold employed (remove values > 1). Lastly, a second linear mixed-effects model was constructed that included competitive match result (win or loss) as a fixed effect. Similar to model 1, observations where coaches did not provide feedback were excluded, resulting in a total of 29 observations during the in-season phase. A full factorial model was constructed and deemed most appropriate.

Inspection of the residuals were performed using diagnostic plots. Coefficients were converted to standardized coefficients (beta weights) to identify which independent variables were most important in explaining the dependent variable. The continuous independent variables were standardised since they were on vastly different scales (e.g. seconds and counts). Standardising adjusts the interpretation of the coefficient for each independent variable in the model. Here, the beta weights represent the z-score change for a 1 standard deviation change in the value of each independent variable (Harrison et al., 2018). The t statistics from the mixed models were converted into partial eta squared effect sizes and associated 95% confidence intervals (Ben-Shachar, Makowski & Lüdecke, 2020). Cut-off scores of 0.01 (small), 0.06 (moderate) and 0.14 (large) were used to interpret the effect sizes (Cohen, 1988). All statistical analyses were conducted using the lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017) and effectsize

(Ben-Shachar, Makowski & Lüdecke, 2020) packages in R statistical software (R Core Team, 2019).

5.4 Results

The intra-class correlation coefficients demonstrated high reliability (r=0.92-0.95) for the annotations of terminal feedback durations and feedback frequency interventions across practice types. Descriptive statistics for feedback durations in each practice type and across season phases are presented in Table 5.4.1. The best model fit included random intercepts for each training condition. Model 1 displayed a marginal r^2 value of 0.60 and a conditional r^2 of 0.65. Practice time (β=0.45[95%CI:0.32-0.58],p<0.001,η^2=0.32), feedback intervention frequency (β=0.48[95%CI:0.36-0.60],p<0.001,η^2=0.38) and a practice time*feedback intervention frequency interaction (β=0.26[95%CI:0.11-0.42],p=0.001,η^2=0.10) were all positively associated with feedback duration (Figure 5.4.1). Longer feedback durations were provided when coaches intervened more often and when the practice time in a drill was longer (Table 5.4.1).

Model 2 focused on feedback duration in-season while incorporating match result as a fixed effect and revealed a marginal r^2 value of 0.88 and a conditional r^2 of 0.99. Practice time (β=0.45 [95%CI:0.29-0.61], p<0.001,η^2=0.62), feedback intervention frequency (β=0.32 [95%CI:0.18-0.45], p<0.001,η^2=0.53) and a feedback intervention frequency*match result interaction (β= 0.61 [95%CI:0.41-0.81], p<0.001,η^2=0.65) were all positively associated with the time coaches spent providing feedback (Figure 5.4.2). The relationship between the number of feedback interventions and the average length of feedback duration was dependent on the previous match result. Specifically, lower feedback intervention frequencies after a loss led to lower feedback durations, whilst higher feedback intervention frequencies after a win led to greater feedback duration.

Conversely, a practice time*match result interaction (β=-0.36 [95%CI:-0.62--0.09], p=0.013, η^2=0.27) was negatively associated with feedback duration. Specifically, the effect of practice duration on feedback duration up to ~400 seconds practice time was higher for a loss, however there was a negligible effect of winning or losing on feedback duration at lower practice durations. Further, the effect of practice duration on feedback duration tended to increase after a win (Figure 5.4.2A). Longer practice durations after a competitive match win led to larger feedback durations. The main effect of match result ($p=0.102, \eta^2=0.13$), the practice time*feedback interventions interaction ($p=0.240, \eta^2=0.07$) and the three-way interaction of practice time*feedback interventions*match result ($p=0.496, \eta^2=0.02$) were not associated with feedback duration.

Table 5.4.1: Descriptive statistics examining the number, duration and proportion of time spent providing feedback during each practice type and across the season (pre- and in-season).

	Practice Type	n	Total Time in Practice Type (mins)	Feedback interventions (n)	Time Spent Providing Feedback (mins)	Proportion of Practice Time Spent Providing Feedback (%)
Whole Season						
	Training Form	**372**	**2207**	**92**	**33**	**1.5**
	Playing Form	**164**	**2114**	**159**	**103**	**4.9**
	Breakdown	38	414	56	24	5.8
	Fitness	63	431	0	0	0
	Fundamentals	129	569	6	2	0.4
	Line Specific	40	485	Continuous*	Continuous *	Continuous *
	Match Simulation	42	664	34	27	4.1
	Skill	180	1207	86	31	2.6
	Transition	44	551	69	52	10.7
Pre-Season	**Training Form**	**277**	**1609**	**81**	**29**	**1.8**
	Playing Form	**82**	**1220**	**113**	**69**	**5.7**
	Breakdown	23	310	54	23	7.4
	Fitness	63	431	0	0	0
	Fundamentals	117	495	6	2	0.4
	Line Specific	13	194	Continuous *	Continuous *	Continuous *
	Match Simulation	19	301	0	0	0
	Skill	97	683	75	27	3.9
	Transition	27	415	59	46	11.1
In-Season						
	Training Form	**95**	**598**	**11**	**4**	**0.7**
	Playing Form	**82**	**894**	**46**	**34**	**3.8**
	Breakdown	15	104	2	1	1.0
	Fitness	0	0	0	0	0
	Fundamentals	12	74	0	0	0
	Line Specific	27	291	Continuous *	Continuous *	Continuous *
	Match Simulation	23	363	34	27	7.4
	Skill	83	524	11	4	0.8
	Transition	17	136	10	6	4.4

* Continuous indicates continuous feedback throughout. It was not possible to quantify augmented feedback in this practice type

Table 5.4.2: Standardised coefficients, 95% confidence intervals, degrees of freedom, t-values, -2log likelihood ratio tests, p-value, AIC, partial eta squared effect size and associated 95% confidence intervals for each independent variable using a step-up approach.

	Beta Weights (β)	95% CI	df	t value	Likelihood ratio test	AIC difference	Effect size (95% CI)
	Feedback time – observations across the whole season (Model 1)						
Fixed Effects							
(Intercept)	-0.08	-0.22-0.06	50.9	-1.12	<0.001		0.01 (0.00-0.09)
Practice time	0.45	0.32-0.58	97.6	6.85	<0.001	37	0.32 (0.18-0.45)
Feedback interventions	0.48	0.36-0.60	87.3	7.87	<0.001	48	0.38 (0.24-0.50)
Practice time*Feedback interventions	0.26	0.11-0.42	107.0	3.38	0.001	8	0.10 (0.02-0.22)
	Feedback time – observations with a competitive match result (Model 2)						
Fixed Effects							
(Intercept)	-0.23	-0.42 - -0.04	23.2	-2.34	<0.03		0.22 (0.00-0.51)
Practice time	0.45	0.29-0.61	28.3	5.56	<0.001	3	0.62 (0.31-0.78)
Feedback interventions	0.32	0.18-0.45	11.8	4.64	<0.001	31	0.53 (0.20-0.72)
Match result	0.28	-0.04 - -0.59	22.3	1.70	0.10	12	0.13 (0.00-0.42)
Practice time*Feedback interventions	0.14	-0.09 - -0.36	26.1	1.20	0.230	9	0.07 (0.00-0.35)
Practice time*Match result	-0.36	-0.62 - -0.09	27.1	-2.64	0.01	12	0.27 (0.01-0.54)
Feedback interventions*Match result	0.61	0.41-0.81	19.8	5.89	<0.001		0.65 (0.34-0.79)
Practice time*Feedback interventions*Match result	0.09	-0.16-0.34	23.0	0.69	0.490		0.02 (0.00-0.27)

CI: confidence interval; df: degrees of freedom; AIC: Akaike Information Criterion
Note: Likelihood ratio test based on comparison with previous model
Effect size is an approximation based on the t value obtained from each variable included in the model
Beta weights (or standardised coefficients) refer to how many standard deviations the dependent variable will change, per standard deviation increase in the predictor variable. They are sample specific weightings to ease the interpretability of coefficients.

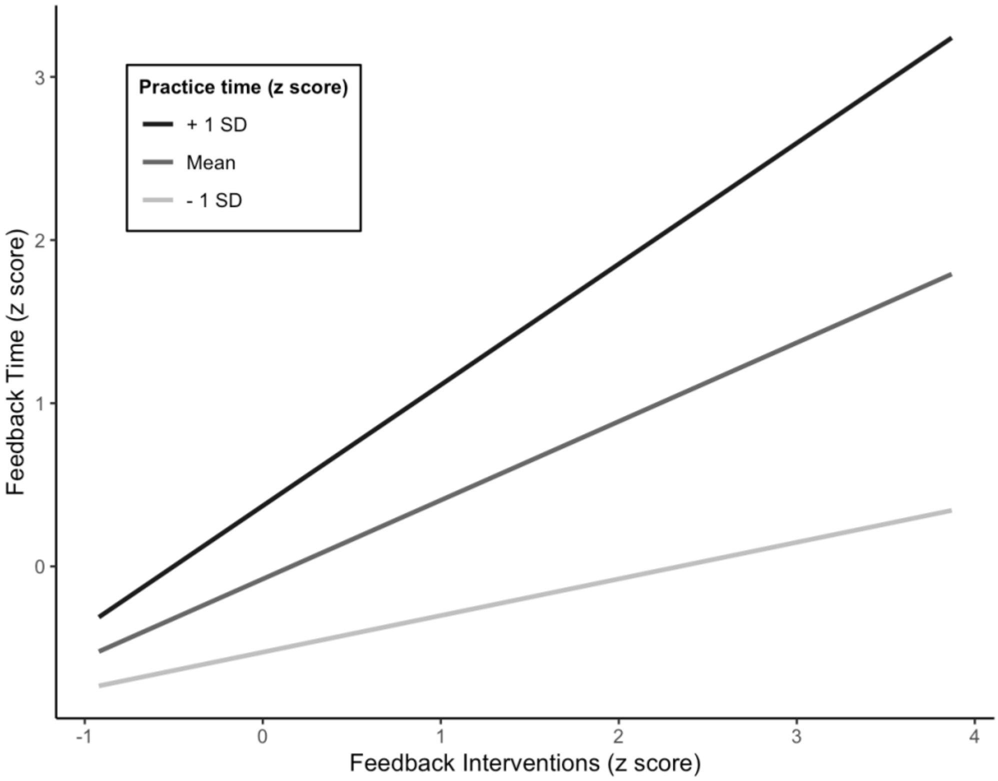

Figure 5.4.1: Z-score relationships between number of feedback interventions and practice time on total feedback duration per practice activity.

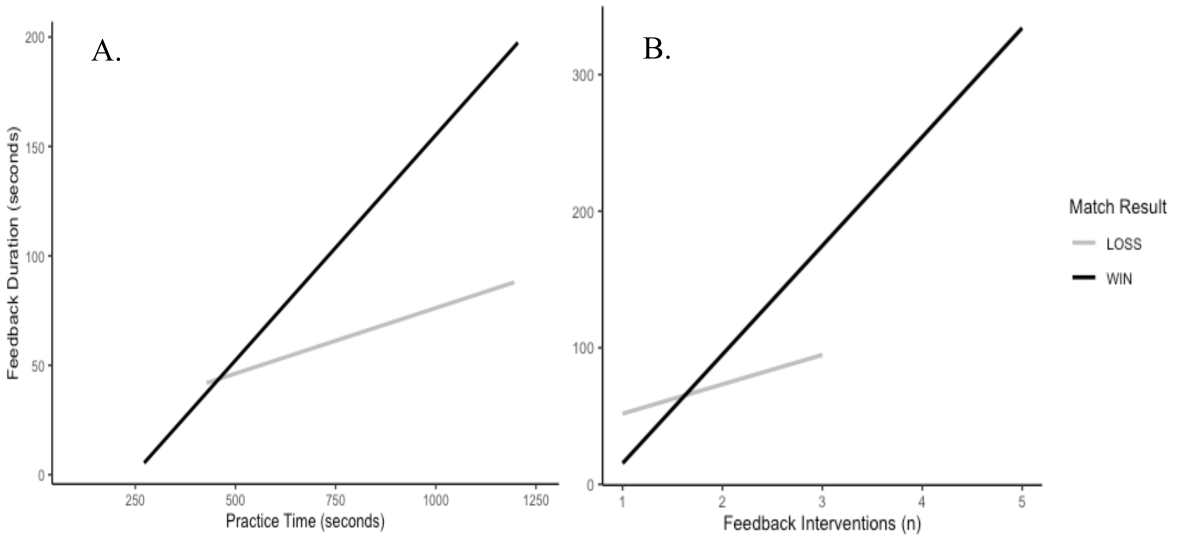

Figure 5.4.2: The model fitted time spent providing feedback interaction plots presenting (A) Interaction effects between practice time and match result on feedback duration and (B) Feedback interventions and match result on feedback duration.

5.5 Discussion

This study investigated the factors associated with team-level terminal verbal feedback duration provided by AFL coaches during practice. The main findings revealed that a practice time*feedback intervention frequency interaction explained 65% of the variance in terminal feedback durations provided across the season. Further, a practice time*match result interaction, and match result*feedback intervention frequency interaction explained 99% of the variance in terminal feedback duration during practice in-season. These findings highlight the duration of terminal feedback AFL coaches provide to the team during practice is mainly associated with the number of times they intervene, the duration spent in a particular practice activity, and the previous game's result as opposed to the type of practice activity, the representativeness of the practice activity or the phase of the season.

Coach interaction with players in practice can substantially influence skill transfer in team sport (Davids et al., 2008). Here, terminal feedback duration during practice activities was associated with greater practice time spent in the particular activity (η^2=0.32[95%CI 0.18:0.45]; $p < 0.001$) and feedback intervention frequency within the particular activity (η^2=0.38[95%CI 0.24:0.50]; $p < 0.001$) (Figure 5.4.1). The results indicate that longer activities provide more opportunity to provide feedback, potentially because more information has been observed. This leads to an increased terminal feedback duration. Here, coaches may provide longer feedback duration when the practice activity is longer because the relationship between collective team behaviour and augmented feedback delivery is mediated by time. That is, the more complex the collective behaviour exhibited in the activity is, the more time the coaches allocate to it, which leads to increased feedback duration. Recent research has confirmed that practice types with increased complexity e.g. match simulation, comprise a large proportion of practice across the pre- and in-season phases (Tribolet et al., 2021). Moreover, although the results from this study confirm that practice type did not contribute any explanatory power to either model, the largest proportions of time spent providing augmented terminal feedback relative to the total practice activity time across the in-season period were match simulation (7.4%) and transition (4.4%), suggesting that coaches provide increased information in more complex practice types.

It has been documented that coaches implement longer average practice activity durations in match simulation, transition and breakdown practice types in professional AF (Tribolet et al., 2021). Coaches may implement longer practice activities because they want players to adequately attune to relevant information sources by maximising their exposure to those specific environments e.g. match simulation. However, by extending the practice activity time, coaches tend to provide increased terminal feedback durations, based on the results of this study. We speculate these results are mediated by the relationship between time on task and errors, where more errors are committed over longer timeframes. This may be a result of attention-limit issues as the activity progresses, where an increase in errors may be attributed to a delay in perceptual recognition and processing (Edwards, 2010; Magill 1994), rather than delayed motor responses. Nonetheless, coaches may feel the innate urge to quickly provide prescriptive information on how to correct these errors. Indeed, Bjork (1994) identified that players and coaches alike do not value errors for their self-organisational characteristics and subsequent benefits of self-discovery in the post-training environment e.g. competition, and would rather provide direct feedback quickly, to correct the error. Additionally, it may also be that coaches provide feedback because it is an implicit inclination to correct these errors or motivate the players and team. This may suggest that feedback is reflective and the direct consequence of performance, rather than being prospective and strategically planned. These findings have implications for the salience and potency of augmented feedback. For example, if coaches provide increased terminal feedback durations as the practice drill continues, players may use this source of information for regulating movements instead of task-intrinsic feedback as augmented feedback is the most easily accessible source of information (Todorov & Jordan, 2002).

The findings of this study would be valuable to share with coaches, along with existing strategies on skill transfer e.g. a scheduling method that can help coaches intervene less to enhance skill transfer uses a bandwidth approach to provide feedback (Anderson et al., 2019). For example, a coach can intervene and provide feedback when five positional errors in the defensive half have been committed. No feedback is provided on the first 4 errors made. This approach helps players self-regulate behaviour by providing opportunities to identify the mistake, then correct and reorganise in relation to the appropriate aspects of information in the activity, such as their teammates, the opponents and their position. Moreover, coaches may decide which situations they will provide feedback in prior to the activity beginning. This way, coaches only intervene when something of importance to the team or individual occurs.

The second model described terminal feedback duration including match result as a fixed effect. Match result did not explain feedback duration as a main effect. Relative to practice activity duration, the relationship between feedback duration and match result was mixed. Although there was a limited effect, practice activities with low practice durations observed slightly higher terminal feedback durations after a loss. In longer duration practice activities, AFL coaches provided increased terminal feedback durations after a win (Figure 5.4.2(A)). For example, in a practice activity that was 10minutes long, coaches intervened to provide 50% more augmented feedback the week after winning a competitive match (75 seconds) compared to losing (50 seconds). Although previous research has reported the number of interactions of feedback coaches provide does not change when there is a higher chance of winning or losing during a competitive AFL match (Mason et al., 2020), the current findings indicate a change in coaching style and information delivery during practice the week after winning or losing a match, relative to practice time. Enhanced learning and increased motivational properties of augmented feedback have been established when provided after successfully performed trials (Badami et al., 2012; Chiviacowsky et al., 2009), which may help explain why coaches provide increased feedback durations during practice after a win when practice time is longer.

A positive association between feedback interventions and feedback duration was evident, however, there was an interaction between feedback interventions and match outcome (η^2=0.65[95%CI 0.34:0.79];$p < 0.001$) such that the effect of feedback interventions on feedback duration increased following a win (when compared with following a loss, Figure 5.4.2(B)). This was a crossover effect whereby when only one feedback intervention was provided, it tended to be of longer duration than following a loss, whereas, when two or more feedback interventions were provided, the total feedback duration tended to be longer following a win, with increasing effects based on the number of interventions provided. This positive relationship becomes increasingly stronger after winning. Feedback duration appears to be short when a few interventions are used, however they are much longer when several feedback interventions are provided. Such a finding implies that the professional coaches in this study provided more information after recent success.

The information players perceive and subsequently utilise depends on the task being performed (Fajen et al., 2008). In this study, practice type and practice activity form did not have any explanatory importance to terminal feedback duration in either model. These findings and notable absence of factors that skill acquisition specialists typically think would influence feedback duration are particularly noteworthy, as it showcases that these AFL coaches did not explicitly change feedback durations depending on the practice activity being performed. For example, some practice types involved more complex representations of gameplay such as collective offensive organisation against multiple opponents, higher pressure from defenders during kicking activities and positioning at stoppages. In simple practice activities, expert performers are able to identify and correct errors intrinsically and without recognition or communication from coaches. However, more complex practice activities may require more augmented feedback as players are unable to identify critical information sources. Thus, approaches to augmented feedback should be context dependent. Skill acquisition specialists can help coaches reflect on the appropriateness of interventions during practice and determine whether the additional information given to the players is necessary to firstly, acquire the skill or behaviour, or secondly, achieve the skill or behaviour at a higher rate than without the augmented feedback.

Although this was the first study to provide a longitudinal analysis of augmented terminal feedback in a professional AF team practice, some limitations must be considered. Firstly, terminal augmented feedback content is an important factor when determining its usefulness in team sport. This study was not able to measure the content of the feedback provided. A potential avenue for future research is putting microphones on the coaches and performing qualitative analyses to further understand the feedback content. Moreover, our initial approach involved analysing all observations, including where zero seconds of feedback was provided by coaches. However, after trying different error structures and removing influential datapoints, the resulting models were extremely poor fits for the dataset. Consequently, we must acknowledge this limitation in the analyses. Additionally, the analyses were only performed within one professional AF team, and therefore may not be generalisable to other teams. Nonetheless, the longitudinal data collection strengthens the interpretation and provides crucial insights into how augmented feedback is provided by coaches in the ecologically valid environment of professional AF practice.

5.6 Conclusion

This study explored the factors associated with terminal feedback duration in professional AF practice. When coaches provided terminal augmented feedback during practice, feedback intervention frequency, practice time and an interaction between the two variables explained 65% of the variance in feedback duration. When the previously played match result was added as a fixed effect in-season, feedback intervention frequency, practice time, a practice time*match result interaction and a feedback intervention frequency*match result interaction effect explained 99% of the variance in feedback durations. Importantly, practice type and the practice activity form did not contribute any explanatory power in either model. Skill acquisition specialists can help coaches navigate how to optimise augmented feedback delivery within team sport. The relationships between factors that explain feedback duration in professional AF illustrates a complex interplay of interactions however these did not include factors that are typically thought to guide feedback during training. Coaches and practitioners working in Australian football and other team sports should discuss the systematic and beneficial implementation of augmented feedback for task-related performance and learning.

Practical applications

- An *in-situ* measurement of augmented feedback can assist practitioners working with coaches about when and how often they provide additional information to the team
- Feedback durations (implicitly) change the week after a competitive match depending upon the previous match result. Coaches must be aware of the implications this can have on the transfer of practice to matches
- There is a complex interaction of factors that explained feedback duration, highlighting the importance of skill acquisition specialists to help implement pedagogical frameworks to aid in the delivery of augmented feedback

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Declaration of interest statement

The authors have no conflicting interests.

5.7 References

Adams, J. A. (1971), A closed-loop theory of motor learning, *Journal of Motor Behaviour*, 3, 111-150.

Anderson, D. I., Rymal, A. M., & Ste-Marie, D. M. (2014), Modelling and feedback. In A. Papaioannou & D. Hackfort (Eds.), The Routledge handbook of sport and exercise psychology (pp. 272–288). New York: Routledge.

Anderson, D.I., Magill, R.A., Mayo, A.M. & Steel, K.A. (2019), Enhancing motor skill acquisition with augmented feedback, Skill Acquisition in Sport: Research, Theory and Practice, 3rd Ed. Routledge London.

Badami, R., VaezMousavi, M., Wulf, G. & Namazizadeh, M. (2012), Feedback about more accurate versus less accurate trials: Differential effects on self-confidence and activation, *Research Quarterly for Exercise and Sport,* 83(2), 1-8.

Bates, D., Maechler, M., Bolker, B. & Walker, S. (2015), Fitting Linear Mixed-Effects Models Using lme4, *Journal of Statistical Software*, 67(1), 1-48. DOI:10.18637/jss.v067.i01.

Ben-Shachar, M.S., Makowski D. & Lüdecke, D. (2020), Compute and interpret indices of effect size. CRAN. Available from https://github.com/easystats/effectsize.

Causer, J., & Williams, A. M. (2013). Improving anticipation and decision making in sport. In T. McGarry, P. O'Donoghue, & J. Sampaio (Eds.), Routledge handbooks. Routledge handbook of sports performance analysis (p. 21–31). Routledge/Taylor & Francis Group.

Chiviacowsky, S., Wulf, G., Wally, R. & Borges, T. (2009), Knowledge of results after good trials enhances learning in older adults, *Research Quarterly for Exercise and Sport*, 80(3), 663-668.

Cohen, J. (1988). Statistical Power Analysis for the Behavioural Sciences (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Côté, J., Baker, J. & Abernethy, B. (2003), Sport specific training, deliberate practice and the development of expertise in team ball sports, *Journal of Applied Sport Psychology*, 15, 12–25.

Côté, J., Baker, J., & Abernethy, B. (2007). Practice and play in the development of sport expertise. In G. Tenenbaum & R. C. Eklund (Eds.), *Handbook of sport psychology* (p. 184–202). John Wiley & Sons Inc.

Côté, J. & Gilbert, W. (2009), An integrative definition of coaching effectiveness and expertise, *International Journal of sports Science and Coaching*, 4(3), 307-323.

Cushion, C.J., Armour, K.M. & Jones, R.L. (2003), Coach Education and Continuing Professional Development: Experience and Learning to Coach, *Quest*, 55(3), 215-230.

Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of skill acquisition: A constraints-led approach.* Champaign, IL: Human Kinetics.

Edwards, W.H. (2010). Motor Learning and Control: From Theory to Practice, Wadsworth, OH: Cengage Learning.

Farrow, D., Baker, J. & MacMahon, C. (2013), Developing sport expertise: Researchers and coaches put theory into practice, London: Routledge.

Fajen, BR., Riley, M.A. & Turvey, M.T. (2008), Information, Affordances, and the control of action in sport, *International Journal of Sport Psychology*, 40, 79-107.

Ford, P.R., Yates, I. & Williams, A.M. (2010), An analysis of practice activities and instructional behaviours used by youth soccer coaches during practice: Exploring the link between science and application, *Journal of Sports Sciences*, 25(5), 483-495.

Gilbert, W.D. and Trudel, P., (2004), Analysis of Coaching Science Research Published from 1970-2001, *Research Quarterly for Exercise and Sport*, 75, 388-399.

Groom R and Nelson L. The application of video-based performance analysis: the coach supporting athlete learning. In: P Potrac, W Gilbert and J Denison (eds) Routledge handbook of sports coaching. Oxon: Routledge, 2013, pp.96–107.

Harrison, X.A., Donaldson, L., Correa-Cano, M.E., Evans, J., Fisher, D.N., Goodwin, C.E.D., Robinson, B.S., Hodgson, D.J. & Inger, R. (2018), A brief introduction to mixed effects modelling and multi-model inference in ecology, *PeerJ*, DOI: doi.org/10.7717/peerj.4794.

Henderson, M., Fransen, J., McGrath, J.J., Harries, S.K., Poulos, N. & Coutts, A.J. (2019), Situational factors affecting rugby sevens match performance, *Science and Medicine in Football,* 3(4), 275-280.

Johnston, R.D., Black, G.M., Harrison, P.W, Murray, N.B. & Austin, D.J. (2018), Applied sport science of Australian football: A systematic review, *Sports Medicine*, 48(7), 1673–1694.

Kahneman, D. & Klein, G. (2009), Conditions for intuitive expertise: A failure to disagree, *American Psychologist*, 64(6), 515-526.

Kuznetsova, A., Brockhoff, P.B. & Christensen, R.H.B. (2017), lmerTest Package: Tests in Linear Mixed Effects Models, *Journal of Statistical Software*, 82(13), 1-26. DOI: 10.18637/jss.v082.i13 (URL: https://doi.org/10.18637/jss.v082.i13).

Madden, C. C. (1995). The Nature and Relative Importance of Coaching Communications in Australian Rules Football, *International Journal of Sport Psychology*, 26(4), 524–540.

Magill, R.A. (1994), The Influence of Augmented Feedback on Skill Learning Depends on Characteristics of the Skill and the Learner, *Quest*, 46, 314-327.

Magill & Anderson, (2014), Motor Learning and Control: Concepts and Applications, 10th Ed. McGraw-Hill Australia.

Markland, R. & Martinek, T.J. (1988), Descriptive analysis of coach augmented feedback given to high school varsity female volleyball players, *Journal of Teaching in Physical Education*, 7, 289-301.

Mason, R.J., Farrow, D. & Hattie, J.A.C. (2020), An analysis of in-game feedback provided by coaches in an Australian Football League competition, *Physical Education and Sport Pedagogy,* DOI: 10.1080/17408989.2020.1734555.

Newell, K.M., Morris, L.R. & Scully, D.M. (1985), Augmented information and the acquisition of skill in physical activity, *Exercise and Sports Sciences Reviews*, 13, 235-261.

Nicholson, D.E. & Schmidt, R.A. (1991), Feedback schedules to enhance training effectiveness, Proceedings of the Human Factors Society, 35th Annual Meeting, Santa Monica, CA.

R Core Team. R: A language and environment for statistical computing. *R Foundation for Statistical Computing.* 2019; Vienna(Austria): https://www.R- project.org/.

Rangeon, S., Gilbert, W., Trudel, P. and Côté, J., Coaching Science in North America, Paper Presented at the 12th ISSP World Congress of Sport Psychology, Marrakesh, Morocco, 2009, June.

Schmidt, R.A. (1982). Motor control and learning: A behavioural emphasis. Champaign, IL: Human Kinetics Publishers.

Sheehan, W.B., Tribolet, R., Watsford, M.L., Novak., A.R., Rennie, M.J. & Fransen, J. (2019), Using cooperative networks to analyse behaviour in professional Australian football, *Journal of Science and Medicine in Sport*, 23(3), 291-296.

Silva, P., Garganta, J., Araújo, D., Davids, K. & Aguiar, P. (2013), Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports, *Sports Medicine*, 43, 765-772.

Swinnen, S., Schmidt, R.A., Nicholson, D.E. & Shapiro, D.C. (1990), Information feedback for skill acquisition: Instantaneous knowledge of results degrades learning, *Journal of Experimental Psychology: Learning, Memory and Cognition*, 16, 706-716.

Todorov, E. & Jordan, M.I. (2002), Optimal feedback control as a theory of motor coordination, *Nature Neuroscience*, 5(11), 1226-1235.

Tribolet, R., Sheehan, W.B., Watsford, M.L. & Fransen, J. (2021), A descriptive and exploratory study of the training structures and practice activities implemented by a professional Australian football team,

Walsh, J. & Jureidini, J. (2016). Language as a Key Resource for the Football Coach: A Case Study of In-Game Coaching at One Australian Rules Club, *The Discourse of Sport: Analyses from Social Linguistics*, edited by D. Caldwell, J. Walsh, E. W. Vine, and J. Jureidini, 13–33. Oxon: Routledge. Challenging tradition, *Journal of Sports Sciences*, 23(6), 637-650.

Chapter 6 | Factors associated with cooperative network connectedness in professional Australian football practice

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6.1 Abstract

Connectedness is a cooperative network measure that describes how well players in the team bi-directionally connect and how easily reachable they are to other players. It has been associated with an increased probability of winning competitive matches in professional Australian Football (AF), although applications towards training have not been reported. Therefore, this study investigated associations between constraints manipulated by professional AF coaches and the connectedness of cooperative passing networks during a small-sided game (SSG). Data were collected describing the task constraints manipulated by professional coaches across one SSG performed on multiple occasions. The SSG focused on transitioning between defence and attack and was performed fifteen times across a whole season, resulting in 36 observations of team connectedness. A linear mixed-effects model was constructed to examine the collective influence of constraints manipulations made by professional coaches (e.g. field size) and team skill characteristics (e.g. kick efficiency) on connectedness scores. The number of team shots on goal and the time on task both positively contributed to connectedness scores, explaining 65% of its variance. The findings show that the number of shots on goal and the time on task may be used to elicit higher or lower connectedness scores in AF SSGs. Skill acquisition specialists, in conjunction with coaching staff, can use these metrics to aid practice design in professional AF or indeed other evasion-style team sports.

6.2 Introduction

Australian football (AF) is a complex team sport characterised by intermittent high-speed running and changes of direction, (Johnston et al. 2018) and the use of bimanual and bipedal skills for passing, scoring and gaining possession (Johnston et al. 2018; Rennie et al. 2018). Coaches and support staff design-specific tactical strategies that depend on the opposition, nature of the venue and other contextual factors. These strategies, combined with players' individual actions within the game's constraints, influence collective behaviour such as cooperative passing networks, for example, network centrality, network density (Ribeiro et al. 2017) and spatiotemporal metrics for example, movement regularity and dispersion (Low et al. 2019). Recent studies have used cooperative network characteristics to investigate the collective demands of Australian Football League (AFL) match-play (Braham & Small 2018; Fransen et al. 2021a; Young et al. 2020), the professional competition of AF, revealing that the analysis of collective behaviour may inform the strategic decisions at the team level to increase the probability of winning. Along with its relevance for strategy, the analysis of collective behaviour can inform practice design aimed at improving this property.

It has recently been established that performance outcome measures such as goal conversions, total kicks, metres gained, team ratings and player ratings (Fahey-Gilmour et al. 2019; Robertson et al. 2016; Young et al. 2019) are related to match outcome and/or score margin in AFL. Additionally, other studies have focused on performance production measures such as network density, edge count, and network interaction (Braham & Small 2018; Fransen et al. 2021a; Young et al. 2020) to explain variations in match outcomes. Furthermore, performance production measures in team sports, such as collective spatiotemporal data and cooperative networks, can be targeted in practice (Mendes et al. 2018; Moreira et al. 2019; Ometto et al. 2018). Moreover, Mendes and colleagues (Mendes et al. 2018) reported positive relationships between network density (global level of mutual interaction within the network) and final score in association football, and negative relationships between network density and goals conceded. Thus, teams with passing networks where players are easily reachable (e.g., a player is considered more reachable if they are within one or two passes of all other players in the passing network) score more often. Recent analyses incorporating cooperative network measures identified moderate associations with match outcome (Braham & Small 2018; Fransen et al. 2021a; Young et al. 2020). One notably important network metric for AFL is the connectedness of a team's passing network (Fransen et al. 2021a).

Connectedness provides insight into the level of interaction within a team's passing strategy. Connectedness is a construct obtained from principal component analysis used to dimensionally reduce various team cooperative network characteristics from several seasons of AFL matches and includes positive contributions from a team's network density, intensity and in- and out-closeness centrality (Sheehan et al. 2019). Connectedness is composed of network density, that is, the global level of interaction within the passing network; values closer to 1 signify a network where most players exchange passes, (Grund 2012) and network intensity, which is the amount of passing exchanges in the network. Team in-closeness and out- closeness also compose part of connectedness, that is, how easy it is for players to be reached or reach others by other players in the passing network, respectively, where higher values indicate greater 'reachability' or proximity to each other. Lastly, betweenness, which represents how often a player appears on the shortest path between two players, with high values indicating a 'link' or 'bridge' between connecting players in the passing network (Gudmundsson & Horton 2017). Higher connectedness values signify that most players connect bi-directionally and are easily reachable, that is, it is a well-connected network with equal contributions from each player (Sheehan et al. 2019). Additionally, all metrics in the connectedness calculation contribute positively to connectedness values with the exception of betweenness, which contributes negatively, with low scores meaning that most players connect with one another without over-reliance on linking individuals.

Recent analyses performed by Fransen and colleagues (2021a) reported that a one standard deviation increase in a team's connectedness increased the probability of winning an AFL match by 79.5%. Here, the authors analysed the effect of connectedness, indegree variability and outdegree variability on a team's relation to winning or losing an AFL match over the 2016–2019 AFL seasons. Whilst showing a strong relationship between connectedness and winning an AFL match, the generalised mixed-effects regression model also showed a 69% classification accuracy, which is comparable to other studies in AF considering the number of inputted independent variables in the developed models (Fahey-Gilmour et al. 2019; Young et al. 2019). While no causation was inferred, the observed relationship between connectedness and winning AFL matches warrants an investigation into how practice design could influence this variable.

According to the constraints-led approach to skill acquisition, skilled behaviour emerges through the interaction of individual, environmental and task constraints (Davids et al. 2008).

Due to the complexity of team sport performance, a collective of performers aim to satisfy an array of interacting constraints to achieve functional movement solutions (Silva et al. 2013). Consequently, coaches aim to adapt practice so behaviours acquired during these sessions transfer to match-play. Here, increased transfer of practice to competition is regulated by the similarity of interacting constraints between both contexts. For example, it has been demonstrated that professional AF practice differs from competitive matches (Ireland et al. 2019) specifically, the opposition pressure, the prevalence of specific kick types and ball possession duration all differ between AFL matches and practice. Therefore, structuring practice to include key interacting constraints preserves the relationship between perception and action (Pinder et al. 2011). Consequently, representative learning design is predicated on practice incorporating relevant information for decision-making and action regulation that is similar to performance contexts (Pinder et al. 2011). However, there is a lack of research comparing the efficacy of the constraints-led approach to more traditional, prescriptive type practice strategies (Gray, 2020). Additionally, there is a lack of longer-term studies assessing the constraints-led approaches effectiveness. Resultantly, the complexity of in-game interactions, contextual factors and dynamic behaviours means representative learning design of collective behaviour can be difficult to achieve in practice. This may be made even more difficult in situations where there are limited numbers of players and/or a representative playing area is not available.

To help achieve representative practice, AF coaches often use small-sided games (SSGs) (Tribolet et al. 2021). SSGs integrate physical, technical and tactical aspects into the same activity and are useful to develop players and team's individual and collective decision-making and skill execution in high validity environments. These environments present opportunities for action embedded within the performance environment that are collectively available to all players and are termed shared affordances (Silva et al. 2013). For example, a team may self-organise into positional formations that facilitate moving the ball through the middle of the field after an opposition turnover. To encourage this behaviour to emerge, coaches commonly manipulate player numbers, field size and the time spent in the practice activity, among other variables. Recently, Moreira and colleagues (2019) reported reducing the playing space increased the network interaction between players. Players who were physically closer were more easily reachable using less complicated passing movements, resulting in a higher frequency of interactions between a greater proportion of players. Despite this novel research, no information is available for coaches on how practice design could influence passing network characteristics in AF.

Therefore, the aim of the current study was to investigate which manipulable constraints influence team connectedness in a commonly used SSG in professional AF practice. It was hypothesised that increased field size and subsequent increased space per player, and longer practice durations would have positive associations with team connectedness scores.

6.3 Methods

Participants

The study followed an observational longitudinal design where one professional AF club consisting of 46 male footballers (23.3 ± 4.4 years) and 13 academy players (18.1 ± 0.9 years) participated in their normal training across one season from November 2018 to September 2019. The eight coaches had an average of 6.8 ± 6.5 years AFL coaching experience and an average of 11.5 ± 5.1 years of playing professionally. The coaching staff designed and implemented the training with no intervention from the researchers, ensuring ecological validity of the data collection. The researchers informed the coaches on the purpose, advantages and limitations of the research. Furthermore, the playing group was informed about the purpose of the research through a formal meeting. They were explained of the process, ensured that this would be part of their normal training commitments and were informed that they were able to withdraw participation if they preferred to. Informed consent was obtained from each player and the organisation. Ethics approval (approval no: ETH19-3597) was obtained for this study from the University's ethics committee.

Practice activities

Pre-season training consisted of three sessions per week, whilst in-season training consisted of 1–2 sessions per week. Training sessions were typically between 30 and 120 minutes and consisted of conditioning, skill and tactical activities. The purpose of the SSG was to beat the opposition by scoring more goals and adhered to normal AFL rules and regulations. According to the coaches, the main tactical focus of this SSG was the transition between attack and defence. It was always performed as part of the main session during training. Constraint manipulations were administered by the coaches without researcher feedback and were based on player numbers and determining sufficient space to facilitate their behaviours during attacking and defending transitions. Each of the SSG conditions are outlined in (Table 6.3.1). Specific target constraints were not verbalised by the coaches. Additionally, each variation of the SSG was performed on a rectangle-shaped field and was officiated by a single coach with the other coaches scattered around the boundary to throw a replacement ball in when needed.

Outcome measures

To quantify network metrics, an interaction between two players was coded if a handball or kick reached the intended target player. A matrix was subsequently created detailing the number of interactions between each possible player dyad. A weighted and directed graph was then created with nodes representing individual players and edges representing the direction and number of passes between each player. Subsequently, global-level characteristics of the teams passing network can be calculated. However, as there is a large resulting number of team-level passing metrics, Sheehan and colleagues (2019) used a data reduction technique to help enhance their interpretability and create global-level indicators. In the current study, we used a resultant principal component score, connectedness, to indicate the overall level of bi-directional passing connections within the team. Being a principal component score, connectedness is comprised of multiple metrics as explained by Sheehan and colleagues: 'higher [connectedness] values signify that most players connect bi-directionally (network density) and are easily reachable for others (team in- and out- closeness centrality). Additionally, the negative contribution of team betweenness centrality indicates that lower scores benefit overall connectedness. A lower team betweenness centrality score signifies that most players within the network can connect with one another without relying on a linking individual.' Here, network density is the global level of interaction within the network with values closer to 1 signifying a network whereby most players interact with each other, (Grund 2012) team in-closeness and out-closeness represent how easy it is for a player to reach (out-closeness) or be reached (in-closeness) by other players in the passing network, (Gudmundsson and Horton 2017) where higher values indicate greater proximity and as a result, require fewer passes to connect with other players, whereas betweenness represents how often a player appears on a shortest path between two players in the passing network, where players with higher values are generally seen as a 'bridge' between connecting players in the network. The exact equation to calculate connectedness using these metrics is described by Sheehan and colleagues (2019).

Independent variables

Independent variables were coded and calculated to assess which contribute to connectedness variance (Table 6.3.2). Task constraints were collected on field consistently by the lead researcher (Table 6.3.1). These task constraints were considered because they are the most manipulatable constraints and contribute to the types of behaviours and states of organisation that teams are afforded. For example, smaller space per player affords different passing behaviours compared to larger space per player. Specifically, the SSG length and width (metres) define the space that the players can behave within, and contribute to determining the amount of space per player, which is calculated by dividing the total area of the SSG condition (length × width) by the total number of players in the condition. For example, if the area was 6000 m^2 for 15 players, the space per player was 400 m^2. The time spent in each condition was recorded in seconds and considers the time spent on task, determined by the coaches. Hence, even though this analysis is exploratory, these task constraints are thought to influence connectedness.

Team outcomes related to passing behaviours and shots on goal were notated. Kick and handball efficiency (%) were calculated by dividing effective passes by the total number of passes. A turnover was notated if a change of possession occurred. Additionally, a shot on goal was notated if any player made a shot for goal. For each practice session, training was filmed by elevated cameras perpendicular to the field and behind the goals. Training footage was coded using SportsCode (SportsTec Limited, version 9.4.1, Warriewood, Australia) with the lead researcher notating all of the information. All practice sessions were annotated by the same experienced observer, who had annotated more than 250 hours of AF training and match-play. Coding reliability was assessed using an intra-class correlation coefficient (3, k) (Koo and Li, 2016). The intra-class correlation coefficients between test 1 and test 2 demonstrated excellent reliability ($r = 0.94$–0.98) for the annotations of passing networks, skill characteristics and time spent in each SSG condition.

Data Analysis

Prior to statistical analyses, connectedness scores were converted to z-scores. These z-scores were normalised to the same unit and magnitude, with a set average and standard deviation (Quotient scores = 100+(z-score*15); where the mean = 100 and standard deviation = 15) to facilitate their reporting (Sheehan et al. 2019). Connectedness sum scores were coded and calculated using Microsoft Excel (Microsoft, Redmond, WA, USA) and MATLAB R2018b routines (The MathWorks Inc., Natick, MA, USA). Explanations of the connectedness calculation were provided by Sheehan et al (2019).

Table 6.3.1: Each SSG condition and the associated phase of the year, tactical purpose and task constraints.

Condition	Number of Competing Teams	Phase	Tactical Purpose	Total Players (n)	Player Numbers (n)	Drill Shape	Field Length (m)	Field Width (m)	Area (m^2)	Space per Player (m^2)	Time (seconds)
1	2	Pre-season	Press in Defence. Outnumber & advantage	20	10v10	Rectangle	100	65	6500	325	792
2	2	Pre-season	Link out of defence	19	10v9	Rectangle	90	63	5695	300	936
3	2	Pre-season	Defend as high as possible	19	10v9	Rectangle	90	63	5695	300	1015
4	3	Pre-season	Off-ball defensive shape and 'squeezing' the ground	19	10v9	Rectangle	92	56	5168	272	1347
5	2	Pre-season	Off-ball defensive shape. Transition between attack and defence	17	9v8	Rectangle	82	66	5413	319	1122
6	3	Pre-season	Off-ball defensive shape. Transition between attack and defence	19	10v9	Rectangle	104	71	7376	388	951
7	2	Pre-season	Off-ball defensive shape. Transition between attack and defence	15	8v7	Rectangle	91	60	5460	364	394
8	2	Pre-season	Off-ball defensive shape. Transition between attack and defence	17	9v8	Rectangle	91	60	5460	321	1063
9	3	In-season	Off-ball defensive shape. Transition between attack and defence	21	11v10	Rectangle	92	71	6553	312	906
10	2	In-season	Off-ball defensive shape. Transition between attack and defence	17	9v8	Rectangle	82	51	4193	247	680
11	3	In-season	Off-ball defensive shape. Transition between attack and defence	21	11v10	Rectangle	94	74	6979	332	959
12	2	In-season	Off-ball defensive shape. Transition between attack and defence	15	8v7	Rectangle	101	53	5353	357	330
13	2	In-season	Off-ball defensive shape. Transition between attack and defence	19	10v9	Rectangle	120	56	6720	354	378
14	2	In-season	Off-ball defensive shape. Transition between attack and defence	19	10v9	Rectangle	88	58	5104	269	492
15	3	In-season	Off-ball defensive shape. Transition between attack and defence	19	10v9	Rectangle	87	59	5133	270	439

Table 6.3.2: Predictors included in model specification, predictor values and the range of predictor variables.

Level of Data		Factors	Type	Average (Min – Max)
Level 2	**Cluster of Units (random)**	*Practice condition identifier*		
Level 1	**Unit of Analysis**	*Individual condition sample*		
	Dependent Variable	Connectedness	Continuous	96.3 (82 – 116)
	Predictors			
		SSG width (m)	Continuous	62.3 (51.2 – 74.4)
		SSG length (m)	Continuous	93.5 (81.9 – 120.0)
		Space per player (m^2)	Continuous	313.8 (246.7 – 388.2)
		Total number of players	Continuous	18.6 (15 – 21)
		Number of players on each team	Continuous	9.2 (7 – 11)
		Time in SSG condition (seconds)	Continuous	797.3 (330 – 1347)
		Team HB efficiency (%)	Count	88.2 (59.3 – 100)
		Team Kick efficiency (%)	Count	68.1 (31.0 – 89.2)
		Total number of turnovers	Count	4.2 (1 – 11)
		Average number of shots	Count	3.0 (0 – 9)

HB = Handball; m = metres; SSG = Small Sided Game

Assumptions of independence and collinearity were checked prior to performing linear mixed-effects models, and scatterplots were used to determine potential influential data points. Following analysis, visual inspections of the model's residual plots were used to determine obvious deviations from homoscedasticity or normality.

The study design located units of analysis, which were individual SSG condition samples clustered in the practice condition constraints (Table 6.3.2). This form of analysis involves both fixed effects, defined as variables yielding a systematic influence on the entire dataset, and random effects, which has non-systematic influences on the data. Random factors were included in the model to allow random deviations for each SSG condition around the overall fixed intercept. Here, practice condition was specified as a random effect. 95% confidence intervals were calculated to assess the precision of the estimates.

A 'step-up' model construction was employed, similar to models previously used in team sport (Henderson et al. 2019). The process began with an 'unconditional' model containing only a fixed intercept and random factor (condition identifier) from level 2. The unconditional model does not contain any predictor or specific fixed-effect but has the specified random effects structure contained in it, that is, condition identifier. The model was then developed by adding each single independent variable from level 1 as a fixed effect. Variables were retained when they yielded better model fits considering model strength and parsimony, denoted by lower AIC and significant Likelihood Ratio Test p value. The t statistics from the mixed models were converted into pseudo partial eta squared effect sizes and associated 95% confidence intervals. Effect size interpretations were 0.01 (small), 0.06 (moderate) and 0.14 (large) (Cohen 1988). All statistical analyses were conducted using the lme4 (Bates et al. 2015), lmerTest (Kuznetsova et al. 2017) and effectsize (Ben-Shachar et al. 2020) packages in R statistical software (R Core Team 2019). Visual inspections of residual plots revealed no obvious deviations from homoscedasticity or normality, whilst Q–Q plots demonstrated good model fit.

6.4 Results

Fifteen variations of the SSG were performed resulting in 36 observations. Collective skill characteristics are presented (Table 6.3.2). The effect of the different independent variables on connectedness are presented (Table 6.4.1). A collinear relationship was detected between the number of shots and average goals ($r = 0.85$). Since number of shots presented a stronger relationship with the dependent variable connectedness ($r = 0.71$), average goals were removed from the analysis. The best model fit included random intercepts for each practice condition, demonstrating significant variance between training sessions, which accounts for some portion of connectedness variance.

When considering the explained variance from fixed effects only, the model displayed a marginal r^2 value of 0.56. Considering the explained variance from both fixed and random effects yielded a conditional r^2 value of 0.65. The mean connectedness score was 97.3 ± 9.6 quotient points. Time spent in the small-sided game condition (0.01[95% CI:0.00–0.02], $\eta^2 = 0.11$ $p = 0.05$,) and the collective number of shots on goal (2.58[95% CI:1.58–3.66], $\eta^2 = 0.44$ $p < 0.001$,) were both positively associated with connectedness.

Subsequently, every second increase in the SSG was associated with increased connectedness by 0.01 (0.00–0.02) quotient points and one team shot at goal was associated with an increase in connectedness of 2.58 (1.50–3.67) quotient points. All other factors examined did not contribute to the model. That is, if the predictor did not produce a lower AIC value or significant Likelihood ratio test p value, it was discarded from the model.

Table 6.4.1: Associations between fixed effects and Connectedness.

	Coefficients	95% CI	df	t value	Likelihood ratio test	AIC difference	Effect size (95% CI)
Fixed Effects							
(Intercept)	82.33	75.83 – 88.82	3	24.85	<0.001		0.95 (0.92 – 0.97)
Time (seconds)	0.01	0.00 – 0.02	4	1.96	p=0.05	4	0.11 (0.00 – 0.34)
Team shots (n)	2.58	1.58 – 3.66	5	4.94	<0.001	16	0.44 (0.18 – 0.63)

CI: confidence interval; df: degrees of freedom; AIC: Akaike Information Criterion;
Note: Likelihood ratio test based on comparison with previous model
Effect size is an approximation based on the t value obtained from each variable included in the model

6.5 Discussion

This study examined the factors associated with connectedness scores during practice in professional AF. In partial agreement with the hypothesis, the time the players spent on the field during the SSG and the number of team shots on goal explained 65% of the variance in connectedness scores across conditions, however, field size was not related. Practitioners and coaches working in AFL may use these findings to manipulate practice to influence connectedness scores and simulate desired behaviours during practice.

In complex systems, mechanisms that support pattern formation and coordinative behaviour are supported by a spontaneous process of self-organisation under interacting task, individual and environmental constraints (Silva et al. 2016). This study assessed the constraints and metrics that influence connectedness in-situ during professional AF practice designed by experienced coaches (Table 6.3.1). The main finding indicated that the number of shots is strongly associated with a team's connectedness scores during the SSG ($\eta^2 = 0.44$ [95% CI:0.18–0.63]). This is not surprising given that more network interactions positively relate to final scores in association football across varying competitive levels (Mendes et al. 2018). In the current study, each additional shot at goal increased connectedness by 2.58 (1.58–3.66) quotient points (Table 6.4.1). The association with number of shots on goal may reflect two mechanisms: 1) the higher number of passes involving more players and 2) the direction of passes are towards more favourable areas on the field that are closer to the attacking goals. For example, it is likely that making effective 20 m passes towards goal will increase connectedness. Here, passing the ball forward results in multiple players receiving and distributing possession, compared to a long kick down the wing to a large contest of players. Thus, coaches can manipulate specific constraints to optimise the number of players that receive and distribute passes, and the direction of those passes, to enhance the number of shots at goal. This may help transfer favourable behaviours to match play as it encourages continual passing interactions, increasing the relevance of the constraints being sampled and preserving the relationship between perception and action (Pinder et al. 2011). Specifically, a higher number of passes towards goal likely results in more favourable off-ball movements, provides more passing opportunities as players find and fight for available space to receive possession and may create unpredictable movement patterns for the opposition team to defend against. Thus, the consequences of increased connectedness during training likely has a positive transfer to competitive matches.

The relationship between practice time and connectedness was moderate (η^2 = 0.11 [95% CI:0.00–0.34]). Connectedness incorporates not only the density and intensity of the network, but also the reachability of players (in- and out-closeness). The time spent in the SSG indicates that for longer activities, connectedness scores were higher as this provides teams with not only the opportunity to accumulate more passing connections, but to reach and interact with each player. This may not be the case for shorter activities, as some players may have limited opportunities to be involved in the network. As determined by the positive coefficient, every second of play in the SSG results in a 0.01 (0.00–0.02) unit increase in connectedness. The amount of time spent practicing the task may be dependent on the degree of attention and cognitive processing required (Fitts & Posner 1967; Goldhammer et al. 2014). Consequently, the time on task should be implemented as a task constraint when attempting to optimise collective skill acquisition. With effective planning, optimal connectedness for a specific amount of time can be determined in a SSG. For more complex SSGs where more players are involved, or a larger field size is implemented, increased time on task is important based on task difficulty and the temporal nature of learning (Hodges & Williams 2012). Comparatively, less representative practice may have less defenders or less passing options, which should reduce the time in the activity. Nonetheless, these findings verify the importance of time on task when designing practice for collective skill acquisition. Practitioners and coaches may use these findings to help increase the positive transfer to competitive matches. For example, coaches can allocate more time in passing/ball movement activities that are 'more representative' of competition, such as SSGs or match simulations. Whilst this may seem obvious, recent research has shown coaches allocate more time to 'skill' type activities rather than match simulation (Tribolet et al. 2021). As such, players may have a superior transfer of skill if ball movement behaviours (to increase connectedness) are performed for increased amounts of time in contextually appropriate activities.

Nonetheless, a larger sample is required to determine whether time on task effects are heterogenous and are mediated by task representativeness. Interestingly, the number of players, field length and width, space per player, kick efficiency and the number of turnovers did not contribute any explanatory power to the model. This is surprising considering previous findings in association football (Moreira et al., 2019) and that these are common manipulations coaches implement to elicit specific collective behaviours. It may be that the effects of these constraints themselves may be dependent on the task constraints, such as the type of SSG, or that a larger sample is required. Moreover, there may not have been sufficient variance in the measures collected, for example, the average space per player collected across 15 training sessions was 313.8 (246.7–388.2) m^2, whereas most AFL grounds elicit >400 m^2. SSGs with more accurate space per player relative to AFL grounds may demonstrate greater relevance for the currently unassociated factors reported in this study.

Whilst this study is the first to examine factors that contribute to connectedness during professional AF practice, there are some important limitations. Performance in team sport, and AF in particular, involves many elements including physical, tactical and technical components. Thus, it is difficult to encapsulate team performance based on one value, despite its derivation as a multivariate score and its importance to match outcome in professional AF (Fransen et al. 2021a). Additionally, the analyses were only performed on one SSG. Relatedly, the small sample size here is common in high-performance sport, where we collected a convenience sample. Therefore, whilst the metrics were collected longitudinally over one season using the same cohort of professional athletes, the scope of generalising the findings to alternative SSGs or other team evasion sports may be limited. Regardless, the examination of the collective behaviour of professional athletes ensured strong ecological validity in the current study. Future research is required to determine whether these metrics remain important when explaining connectedness, and whether these findings are applicable to other practice contexts. Future research should also aim to discover whether connectedness scores during practice relate to a team's performance in competitive AFL matches.

6.6 Conclusion

This study collected task constraints and cooperative network scores in-situ from one type of SSG performed by professional AF players to simulate transitions between attack and defence. Connectedness scores were positively associated with the number of team shots on goal and the time on task. Using the constraints-led approach, coaches and skill acquisition specialists can manipulate the time on task and other related constraints, such as task rules facilitating the amount and direction of passes to maximise shots on goal. Additionally, team shots on goal and task duration are simple indicators that a performance analysts can use as simple proxies for connectedness, although this should be tested in the specific SSG and team considering the unexplained variance requiring further investigation. Integrating performance production measures, such as cooperative networks, into practice analyses can help support decision-making regarding practice design in team sport.

Practical Implications

- Performance analysts can use the number of shots on goal and the time on task to monitor connectedness scores in Australian football SSGs practice.
- Coaches and practitioners should manipulate constraints to maximise the number of players that receive and distribute passes e.g. task rules, and the direction of those passes, to increase the number of shots at goal.
- To achieve higher connectedness scores and provide the teams the opportunity to accumulate more meaningful and adaptive passing relationships, an increased amount of time is required and recommended in SSGs.

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Declaration of Interest Statement

The authors have no conflict of interest to declare.

6.7 References

Bates, D., Maechler, M., Bolker, B. & Walker, S. (2015), Fitting Linear Mixed-Effects Models Using lme4, *Journal of Statistical Software*, 67(1), 1-48. DOI:10.18637/jss.v067.i01.

Ben-Shachar, M.S., Makowski D. & Lüdecke, D. (2020), Compute and interpret indices of effect size. CRAN. Available from https://github.com/easystats/effectsize.

Braham, C. & Small, M. (2018), Complex networks untangle competitive advantage in Australian football, *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 28(5), 053105.

Cohen, J. (1988). Statistical Power Analysis for the Behavioural Sciences (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Davids, K., Button, C., & Bennett, S. (2008). Dynamics of skill acquisition: A constraints-led approach. Champaign, IL: Human Kinetics.

Fahey-Gilmour, J., Dawson, B., Peeling, P., Heasman, J. & Rogalski, B. (2019), Multifactorial analysis of factors influencing elite Australian football match outcomes: a machine learning approach, *International Journal of Computer Science in Sport*, 18(3), DOI: https://doi.org/10.2478/ijcss-2019-0020.

Fitts, P. M., & Posner, M. I. (1967). Human performance. Oxford, England: Brooks/Cole.

Fransen, J., Tribolet, R., Sheehan, W.B., McBride, I., Novak, A. & Watsford, M.L. (2021), Cooperative passing network features are associated with successful match outcomes in the Australian Football League, *International Journal of Sports Sciences and Coaching*, DOI: doi.org/10.1177/17479541211052760.

Goldhammer, F., Naumann, J., Stelter, A., Tóth, K., Rölke, H. & Eckhar, K. (2014), The Time on Task Effect in Reading and Problem Solving Is Moderated by Task Difficulty and

Skill: Insights from a Computer-Based Large- Scale Assessment, *Journal of Educational Psychology*, 106(3), 608-626.

Gray, R. (2020), Comparing the constraints led approach, differential learning and prescriptive instruction for training opposite-field hitting in baseball, *Psychology in Sport & Exercise*, DOI:10.1016/j. psychsport.2020.101797.

Grund, T.U. (2012), Network structure and team performance: the case of English premier league soccer teams. *Social Networks*, 34(4), 682–690.

Gudmundsson, J. & Horton, M. (2017), Spatio-temporal analysis of team sports. ACM Computer Science (CSUR). 50(2), 22.

Henderson, M., Fransen, J., McGrath, J.J., Harries, S.K., Poulos, N. & Coutts, A.J. (2019), Situational factors affecting rugby sevens match performance, *Science and Medicine in Football,* 3(4), 275-280.

Hodges, N.J., & Williams, A.M. (2012). Skill acquisition in sport: Research, theory and practice. 3rd Edn. London, UK: Routledge.

Ireland, D., Dawson, b., Peeling, P., Lester, L., Heasman, J. & Rogalski, B. (2019), Do we train how we play? Investigating skill patterns in Australian football, *Science and Medicine in Football,* 3(4), 265-274.

Johnston, R.D., Black, G.M., Harrison, P.W, Murray, N.B. & Austin, D.J. (2018), Applied sport science of Australian football: A systematic review, *Sports Medicine*, 48(7), 1673–1694.

Koo, T.K. & Li, M.Y. (2016), A guidelines of selecting and reporting intraclass correlation coefficients for reliability research, *Journal of Chiropractic Medicine*, 15(2), 155–163.

Kuznetsova, A., Brockhoff, P.B. & Christensen, R.H.B. (2017), lmerTest Package: Tests in Linear Mixed Effects Models, *Journal of Statistical Software*, 82(13), 1-26. DOI: 10.18637/jss.v082.i13 (URL: https://doi.org/10.18637/jss.v082.i13).

Low, B., Coutinho, D., Gonçalves, B., Rein, R., Memmert, D. & Sampaio, J. (2019), A Systematic Review of Collective Tactical Behaviours in Football Using Positional Data, *Sports Medicine*, 50, 343-385.

Mendes, B., Clemente, F.M. & Maurício, N. (2018), Variance in prominence levels and in patterns of passing sequences in elite and youth soccer players: A network approach, *Journal of Human Kinetics*, 61, 141-153.

Moreira, P.E.D., Barbosa, G.F., Murta, C.D.C.F., Morales, J.C.P., Bredt, S.D.G.T., Praça, G.M. & Greco, P.J. (2019), Network analysis and tactical behaviour in soccer small-sided and conditioned games: influence of absolute and relative playing areas on different age categories, *International Journal of Performance Analysis in Sport*, 20(1), 64-77.

Ometto, L., Vasconcellos, F.V.A., Cunha, F.A., Teoldo, I., Souza, C.R.B., Dutra, M.B., O'Sullivan, M. & Davids, K. (2018), How manipulating task constraints in small-sided and conditioned games shapes emergence of individual and collective tactical behaviours in football: A systematic review, *International Journal of Sports Science and Coaching*, 13(6), 1200-1214.

Pinder, R.A., Davids, K., Renshaw, I. & Araújo, D. (2011), Representative learning design and functionality of research and practice in sport, *Journal of Sport and Exercise Psychology*, 33(1), 146-155.

R Core Team. R: A language and environment for statistical computing. *R Foundation for Statistical Computing.* 2019; Vienna(Austria):https://www.R- project.org/.

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

Ribeiro, J., Silva, P., Duarte, R., Davids, K. & Garganta, J. (2017), Team sports performance analysed through the lens of social network theory: implications for research and practice, *Sports Medicine*, 47(9):1689–1696.

Robertson, S., Back, N. & Bartlett, J.D. (2016), Explaining match outcome in elite Australian Rules football using team performance indicators, *Journal of Sports Sciences*, 34(7), 637-644.

Sheehan, W.B, Tribolet, R., Watsford, M.L., Novak, A.R., Rennie, M.J. & Fransen, J. (2019), Using cooperative networks to analyse behaviour in professional Australian Football, *Journal of Science and Medicine in Sport*, 23(3), 291-296.

Silva, P., Garganta, J., Araújo, D., Davids, K. & Aguiar, P. (2013), Shared Knowledge or Shared Affordances? Insights from an Ecological Dynamics Approach to Team Coordination in Sports, *Sports Medicine*, 43, 765-772.

Silva, P., Vilar, L., Davids, K., Araújo, D. & Garganta, J. (2016), Sports teams as complex adaptive systems: manipulating player numbers shapes behaviours during football small-sided games, *SpringerPlus,* 5.

Tribolet, R., Sheehan, W.B., Watsford, M.L. & Fransen, J. (2021), How does practice change across the season? A descriptive study of the training structures and practice activities implemented by a professional Australian football team, *International Journal of Sports Science and Coaching*, DOI: 10.1177/17479541211019829.

Young, C.M., Luo, W., Gastin, P., Tran, J. & Dwyer, D.B. (2019), The relationship between match performance indicators and outcome in Australian football, *Journal of Science and Medicine in Sport*, 22(4), 467-471.

Young, C.M., Luo, W., Gastin, P.B. & Dwyer, D.B. (2020), Understanding the relative contribution of technical and tactical performance to match outcome in Australian football, *Journal of Sports Sciences*, 38(6), 676-681.

Chapter 7 | Match simulation practice may not represent competitive match play in professional Australian football

As per the published article:

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7.1 Abstract

Match simulation in team sport should sample representative constraints and behaviours to those observed in competitive matches to enhance near skill transfer. This study compared task constraints (field length, field width, length per width ratio, space per player), time-standardised skill metrics (goals, shots on goal, handballs, kicks, marks, turnovers, tackles, handball proficiency, kick proficiency) and cooperative passing metrics (connectedness, indegree variability and outdegree variability) between match simulation practice and competitive Australian Football League (AFL) games for one professional team. MANOVAs identified activity-related differences for task constraints, skill metrics and cooperative passing networks. During match simulation, goals were scored more frequently, but with less passing actions per minute. Receiving and distributing passing networks were more centralised (reliance on fewer key individuals), with less turnovers and tackles per minute compared to AFL matches. If match simulation is designed to reflect competition, then player and team skill preparation may be compromised. Furthermore, the competing demands in high-performance sport may restrict the degree of representativeness that can be achieved during practice. These findings provide valuable insight and may assist practitioners and/or coaches to understand the value of match simulation practice and to maximise near skill transfer from match simulation to competition.

7.2 Introduction

A key objective for practitioners working in competitive team sport is to assess and enhance practice design to augment skill or behaviour transfer to competition (Maloney et al., 2018). An established framework to evaluate the usefulness and applicability of practice design is ecological dynamics (Davids et al., 2008; Renshaw & Gorman, 2015), which integrates perspectives and concepts from Dynamical Systems Theory (Clark, 1995; Kugler et al., 1980) and ecological psychology (Gibson, 1979). The integration of these theories assists researchers and practitioners working in sport to explain how coordinated behaviour in athletes and teams of athletes emerges as a result of the properties of the performer(s)-environment relationship. For example, in order to keep an opponent from counter-attacking and scoring, coordinated defensive behaviour emerges in response to a sudden turnover of possession. This highlights the tightly coupled relationship between the perceptual information embedded within the performance environment, and the actions of the performers that reside within it. Ecological dynamics forms the foundation of several coaching and educational pedagogies, such as the constraints-led approach, in which characteristics of the individual, task and/ or environment are altered in order to elicit functional coordinated behaviour (Davids et al., 2008; Handford et al., 1997). One of the central tenets of ecological dynamics is that to facilitate skill acquisition, practice environments should represent, as much as possible, the performer-environment interactions observed during competition. This is often referred to as representative learning design (Pinder et al., 2011).

Successful cooperative behaviour in team sport is predicated on the continuous self-organising adaptability of behaviours with dynamic and interacting constraints (Silva et al., 2013). In other words, optimising team performance can be viewed as a function of a team's adaptability to a range of varying and interacting constraints. Thus, practice that adequately represents the close-knit relationship between perception and action observed in competitive play, facilitates the development of adaptable team behaviour (i.e., actions) from a practice to a competition context. However, maintaining the fidelity, i.e., the relationship between performance in competition and performance in practice (Pinder et al., 2011), of perception-action couplings in practice can be difficult. Several studies have investigated ways in which perception-action couplings can be altered, with one such method being the mediating role of interacting constraints (Clark, 1995; Kugler et al., 1980; Newell, 1986;). As Clark (1995) explains, a dynamical system's behaviour, such as a football team's offensive organisation, self-organises as a function of time and emerges from constraints. Hence, skilled behaviour in performers is a remarkable consequence of the interacting constraints that influence the skill (Newell, 1986).

In Australian football (AF), skilled coordinative behaviour develops through sustained exposure to representative training environments which help the performer(s) couple key information sources with the actions they invite (Farrow et al., 2013). The notion of direct perception, i.e., humans are invited by their performance environment to act, is closely related to the concept of affordances, which describes how environmental features afford certain actions (Gibson, 1979; Handford et al., 1997). In a team sport context, cooperative collective behaviour depends on being attuned to shared affordances, which are established and developed on previous experiences of communication or information exchange (Silva et al., 2013). For example, a defensive team which is too slow getting back to a compact defensive structure affords a rapid counterattack from the opposing team after a turnover of possession. In other words, environmental features in the environment created by the defensive team become actionable by the attacking team as a collective. Through practice, coaches can design activities which allow individual players and the team to become collectively perceptually attuned to a variety of affordances, which helps players more readily act on similar affordances during competitive matches. For instance, in a study by Woods et al. (2019), AF coaches adjusted informational constraints during practice to simulate a negative score differential for one team and thus artificially reduce the time left to score. The team with a negative score differential reported lower times in possession and increased their ball movement through the centre of the ground, leading to faster ball movement speed. In conclusion, manipulating a variety of constraints in practice can afford different decisions and actions to a (group of) individual(s) in order to enhance its representativeness.

Representative learning design emphasises the need for the task constraints of practice to be a representative sample of the task constraints in competition (Pinder et al., 2011). Recently, it was reported that professional AF coaches commonly integrate match simulation into practice – 24% of in-season practice was considered match simulation (Tribolet et al., 2021). Match simulation practice is also common in association football (Olthof et al., 2019) and basketball (Svilar et al., 2019). Recent research has shown that disposal type (kick or handball) and related constraints such as time in possession differ between professional AF small-sided games, match simulation and competitive matches (Browne et al., 2020; Corbett et al., 2017). Additionally, skill and physical outcomes in youth AF small-sided games differ to competitive matches (Bonney et al., 2020). The differences in constraints and skill and physical outcomes between practice and competitive matches may affect an individual and team's ability to perform learned behaviours during practice in competition. Furthermore, the collective action fidelity in practice tasks is impacted when coaches or practitioners omit key ecological constraints that create non-representative practice conditions (Greenwood et al., 2016; Pinder et al., 2009). Thus, the constraints sampled during match simulation must be integrated with relevant measures of collective behaviour and skill metrics to effectively evaluate the similarity, or potential lack thereof, to competition. Examples of task constraints coaches typically manipulate include player numbers, field length and width, the amount of space per player or task rules. Moreover, it may also be useful to understand if certain behaviours are exhibited during match simulation leading into competitive matches that are won compared to matches that are lost. Here, practitioners may be able to understand which metrics may have superior transfer to competitive matches that are won. For example, research suggests some level of difficulty must be present for performers during practice to help enhance the level of skill transfer (Schmidt & Bjork, 1992; Guadagnoli & Lee, 2004). Thus, it may be useful to notate collective behaviours and skill metrics and retrospectively assess if specific metrics can be encouraged or focused on more when performing match simulation leading into competitive matches.

Previous research in association football reported differences in spatiotemporal movements between competitive matches and 11v11 match simulations (Olthof et al., 2019). Specifically, players covered more distance and sprinted more often whilst team width was smaller, and the length-per-width ratio was larger in competitive matches. Resultantly, the seemingly most representative form of practice differs to match-play in association football. As AF match simulation, i.e., 18 versus 18, theoretically provides the most representative practice activity that 1) can be performed during practice allowing coaching staff to carefully observe and analyse performances and 2) incorporates information directly related to the attributes required and exhibited during match performance (Baker & Farrow, 2015), it seems appropriate to assess whether match simulations are representative of competition. Currently, limited research has compared the collective team behaviour of professional AF teams between competitive matches and match simulation.

The extent to which match simulation practice samples relevant constraints and whether the resultant skill behaviours adequately reflect competitive matches has been investigated in

Australian football (Browne et al., 2020). However, the present study extends on previous findings by also exploring skilled behaviour in addition cooperative passing networks. Therefore, the aims of this research were threefold: 1) explore and compare the differences in task constraints such as field length, field width and space per player that are sampled during match simulation and competitive AFL matches, 2) compare the skill and cooperative passing network behaviours between match simulation and competitive AFL matches and 3) investigate whether there are any differences in task constraints, skill or cooperative passing behaviours between match simulations preceding a competitive AFL match win versus loss. We hypothesise to find differences in cooperative passing networks and skill metrics between match simulation practice and competitive matches. Specifically, we expected metrics reflecting more even passing contributions from players to be higher during competitive matches than training. Moreover, we expected handball and kick proficiency to be lower going into a competitive match that was won compared to a loss, partially due to learning effects.

7.3 Methods

Participants

One professional AF club agreed to be involved in the research. The team consisted of 48 male professional Australian footballers (age: 23.28 ± 4.35 years) who participated in their normal training across one entire season. The in-season phase lasted six months from March to September 2019. The eight senior and development coaches within the professional club had an average of 6.8 ± 6.5 years of AFL coaching experience, in addition to an average of 11.5 ± 5.1 years of playing professional level AF. Training occurred without intervention from researchers. Ethics approval was obtained for this study from the University's ethics committee (ETH19-3597).

Procedures

The professional team played 22 official Australian Football League (AFL) matches and 21 18 versus 18 match simulations during the 2019 season. Each official match and match simulation was played according to the official playing rules and field markings. Each AFL match was classified according to the result (win or loss). A cross-sectional design was used to compare the differences in the sampled task constraints, team skill and cooperative passing measures between competitive AFL matches and match simulations (Table 7.3.1). These comparisons were performed to investigate whether match simulations are truly representative of actual competitive matches. The average duration of competition matches was 99 minutes and 35 seconds (SD: 4 minutes 30 seconds), whilst the duration of match simulations was 15 minutes 42 seconds (SD: 2 minutes 45 seconds).

Competitive AFL matches were played at nine different venues reflective of the home and away schedule for the 2019 season. Match simulation was always performed at one of two grounds where the team's home training facility is located. As is common in team sport preparation, match simulation involved a first team and a reserves team competing against each other. In an attempt to maximise performance against the upcoming opposition, match simulation often sees the reserve team emulate the behaviour of the firsts team upcoming opponent, e.g., method of ball movement or structures/positions at stoppages. Although this may constrain team behaviour itself, it was not the purpose of the study to monitor the impact

Table 7.3.1. Activity and result related differences between task constraints, team skills and team passing networks

	Activity			Activity Effect			Result			Result Effect		
	Match Simulation	Competition	Pairwise Difference (95% CI)	df, df error	F	η^2	Win	Loss	Pairwise Difference (95% CI)	df, df error	F	η^2
Task Constraints												
Field length (m)	155.57 ± 0.75	158.64 ± 4.63	-3.07 (-4.99:-1.16)	4, 17	11.20*	0.36	155.38 ± 0.69	159.69 ± 0.78	-0.32 (-1.02:0.39)	2, 18	0.89	0.05
Field width (m)	132.38 ± 4.73	132.35 ± 5.90	0.03 (-2.99:3.05)	4, 17	0.00	0.00	133.63 ± 4.40	131.62 ± 4.93	2.01 (-2.45:6.47	2, 18	0.89	0.05
Length per width ratio (units)	1.18 ± 0.05	1.20 ± 0.09	-0.03 (-0.06:0.01)	4, 17	1.93	0.09	1.17 ± 0.05	1.19 ± 0.52	-0.02 (-0.07:0.03)	2, 18	0.89	0.05
Space per player (m^2)	453.00 ± 12.21	457.39 ± 12.94	-4.39 (-12.99:4.22)	4, 17	1.13	0.05	456.16 ± 9.89	451.05 ± 13.44	5.11 (-6.41:16.63)	2, 18	0.86	0.04
Team Skills												
Goals per min	0.19 ± 0.10	0.11 ± 0.03	0.08 (0.02:0.13)	9, 12	9.28*	0.32	0.15 ± 0.08	0.21 ± 0.11	-0.06 (-0.16:0.03)	9, 11	1.94	0.09
Shots on goal per min	0.27 ± 0.12	0.21 ± 0.03	0.06 (-0.00:0.11)	9, 12	4.28	0.18	0.22 ± 0.08	0.30 ± 0.13	-0.08 (-0.18:0.03)	9, 11	2.20	0.10
Turnovers per min	0.42 ± 0.14	0.72 ± 0.08	-0.30 (-0.38:-0.23)	9, 12	65.76**	0.77	0.47 ± 0.11	0.38 ± 0.15	0.09 (-0.04:0.22)	9, 11	2.00	0.10
Kicks per min	1.63 ± 0.30	2.21 ± 0.25	-0.58 (-0.72:-0.44)	9, 12	76.04**	0.79	1.70 ± 0.27	1.58 ± 0.32	0.12 (-0.17:0.40)	9, 11	0.75	0.04
Handballs per min	1.36 ± 0.26	1.56 ± 0.25	-0.20 (-0.35:-0.05)	9, 12	7.75*	0.28	1.44 ± 0.30	1.31 ± 0.22	0.13 (-0.11:0.37)	9, 11	1.25	0.06
Kick Proficiency (%)	60.57 ± 11.65	63.87 ± 5.90	-3.30 (-8.91:2.31)	9, 12	1.51	0.07	59.38 ± 12.89	61.31 ± 11.29	-1.93 (-13.13:9.27)	9, 11	0.13	0.01
Handball Proficiency (%)	86.52 ± 7.05	82.70 ± 3.23	3.82 (-0.07:7.71)	9, 12	4.21	0.17	81.50 ± 5.68	89.62 ± 6.08	-8.12 (-13.70:-2.53)	9, 11	9.26*	0.33
Tackles per min	0.23 ± 0.15	0.67 ± 0.11	-0.43 (-0.52:-0.35)	9, 12	108.33**	0.84	0.22 ± 0.17	0.24 ± 0.15	-0.03 (-0.17:0.12)	9, 11	0.13	0.01
Marks per min	1.03 ± 0.30	0.94 ± 0.23	0.09 (-0.04:0.22)	9, 12	1.95	0.09	1.02 ± 0.26	1.03 ± 0.34	-0.01 (-0.30:0.28)	9, 11	0.00	0.00
Team Passing Networks												
Connectedness	95.31 ± 10.77	97.12 ± 14.18	-1.81 (-7.72:4.11)	3, 18	0.41	0.02	97.04 ± 9.04	94.25 ± 11.94	2.78 (-7.53:13.09)	3, 17	0.32	0.02
Outdegree Variability	114.24 ± 11.45	104.46 ± 16.55	-9.78 (0.47:19.08)	3, 18	4.80*	0.19	114.29 ± 9.51	114.21 ± 12.88	0.08 (-10.97:11.13)	3, 17	0.00	0.00
Indegree Variability	111.73 ± 12.01	98.01 ± 11.08	13.72 (7.49:19.95)	3, 18	21.12**	0.51	109.32 ± 11.70	113.21 ± 12.43	-3.89 (-15.33:7.55)	3, 17	0.51	0.03

Note: * = $p < 0.05$, ** = $p < 0.001$, Data are in means and standard deviations. df = degrees of freedom, CI = Confidence Intervals, η^2 = partial eta squared. Pairwise differences are compared from match simulation to competition, and from win to loss.

of this. As such, we only included the metrics for the first team in the subsequent analysis and did not include the reserves team. Additionally, the match simulation was officiated by a single coach with the other coaches scattered around the boundary to throw a replacement ball in when needed.

Data Collection

Task constraints

The field length, width and the time spent in match simulation were collected on field at each training session by the lead researcher. The field length and width were collected in metres with a trundle wheel, whilst the time was collected with a stopwatch. The corresponding task constraints for competitive AFL matches are freely available online. The amount of space per player (m2) was determined by dividing the total area of the match simulation or competitive match (0.5*length (m) x 0.5*width (m) x π) by the total number of players in the condition, e.g., if the area was 17,441 m2 (Melbourne Cricket Ground) for 36 players, the space per player would be 485 m^2. Match footage and skill notations were provided by Champion Data (Melbourne, Australia, Pty. Ltd.), whilst training was filmed by elevated cameras perpendicular to the field and behind the goals. Training footage was coded using SportsCode (SportsTec Limited, version 9.4.1, Warriewood, Australia) with the lead researcher notating all of the information. The lead researcher had annotated more than 250 hours of AF training and match-play. The experienced researchers coding reliability was assessed using an intra-class correlation coefficient (Koo & Li, 2016), whilst Champion Data's reliability has shown a high level of reliability (ICC = 0.980–998) (Robertson et al., 2016).

Collective behaviour metrics

To quantify collective behaviour, cooperative passing networks were notated in training and match-play. To quantify cooperative passing networks, an interaction between two players was coded if a handball or kick reached the intended target player. An adjacency matrix was subsequently created detailing the number of interactions between each possible player dyad. A weighted and directed graph was then created with nodes representing individual players and edges representing the direction and number of passes between each player. That is, instead of a binary "yes or no" interaction between players, the number of times they interact with each other is notated to make it weighted. Previous research conducted in professional AF by Sheehan et al. (2019) created principal component scores which were utilised in this study. Connectedness, in-degree variability and out-degree variability are principal component scores that reflect the bi-directional level of interaction within the teams passing network, and the mutuality of involvement from all players within the passing network in relation to receiving possession and distributing possession, respectively (Sheehan et al., 2019). Briefly, higher connectedness values indicate that most players connect bi-directionally (increased network density) and are easily reachable for and by others (increased team in- and out-closeness). Conversely, lower in-degree and out-degree variability values represent that the passing network is decentralised (lower in- and out-degree node and pass variability) and does not rely on specific players for receiving (in-degree variability) or distributing (out-degree variability). Greater values suggest the opposite, resulting in a network which relies on specific players (Sheehan et al., 2019). Thus, in-degree and out-degree variability relate to the passing network being centralised around specific players to receive or distribute possession. The exact equations to calculate each principal component score are detailed in Sheehan et al. (2019). These metrics were coded and calculated using Microsoft Excel (Microsoft, Redmond, WA, USA) and dedicated MATLAB R2018b routines (The MathWorks Inc., Natick, MA, USA). A visual example of a passing network is represented and described in Figure 7.3.1. In this figure, Player A had only distributed passes to 2 different players (smaller node), compared to player M, who distributed passes to 16 different players (bigger node). Conversely, Player U received possession 15 times whilst player H only received possession 7 times.

Collective skill metrics

Team skill outcomes were counted and evaluated concomitantly with notational analysis. The number of turnovers, the number of shots on goal and the number of goals, handballs, kicks, tackles and marks were all notated from match simulation and collected from competitive AFL matches through Champion Data. Additionally, kick and handball proficiency (%) were derived and calculated by dividing effective passes by the total number of passes for the team. The definition of each metric aligned with how Champion Data notate the metric. Specifically, kicks were considered effective if the kick resulted in the intended target retaining possession or was any kick that travelled greater than 40 m to a 50/50 contest. Effective handballs were handballs that hit the intended target.

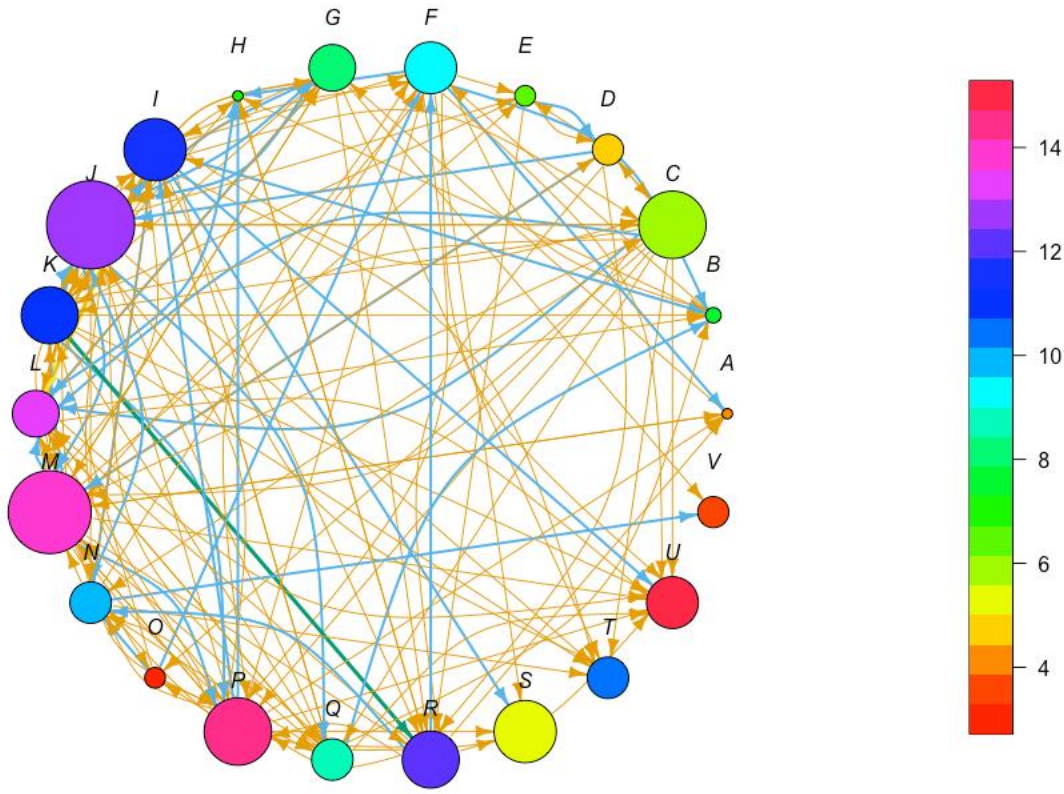

Figure 7.3.1. An example passing network graph. The size of the node represents the players outdegree node, where the bigger the node means the player has distributed passes to a higher number of players. The colour of the node represents the players indegree passes, where higher values indicate the player has received a higher number of passes. The colour corresponds to the respective numbers along the colour bar. The thickness and colour of the edges represent the passes between each player. Note that practitioners could change the colour and size of the nodes depending on which metrics they see fit or deem valuable. For example, the colour of the node could be changed to represent the players indegree pass, where higher numbers indicate the player has received a higher number of passes (indiscriminate of who passed it to them).

Data analysis

Prior to data analyses, one round in the season had no corresponding match simulation for the training week due to a short turnaround between competitive matches. Subsequently, the corresponding competitive AFL match and the related data were removed from the analysis. The sample therefore consisted of 21 match simulations and 21 competitive matches. All measures that were affected by the large discrepancy in time between competition and match simulation were time-standardised (i.e., n/minute) and reported as mean and standard deviation. Subsequently, the number of kicks, handballs, marks, goals and turnovers were all converted to a per minute metric. Connectedness, Out-degree and In-degree Variability were not treated further as these values are already normalised and standardised, as described elsewhere in detail (Sheehan et al., 2019; Tribolet et al., 2021).

All dependent variables were found to be normally distributed using Q-Q plots and histograms. Three separate Repeated Measures (within-subject) MANOVAs with Bonferroni correction for multiple comparisons modelled the main effect of activity (two levels: match simulation and competition) on task constraints (field length, field width, length per width ratio, space per player), collective skill metrics (goals per minute, shots on goal per minute, turnovers per minute, handball proficiency, kick proficiency, kicks per minute, handballs per minute and tackles per minute) and collective behaviour metrics (connectedness, out-degree variability and in- degree variability). Additionally, two further between-subject MANOVAs examined the differences in the task constraints, collective skill and collective behaviour metrics between match simulations preceding games that were won or lost (main effect). These additional MANOVAs were performed to assess the differences in match simulations leading into a competitive match win or loss. Between and within-subject variances were considered equal. All analyses were performed using IBM SPSS 27.0.USA. The significance level for all analyses was set at $p < 0.05$.

Mean values and SDs were calculated for task constraints, collective skill metrics and collective behaviour metrics. Univariate analyses of variance were interpreted when a main effect was detected. Significance level was set at 5%. Eta- squared (η^2) values were calculated and used to determine the effect size. Thresholds for the magnitude of effect sizes were used to interpret effects as small ($\eta^2 < 0.06$), moderate ($0.06 \leq \eta^2$), or large ($\eta^2 \geq 0.15$) (Cohen, 1988). Confidence intervals (95% CIs) were calculated for mean differences in dependent variables between conditions.

7.4 Results

Activity-related differences

Table 7.3.1 displays the results of the MANOVA analyses used to investigate the differences in task constraints, skill and collective behaviour metrics for both activity type and match result. Significant multivariate effects of activity were observed on task constraints ($F(4,17) = 3.21$, $p < 0.05$, $\eta^2 = 0.42$), skill metrics ($F(9,12) = 34.48$, $p < 0.001$, $\eta^2 = 0.96$) and cooperative passing metrics ($F(3,18) = 6.42$, $p < 0.05$, $\eta^2 = 0.52$). Specifically, competitive matches were played on longer fields, had increased turnovers, kicks, handballs and tackles per minute compared to match simulation. Comparatively, match simulation had significantly more goals per minute and increased indegree and outdegree variability relative to competitive matches. Table 7.3.1 presents the means and standard deviation for each condition.

Result-related differences

There were no multivariate effects identified of match results on task constraints ($F(2,18) = 0.49$, $p = 0.621$, $\eta^2 = 0.05$), skill metrics ($F(9,11) = 1.44$, $p = 0.281$, $\eta^2 = 0.54$) and collective behaviour variables ($F(3,17) = 0.260$, $p = 0.853$, $\eta^2 = 0.04$). Subsequently, no further univariate analysis was conducted.

7.5 Discussion

This study expands on the current literature to demonstrate that activity-related differences exist for task constraints, skills and cooperative networks when comparing match simulation and competitive AFL matches. In match simulation, the number of goals were being scored at a higher rate with generally fewer passing actions per minute. Additionally, there was a greater reliance on relatively few key players to receive and distribute possession during match simulation than during competition matches. No differences between match simulations preceding won or lost games were observed. The behavioural mismatch between match simulations and competitive AFL matches demonstrates that match simulations do not necessarily replicate the behavioural demands of match play. Hence, their utility in preparing players for competition games should be discussed.

The results of the current study show match simulation had a smaller turnover ($0.30.min^{-1}$ less) and tackle ($0.44.min^{-1}$ less) rate compared to competitive AFL matches. These findings align with previous research in contact sport, where a lower degree of physical and perceived pressure is commonly prescribed during practice than in games (Dawson et al., 2004). The smaller turnover and tackle rates in match simulations versus competitive matches are unsurprising given that changes of possession are the result of contested game play, where players are under considerable defensive pressure from opposition players (Teune et al., 2021). Turnovers are a crucial component of AF gameplay as it forms the basis for transitions between phases of play, e.g., attack to defence, attack to a stoppage, where the umpire restarts play, etc. (Rennie et al., 2017). Consequently, turnovers in possession lead to a team reorganising to achieve different goals (e.g., prevent a team from scoring in defence, structural positioning during stoppages to gain superior field positioning etc). Moreover, Sheehan et al. (2021) postulated that players may not be permitted sufficient time to co-adapt to each other's movements since contested phases of play are shorter in duration. Given the limited exposure to contested play in training relative to competitive matches (as shown by these results in addition to Tribolet et al., 2021), coaches must attempt to systematically increase the team and players exposure to this aspect of performance in different practice activities in which the constraints of match play are sufficiently represented in order to obtain adequate skill transfer.

The current results revealed the behavioural demands of competitive AFL matches are not adequately sampled during match simulation (Pinder et al., 2011). If these characteristics are trained elsewhere in practice, it may still provide an appropriate level of exposure to these contexts. However, previous research has shown that these contexts, i.e., transition type practice activities, comprise of ~10% of total training time in-season, whereas match simulation comprises 35% (Tribolet et al., 2021). Consequently, the players and team may not have had an appropriate interaction with sampling the constraints that result from turn-overs e.g., reorganising into defence in different areas on the field. Practitioners and coaches working in team sports may organically induce increased turnovers by generating outnumbers in specific parts of the field, restrict certain players to only run into certain zones (these could also be players on reduced running/loading programmes) or wetting the ball intermittently to induce more handling errors. Nonetheless, the usefulness of representative learning design in elite sport may be hampered by competing demands from other performance departments (e.g., physical performance). Specifically, certain aspects of performance such as player availability may not correspond well with representative practice design e.g., creating increased exposure to contested phases of play increases the risk of physical injury. Considering the reticence to have contested play in training due to the injury risk it presents, medical staff are likely to mitigate this risk. Here, the integration of all football staff in high performance sport requires a unique blend of physical, skill and tactical objectives (Farrow et al., 2008). This recognition can help determine the extent to which a more representative task could, or should, be implemented to achieve specific training outcomes (Baker & Farrow, 2015). For example, coaches could increase and encourage the number of tackles and congested scenarios in match simulation to induce higher levels of turnovers, whilst likely increase injury risk only if this risk is properly understood by medical and conditioning staff. However, these competing demands potentially restrict the application of representative learning design, as intended in pedagogical approaches like the constraints-led approach, in professional contact sports like Australian football.

In the current study, match simulation elicited significantly lower kick and handball rates with greater goal scoring rates. Players passed less and scored more often in match simulations. Since the task constraints of field dimensions do not change (except for field length being marginally smaller in match simulation than competition), the less frequent passes per minute are likely a consequence of reduced defensive pressure, evidenced by less tackles per minute. Here, the players can hold possession for longer and do not have to dispose of the ball as quickly during match simulation. This corresponds with research showing passing constraints differed between small-sided games, match simulation and competitive AFL matches (Browne et al., 2020; Ireland et al., 2019). Players are under less pressure and have more time to dispose of the ball during match simulation and SSGs than in competition. Subsequently, match simulation does not appear to emulate the quantity nor the type of passing actions afforded to players during a competitive AFL match, which may affect skill development and compromise skill transfer. The reduced defensive pressure in match simulations may however serve a coaching purpose. Reduced errors during match simulations may result in higher confidence levels going into competition. Additionally, the coaches may want the players to practice and "feel" different passing directions to move the ball (e.g., stretch the field wide, use the centre of the field to move the ball faster etc). These examples may reflect the coach's intentions and further demonstrate what outcomes and benefits the coaches want the players to receive from match simulation.

Passing is a means of cooperation amongst teammates, with the aim to create scoring opportunities (Grund, 2012). Whilst the interaction of task constraints shapes information, it is the similarity of that information that guides action to help facilitate skill and behavioural transfer between tasks (Pinder et al., 2011). The current results reveal differing passing network characteristics between match simulation and competitive AFL matches. Specifically, match simulation had increased out-degree and in-degree variability values, meaning that match simulation is characterised by more centralised passing networks than competitive matches which suggests that specific players are relied upon for receiving (in-degree) and distributing (out-degree) possession (Sheehan et al., 2019). The ability to form a decentralised passing network, where each player contributes equally is an important contributor to success in association football (Gonçalves et al., 2017; Grund, 2012) and the AFL (Fransen et al., 2021a).

Passing networks that have lower in-degree and out-degree variability encourage increased cooperation amongst teammates, where a team with equal passing contributions across players will likely be able to adapt their passing strategies to overcome different styles of play against the opposition. Previous research in association football has shown passing networks can be altered by manipulating such things as player numbers, field size and task rules (Moreira et al., 2019; Ometto et al., 2018). Further research in AF is required to ascertain how such changes in task constraints alter cooperative passing networks.

In supplementing previous research introducing theoretical principles related to ecological dynamics in AF (Woods et al., 2020, 2019), the current study differs in providing empirical evidence that assesses representative design in-situ and across a whole season within an AFL team. Recent research has also reported useful results and helpful outcomes to enhance our empirical understanding of constraints within AF matches and training environments (Browne et al., 2020; Ireland et al., 2019; Teune et al., 2021). Nonetheless, we speculate that the current results, in addition to previous research showing the differences between practice and competitive AFL matches, demonstrates that expert coaches design practice that may not optimally correspond with theoretical "best-practice practice design" according to ecological dynamics. As such, one of two conclusions may be drawn: 1) expert AF coaches do not use the tenets of ED to design practice, or 2) the theoretical principles of ecological dynamics and what is feasible for best-practice practice design misalign in the real world. Given the nature of expertise and the extensive work performed within sporting organisations, we believe the latter to be most plausible. Whilst speculative, these concerns require further investigation in AF and across team sport in general. A mix of the two conclusions could also be drawn, where coaches adapt the purpose of match simulation each week based on the strategies they think will overcome the upcoming opposition whilst concurrently emphasising different aspects of the game (e.g., ball movement rather than contested phases) to enhance the team's performance in these aspects. Nonetheless, although ecological dynamics is a powerful framework to explain skilled behaviour, there is clearly a mismatch between ecological dynamics principles of practice design and what actually occurs in practice. We believe this is a deliberate choice of coaches in a trade-off between task representativeness and increased player availability, which may allude to the fact that team selection remains the most important contributor of performance in a team setting (Hoffman et al., 2019). Other factors to consider may include the match-to-match turnaround, testing and piloting different strategies and tactics, emphasising specific phases or intangible factors e.g., "gut feel".

The findings of this study are limited by the constraints of applied research. For example, we only analysed the "first team" metrics i.e., the team who are playing in the highest level of competition (i.e., the AFL). Since it is common for the first team to play the reserves, there will typically be a difference in skill level and experience. This may partially describe the results as the "first team" may be more highly skilled relative to the opposing team. As a result of being more skilled and having more skilled players, they may score goals at a higher rate but have fewer passing between players and less turnovers and tackles. A potential method to "artificially" enhance the reserves team's ability to be more competitive could be to intermittently provide them an outnumber i.e., becomes 18v19 players. The result likely leads to the first team encountering higher pressure when passing the ball (mitigating the issues identified by Browne et al., 2020, Ireland et al., 2019) and increased difficulty transitioning the ball closer to their goals to score i.e., increase passing actions per minute. Another limitation is that the analyses have only been conducted within one professional team and in-season only, affecting the generalisability of the results of this study. Future research may also consider analysing the interactions between each metric. For example, more turnovers per minute may lead to less shots and increased tackles per minute. This ensures an interaction of constraints to best assess and optimise practice design. Nonetheless, the analysis provides a simple and effective comparison between commonly performed match simulation activities and competitive AFL matches.

7.6 Conclusion

This study compared the similarity between Australian football match simulation and competitive AFL matches. Multivariate activity-related effects were reported for task constraints, skill and cooperative passing behaviour metrics. Match simulation had more goals scored with less passing actions per minute compared to competitive AFL matches. Competitive matches had a significantly higher number of turnovers and tackles per minute compared to match simulation. Additionally, a smaller number of players were relied upon to receive and distribute possession in match simulation compared to AFL matches. These differences suggest match simulation does not adequately sample behaviours observed in competitive AFL matches. Whilst there may be other focal points within match simulation (e.g., player positioning at stoppages across the field, increasing players confidence), coaches and practitioners must work together to continually increase the representativeness of practice and subsequently, the level of skill transfer. Moreover, whilst ecological dynamics is a powerful framework to explain skilled behaviour in professional AF, this study presents a mismatch between ecological dynamics pedagogical principles and what actually occurs in practice. This is likely a result of the competing demands in high performance sport. To help optimise skill preparation, skill acquisition specialists must continue to challenge current practices whilst also integrating not only the coaches' experiential knowledge, but the whole football department staff.

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7.7 References

Baker, J., & Farrow, D. (2015). Routledge handbook of sport expertise. Routledge.

Bonney, N., Berry, J., Ball, K., & Larkin, P. (2020), Can match play kicking and physical performance outcomes be replicated in an Australian football small-sided game? *Science and Medicine in Football*, 4(4), 314–321.

Browne, P. R., Woods, C. T., Sweeting, A. J., Robertson, S., & Rogan, S. (2020). Applications of a working framework for the measurement of representative learning design in Australian football. *PLoS ONE*, 15(11).

Clark, J. E. (1995). On becoming skilful: Patterns and constraints. *Research Quarterly for Exercise and Sport*, 66(3), 173–183.

Cohen, J. (1988). Statistical power analysis for the behavioural sciences (2nd ed). Lawrence Erlbaum Associates.

Corbett, D. M., Bartlett, J. D., O'Connor, F., Back, N., Torres-Ronda, L., & Robertson, S. (2017), Development of physical and skill training drill prescription systems for elite Australian rules football. *Science and Medicine in Football*, 2(1), 51–57.

Davids, K., Button, C., & Bennett, S. (2008). Dynamics of skill acquisition: A constraints-led approach. Human Kinetics.

Dawson, B., Hopkinson, R., Appleby, B., Stewart, G., & Roberts, C. (2004), Player movement patterns and game activities in the Australian Football League, *Journal of Science and Medicine in Sport*, 7(3), 278–291.

Farrow, D., Baker, J., & MacMahon, C. (2013), Developing sport expertise: Researchers and coaches put theory into practice. Routledge.

Farrow, D., Pyne, D. B., & Gabbett, T. (2008), Skill and physiological demands of open and closed training drills in Australian football, *International Journal of Sports Science & Coaching*, 3(4), 485–495.

Fransen, J., Tribolet, R., Sheehan, W. B., McBride, I., Novak, A., & Watsford, M. L. (2021), Cooperative passing network features are associated with successful match outcomes in the Australian football league, *International Journal of Sports Science and Coaching*, In Press.

Gibson, J. J. (1979). The ecological approach to visual perception. Houghton Mifflin.

Gonçalves, B., Coutinho, D., Santos, S., Lago-Penas, C., Jiménez, S., Sampaio, J., & Hayasaka, S. (2017), Exploring team passing networks and player movement dynamics in youth association football, *PLoS One*, 12(1).

Greenwood, D., Davids, K., & Renshaw, I. (2016), The role of a vertical reference point in changing gait regulation in cricket run-ups, *European Journal of Sport Science*, 16(7), 794–800.

Grund, T. U. (2012), Network structure and team performance: The case of English premier league soccer teams, *Social Networks*, 34(4), 682–690.

Handford, C., Davids, K., Bennett, S., & Button, C. (1997), Skill acquisition in sport: Some applications of an evolving practice ecology, *Journal of Sports Sciences*, 15(6), 621–640.

Hoffman, D. T., Dwyer, D. B., Bowe, S. J., Bowe, S. J., Clifton, P., & Gastin, P. B. (2019), Is injury associated with team performance in elite Australian football? 20 years of player injury and team performance data that include measures of individual player value, *British Journal of Sports Medicine*, 54(8), 475–479.

Ireland, D., Dawson, B., Peeling, P., Lester, L., Heasman, J., & Rogalski, B. (2019), Do we train how we play? Investigating skill patterns in Australian football, *Science and Medicine in Football*, 3(4), 265–274.

Koo, T.K. & Li, M.Y. (2016), A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*, 15(2), 155–63.

Kugler, P. N., Kelso, S. J. A., & Turvey, M. T. (1980), On the concept of coordinative structures as dissipative structures: I. Theoretical lines of convergence, *Advances in Psychology*, 1, 3–47.

Maloney, M. A., Renshaw, I., Headrick, J., Martin, D. T., & Farrow, D. (2018), Taekwondo fighting in training does simulate the affective and cognitive demands of competition: Implications for behaviour and transfer, *Frontiers in Psychology*, 9(25).

Moreira, P. E. D., Barbosa, G. F., Murta, C. D. C. F., Morales, J. C. P., Bredt, S. D. G. T., Praça, G. M., & Greco, P. J. (2019), Network analysis and tactical behaviour in soccer small-sided and conditioned games: Influence of absolute and relative playing areas on different age categories, *International Journal of Performance Analysis in Sport*, 20(1), 64–77.

Newell, K. M. (1986). Constraints on the development of coordination. In M. G. Wade & H. T. A. Whiting (Eds.), Motor development in children: Aspects of coordination and control (pp. 341–360). Martinus Nijho.

Olthof, S. B. H., Frencken, W. G. P., & Lemmink, K. A. P. M. (2019), When something is at stake: Differences in soccer performance in 11 vs 11 during official matches and training games, *Journal of Strength and Conditioning Research*, 33(1), 167–173.

Ometto, L., Vasconcellos, F. V. A., Cunha, F. A., Teoldo, I., Souza, C. R. B., Dutra, M. B., O'Sullivan, M., & Davids, K. (2018), How manipulating task constraints in small-sided and conditioned games shapes emergence of individual and collective tactical behaviours in football: A systematic review, *International Journal of Sports Science & Coaching*, 13(6), 1200–1214.

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011), Representative learning design and functionality of research and practice in sport, *Journal of Sport & Exercise Psychology*, 33(1), 146–155.

Pinder, R. A., Renshaw, I., & Davids, K. (2009), Information-movement coupling in developing cricketers under changing ecological practice constraints, *Human Movement Science*, 28(4), 468–479.

Rennie, M. J., Watsford, M. L., Spurrs, R. W., Kelly, S. J., & Pine, M. J. (2017), Phases of match-play in professional Australian football: Descriptive analysis and reliability assessment, *Journal of Science and Medicine in Sport*, 21(6), 635–639.

Renshaw, I., & Gorman, A. D. (2015), Challenges to capturing expertise in field settings. In J. Baker & D. Farrow (Eds.), Routledge handbook of sport expertise (pp. 282–294). Routledge/Taylor & Francis Group.

Robertson, S., Gupta, R., & McIntosh, S. (2016), A method to assess the influence of individual player performance distribution on match outcome in team sports, *Journal of Sports Sciences,* 34(19), 1893–1900.

Sheehan, W. B., Tribolet, R., Watsford, M. L., Novak, A. R., Rennie, M. J., & Fransen, J. (2019), Using cooperative networks to analyse behaviour in professional Australian Football, *Journal of Science and Medicine in Sport*, 23(3), 291–296.

Sheehan, W. B., Tribolet, R., Watsford, M. L., Novak, A. R., Rennie, M. J., & Fransen, J. (2021), Tactical analysis of individual and team behaviour in professional Australian football, *Science and Medicine in Football*, 1–9.

Silva, P., Garganta, J., Araújo, D., Davids, K., & Aguiar, P. (2013), Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports, *Sports Medicine*, 43(9), 765–772.

Svilar, L., Castellano, J., & Jukic, I. (2019), Comparison of 5v5 training games and match-play using microsensor technology in elite basketball, *Journal of Strength and Conditioning Research*, 33(7), 1897–1903.

Teune, B., Spencer, B., Sweeting, A. J., Woods, C. W., Inness, M., & Robertson, S. (2021), Application of a continuous pressure metric in Australian football, *Journal of Sports Sciences*, 39(13), 1548–1554.

Tribolet, R., Sheehan, W. B., Watsford, M. L., & Fransen, J. (2021), How does practice change across the season? A descriptive study of the training structures and practice activities implemented by a professional Australian football team, *International Journal of Sports Science & Coaching*. 10.1177/17479541211019829.

Woods, C. T., McKeown, I., O'Sullivan, M., Robertson, S., & Davids, K. (2020), Theory to practice: Performance preparation models in contemporary high-level sport guided by an ecological dynamics framework, *Sports Med Open*, 6(1).

Woods, C. T., McKeown, I., Shuttleworth, R. J., Davids, K., & Robertson, S. (2019), Training programme designs in professional team sport: An ecological dynamics exemplar, *Human Movement Science*, 66(66).

Chapter 8 | An observational study of player behaviours under varying task constraints in professional Australian football players

As per the manuscript under review:

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8.1 Abstract

This study examined integrative (indegree and outdegree importance) and individual (goals, kicks, handballs, marks and tackles – all per minute of match time, along with kick and handball proficiency) level behaviours at one professional Australian football club across three different types of conditions: small-sided games (SSGs), match simulation and competitive Australian Football League (AFL) matches. Estimated marginal means identified no or negligible changes for integrative measures across changes in conditions. This result may suggest larger changes to control parameters are required to modify this type of behaviour, as it relies on interdependent cooperative behaviour. Individual level behaviours demonstrated varied and inconsistent responses across changing conditions. Most notably, AFL matches revealed the lowest kicks and marks per minute compared to the other conditions, whilst it also had the highest rate of tackles. Players had lower kick proficiency in conditions with a higher number of players. Moreover, one SSG with a floater (a player who participates in attack for both teams) elicited a higher number of handballs per minute relative to every other condition. These findings provide implications for measuring the (in)stability of individual and integrative level behaviours across different conditions and how changes to constraints may alter these metrics. This method may provide a foundation for future hypotheses testing and for player monitoring that can assist practitioners and coaches to examine the changes in players behaviours in response to changing constraints in team sport.

8.2 Introduction

Expert team sport athletes require the ability to apply their skills in a variety of contextual situations (Araújo & Davids, 2011; Renshaw et al., 2019). A truly skilled player can perform against different opponents, under different amounts of pressure and regardless of who their teammates are. This poses a significant challenge to coaches who are tasked with optimally preparing their team for competition. Nonetheless, one of the methods coaches commonly utilise features the manipulation of aspects of the practice environment in order to elicit an adaptation from their team and its players. For example, Australian Football coaches may reduce or increase the field size to increase or decrease the level of defensive pressure under which players receive and distribute possession (Browne et al., 2019). This should make the passing behaviour of the team and its players more robust in the face of real opponents who are capable of dynamically and suddenly varying the amount of defensive pressure. This was also demonstrated by Travassos and colleagues (2012) who showed that a passing activity with more emergent passing options (i.e. passes that are not predetermined and require the player to make a decision who to pass to) was more reflective of competitive match conditions in senior futsal players. This further emphasises that coaches must design practice that is reflective of the dynamic opportunities available for players to make decisions and execute skills during competition.

One of the pedagogical approaches available to coaches when designing practice sessions aimed at developing robust team and player behaviours capable of transferring from the practice environment to match play is the constraints-led approach (CLA). The CLA is built upon the fundamental principles of other scientific domains, such as Ecological Psychology (EP) and Dynamical Systems Theory. First of all, Dynamical Systems Theory describes how a system (e.g. a player, a group of players or an entire team) self-organises into a stable state of behaviour through gradual changes to control parameters, where control parameters are constraints that change the organisation of the system (Clark, 1995; Handford et al., 1997). Here, human behaviour and its organisation may be extremely stable, meaning that only relatively large changes to control parameters may elicit behavioural changes in individuals or the team. Moreover, through its ecological psychology foundations, the CLA emphasises how the manipulation of physical and informational features in the practice environment implicitly invites the performers to behave functionally and beneficially. That is, the individual or team exhibit behaviours that are capable of solving the movement problem at hand. These fundamental principles underpinning the CLA have been described at length elsewhere (e.g. Renshaw et al., 2019) and have been used to theorise how the CLA can be used as a pedagogical framework in sport (Otte et al., 2020; Pinder et al., 2011; Woods et al., 2020). However, despite studies describing how and why coaches should adopt the CLA, little evidence is available to support these claims. Therefore, empirical data is needed to further investigate how fundamental principles of the CLA can be used to develop skilled behaviour in high level athletes.

Team sports such as Australian Football are inherently complex (Alexander et al., 2019; Sheehan et al., 2019). For example, Australian football involves eighteen individual players on the same team engaged in cooperative behaviour (Fransen et al., 2021a). Cooperative behaviour is defined as behaviour in which each member of a larger collective has an independent role and aim that contributes to the attainment of a collective goal (Sheehan et al., 2021). Cooperative behaviour can be classified and measured at three different levels: collective, integrative and individual behaviour (Adams et al., 2003). Individual behaviour relates to the actions of an individual (relatively) independent to those of the collective. For example, monitoring the number of passes performed by a single player during a game. Although these behaviours still partly depend on other individuals within the team or system, these behaviours and actions are typically used by coaches to assess player performance. Integrative behaviour reflects how a single player is embedded within the larger collective. For example, analysing the relative distance covered by a single player in the context of the distance covered by the entire team. Finally, at the collective level, behaviour is measured and analysed independent of that individual team member, such as analysing the total distance covered by a team's eight midfield players. Studies aimed at understanding how practice can be designed to elicit certain player behaviours in team sports should therefore measure individual players' behaviours at both the individual and the integrative level, i.e. in absolute and relative terms.

Some research in Australian football exists that relates the manipulation of constraints in practice, to specific player behaviours. For example, Browne compared the interaction of constraints (e.g. time in possession, pressure encountered when passing the ball) when disposing possession across small-sided games (SSGs), match simulation and competitive AFL matches (Browne et al., 2020). Competition matches incurred a greater frequency of handballs performed within 2 seconds of receiving possession relative to match simulation activities, whilst SSGs also encountered much lower frequencies of kicks with no pressure and with less than and greater than 2 seconds of possession time compared to match simulation activities. Similarly, differently sized SSGs in Australian football produce different collective behaviours (Fleay et al., 2018). Specifically, 'small' SSGs generated more turnovers, ineffective handballs and tackles compared to 'large' SSGs. Additionally, recent research has also reported that teams perform more tackles and produce more turnovers in competitive AFL matches (Tribolet et al., 2021). It was also reported that collective level behaviour changes between these activities, specifically showing that match simulation activities had more centralised passing networks compared to competitive AFL matches. Thus, changes to the activity type exhibit important changes in individual, integrative and collective behaviours. Specific manipulations to the environment have also demonstrated changes to individual level behaviours, where training activities with scoring objectives, kicking only or permitting all disposal types, reduced the disposal frequency per player (Teune et al., 2021). Consequently, current research suggests that we can expect observable differences for individual, integrative and collective level behaviours between activity types along with constraint manipulations.

Based on the current state of literature, we examined how individual skill behaviours such as the number of handballs, kicks and integrative behaviours such as the involvement of individual players in the incoming and outgoing passes of their team's passing network are different between six different game types with differing task demands. Four of these were adapted SSGs, the fifth was a match simulation activity and the sixth consisted of competitive AFL matches. It was hypothesised that both individual and integrative behaviours would be associated with changes in task constraints if the pedagogical principles of the CLA were applied to Australian Football practice design (i.e. constraints are used by coaches to elicit certain individual and team behaviours). This study complements previous research on the relationship between practice design and player behaviour by observing how changes in the relative space available per player and the task rules of a game are associated with differential individual and integrative behaviours.

8.3 Methods

Participants

One professional AFL club was involved in this research. The team consisted of 48 male professional Australian footballers (age: 23.3±4.4 years). They participated in their normal training schedule across the pre-season and in-season. The pre-season phase lasted five months from November to March where the schedule typically involved three field sessions per week lasting 40-120 minutes each, whilst the in-season phase lasted six months from late March to early September where the schedule typically involved one to two field sessions plus a competitive match per week. Each participant and the club's head of high performance provided written informed consent to participate in the study. Before any intervention by the researchers, approval was obtained for this study from the University's Human Research Ethics Committee.

Experimental approach to the problem

To test the study's hypotheses, an observational study design was used. Specifically, a convenience sample of professional footballers were recruited for the study who all engaged in six different game conditions in which the researchers together with the coaches of the team manipulated key environmental features of the games, i.e. their task rules and the relative space available for each player on the field. Each of the game conditions was completed on an outdoor regulation Australian football oval, with the dimensions being manipulated based on specific proportions (%) of the relative space per player (m^2) of the team's home venue. To improve the practicality of the study, the organisation designed (see procedures) four different SSG types, each with their own task rules (aim of the training task, number of players on the field, presence of floating players) which adhered to predetermined relative surface areas per player. This resulted in an observation of player behaviours in a total of four SSGs conditions as well as during match simulation activities and official AFL matches. Therefore, in total, observations were made in six different game conditions (for a description of each game type, the task constraints used and the number of observations, consult Figure 8.3.1).

Procedures

To enhance the useability and translation of this research and its subsequent findings, experiential (coaches', skill acquisition specialists' and performance analysts' experience and knowledge) and empirical (theoretical knowledge and its application) perspectives were integrated to develop the game conditions in which the player behaviours were observed. Two senior coaches and two skill acquisition specialists and performance analysts created the different game conditions and agreed on the individual and integrative behaviours to be coded. Consequently, the overlap of experiential and empirical knowledge implicates real-world application whilst simultaneously being able to articulate the behavioural mechanisms behind the methodology (Renshaw, Davids, Newcombe & Roberts, 2019, pg. 11).

Game Condition 1 N = 1 occurrence of 18 players	Game Condition 2 N = 1 occurrence of 22 players	Game Condition 3 N = 1 occurrence of 30 players	Game Condition 4 N = 1 occurrence of 28 players	Match Condition 1 N = 1 occurrence of 31 players	Match Condition 2 N = 1-15 occurrences of 37 players
Pre-season 1 Week 1 Format: SSG Numbers: 7v7 Length: 111m Width: 83m Space per player: 514m^2 Tactical aim: Transition between attack and defence	Pre-season 2 Week 2 Format: SSG Numbers: 9v9 +1 Floater Length: 110m Width: 84m Space per player: 382m^2 Tactical aim: Transition between attack and defence	Pre-season 3 Week 4 Format: SSG Numbers: 10v10 Length: 120m Width: 84m Space per player: 396m^2 Tactical aim: Transition between attack and defence	Pre-season 4 Week 8 Format: SSG Numbers: 13v13 Length: 120m Width: 90m Space per player: 326m^2 Tactical aim: Transition between attack and defence	Pre-season 5 Week 9 Format: Match Sim Numbers: 15v15 Length: 157m Width: 127m Space per player: 519m^2 Tactical aim: Transition between attack and defence	In-season 1 Format: AFL Match(s) Numbers: 18v18 Length: Variable Width: Variable Space per player: Variable Tactical aim: Transition between attack and defence

Figure 8.3.1. Experimental design and timeline for each condition and the associated task constraints.

Small-sided games

Each of the four small-sided game conditions had regulation Australian football rules implemented, with one senior coach adjudicating. Observations of behaviour in the different SSG conditions took place over the course of an eight-week block during pre-season (Figure 8.3.1). The lead researcher set up and implemented the oval length (m) and width (m) with a trundle wheel.

Match simulation

Two official AFL umpires adjudicated the match simulation according to regulation rules. The match simulation condition took place one week following the conclusion of the eight-week block where each SSG was performed. The lead researcher set up and implemented the oval length (m) and width (m) with a trundle wheel.

Competitive AFL matches

Three field umpires, four boundary umpires and two goal umpires adjudicated the competitive AFL matches. These matches occurred across the 2020 AFL season. The number of AFL matches each player competed in was dependent on selection into the team by the coaching group (range: 1-15 matches).

Across all game conditions, coaches were encouraged to coach and provide feedback as they normally would. The main aim in all conditions was to beat the opponent by scoring more goals in the allotted time frame. The tactical focus for each condition was to transition between attack and defence phases of the game.

Data collection

Data was collected via video analysis. Match footage was provided by Champion Data (Melbourne, Australia, Pty. Ltd.), whilst training was filmed by elevated cameras perpendicular to the field and behind the goals. Training footage was coded using SportsCode (SportsTec Limited, version 9.4.1, Warriewood, Australia) with the lead researcher annotating all of the information. All practice sessions were annotated by the same experienced observer, who had annotated more than 300 hours of Australian football training and match-play. Coding reliability was assessed using an intra-class correlation coefficient (3,k; Koo & Li, 2016).

Integrative measures of skilled behaviour

In this study, passing behaviours were coded as per previous research (Tribolet et al., 2021). We firstly annotated passing interactions to develop a weighted directed cooperative network graph and then used previously reported component scores to determine each player's indegree importance and outdegree importance (Fransen et al., 2021; Sheehan et al., 2019, 2021; Tribolet et al., 2021). These metrics combine several cooperative passing aspects and reflect a player's overall level of interaction regarding incoming or outgoing network relationships, respectively. A higher score for indegree or outdegree importance indicates that they are used by more players to receive or distribute possession, respectively. These metrics have previously been used to assess integrative cooperative behaviour in Australian Footballers (Sheehan et al., 2019, 2021; Tribolet et al., 2021).

Individual measures of skilled behaviour

Seven skill metrics were coded from video. They included the number of goals, kicks, handballs, tackles and marks along with handball and kick proficiencies (effective disposals divided by the total number of disposals via each method). The skill metrics from the SSG and match simulation conditions were coded by the lead researcher. Competitive AFL matches were coded by Champion Data (Champion Data, Southbank, Australia, 2019), the official statistical provider of the AFL. The definition of each metric aligned with how Champion Data notate the metric. Specifically, kicks were considered effective if the kick resulted in the intended target retaining possession or was any kick that travelled greater than 40 m to a 50/50 contest. Effective handballs were handballs that hit the intended target. Each metric with the exception of handball and kick proficiency, was standardised by making the metric relative to time i.e., per minute. This was to account for the large time differences between SSGs, match simulations and competitive AFL matches.

Data analysis

Prior to statistical analyses, indegree and outdegree scores were converted to standardized z-scores (Sheehan et al., 2019). These z-scores were then converted into quotient scores to have a set average and standard deviation (Quotient scores=100+(z-score*15); where the mean=100 and standard deviation=15) to facilitate their reporting to the club's coaching staff. All other metrics excluding kick and handball proficiency were standardised to a per minute unit i.e. kicks per minute, handballs per minute etc. Kick and handball proficiency were measured by calculating the number of effective kicks or handballs divided by the total kicks or handballs attempted, which was then multiplied by 100 to attain a percentage. Assumptions of independence were checked prior to performing linear mixed effects models, and scatterplots were used to determine potential outliers and influential data points. Linear mixed effects models involve both fixed effects i.e., variables yielding a systematic influence on the dataset, and random effects i.e., variables which have non-systematic influences on the dataset. Player identification number was included as a random effect in each model to allow the intercepts for each player to vary randomly, so variance associated with repeated player observations could be accounted for.

Nine separate mixed-effects models, one for each outcome variable of interest, were constructed. The dependent variables in the nine models were the indegree importance, outdegree importance, kick and handball proficiency, and the relative kicks, handballs, tackles, marks and goals per minute of game play. Rather than building a multivariate model which features all dependent variables combined into one model, each dependent variable was modelled and analysed separately (Q-Q plots, r squared, fitted versus actual value plots etc). This method permitted the investigation of whether there was a relationship between game type (four small-sided-game conditions, match simulation and competition AFL matches) on one hand and each dependent variable separately on the other. This may be important for coaches who design practice to elicit very specific behaviours. Following, condition-related differences were examined using estimated marginal means obtained from each mixed model with

Bonferroni-Holm correction applied for multiple comparisons. All statistical analyses were conducted using the lme4 (Bates et al. 2015), lmerTest (Kuznetsova et al. 2017) and emmeans (Lenth, 2021) packages in R statistical software (R Core Team 2019).

Residual plots for kicks per minute, handballs per minute, tackles per minute, marks per minute, goals per minute and handball proficiency revealed some obvious deviations from normality. These models tended not to fit the data at its tails. As a result, a further quantitative investigation into influential data points was performed using the Cook's distance metric. Influential values four times the average Cook's distance value for each model were subsequently removed from the analysis due to their excessively large residuals (Stevens, 1984). Subsequent models for each of these metrics were then built with the remaining datasets. The remaining number of observations for each metric included: 442 (indegree), 442 (outdegree), 405 (handball proficiency), 411 (kick proficiency), 410 (goals per minute), 420 (kicks per minute), 413 (handballs per minute), 426 (tackles per minute) and 412 (marks per minute).

8.4 Results

The estimated marginal means, standard errors, degrees of freedom and 95% confidence intervals for each measure across each condition are presented (Table 8.4.1). The estimated differences between each condition, significance level and 95% confidence intervals are also presented in Figure 8.4.1.

There were no differences between game type and indegree importance. Significant differences between game types were evident for outdegree importance, handball proficiency, kick proficiency, goals per minute, kicks per minute, handballs per minute, tackles per minute and marks per minute. The specific differences between each condition for each dependent variable are outlined (Figure 8.4.1).

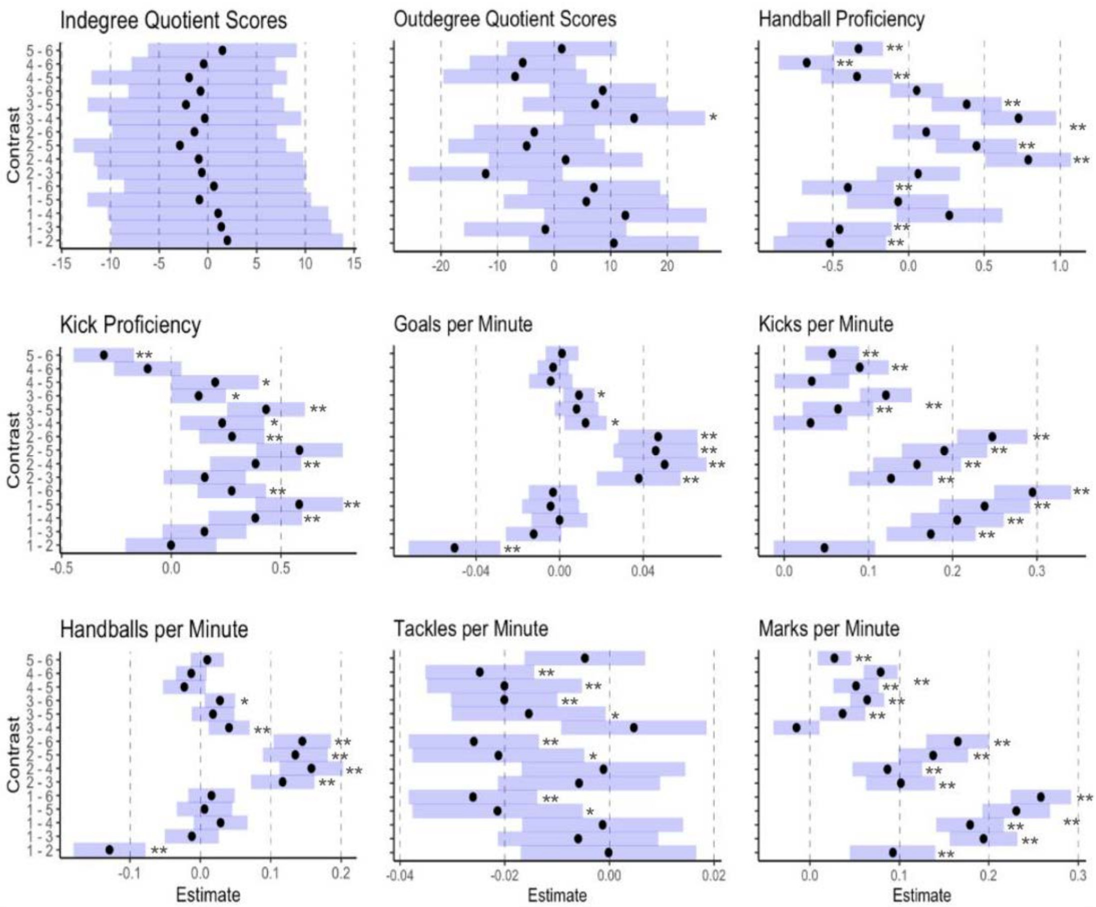

Figure 8.4.1. Estimated differences and confidence intervals between each condition for each dependent variable. The x-axis represents the contrast between each condition. For example, 1-2 represents the comparison of condition one relative to two, whereas 1-3 represents the comparison of condition one relative to three, and so on. The estimate of 0 reflects no difference in the dependent variable between conditions. * = p < 0.05, ** = p < 0.001.

Table 8.4.1. Estimated marginal means, standard errors, degrees of freedom and confidence intervals for each condition.

	Condition	Mean	Std. Error	df	Confidence Intervals (95%) Lower Bound	Upper Bound
Indegree	1	96.58	3.17	410	90.34	102.82
	2	94.58	2.93	399	88.82	100.34
	3	95.20	2.56	366	90.17	100.24
	4	95.53	2.56	364	90.49	100.57
	5	97.46	2.65	375	92.24	102.67
	6	95.96	1.25	46	93.45	98.47
Outdegree	1	101.64	4.14	381	93.51	109.78
	2	91.10	3.83	359	83.55	98.64
	3	103.20	3.38	309	96.56	109.85
	4	89.06	3.38	307	82.40	95.71
	5	95.96	3.49	322	89.10	102.83
	6	94.61	1.85	46	90.89	98.33
Handball Proficiency	1	0.38	0.10	399	0.18	0.58
	2	0.90	0.08	398	0.75	1.05
	3	0.83	0.06	392	0.72	0.95
	4	0.11	0.06	394	-0.01	0.23
	5	0.45	0.05	387	0.34	0.55
	6	0.78	0.02	41	0.74	0.82

Kick Proficiency	1	0.89	0.05	392	0.78	0.99
	2	0.89	0.05	394	0.79	0.99
	3	0.74	0.04	372	0.65	0.82
	4	0.51	0.05	396	0.40	0.61
	5	0.31	0.05	387	0.21	0.40
	6	0.61	0.02	43	0.58	0.65
Goals per Minute	1	0.0000	0.0039	407	-0.0076	0.0076
	2	0.0503	0.0064	406	0.0378	0.0628
	3	0.0124	0.0025	406	0.0076	0.0172
	4	0.0043	0.0025	405	-0.0048	0.0049
	5	0.0043	0.0026	406	-0.0008	0.0094
	6	0.0032	0.0008	43	0.0015	0.0049
Kicks per Minute	1	0.364	0.016	397	0.333	0.396
	2	0.316	0.015	386	0.287	0.345
	3	0.190	0.011	294	0.168	0.212
	4	0.159	0.012	336	0.135	0.183
	5	0.126	0.011	307	0.104	0.149
	6	0.069	0.006	44	0.057	0.082
Handballs per Minute	1	0.067	0.011	402	0.045	0.089
	2	0.196	0.014	407	0.168	0.223

	3	0.079	0.008	333	0.064	0.094
	4	0.038	0.008	332	0.023	0.053
	5	0.061	0.008	355	0.045	0.077
	6	0.051	0.004	43	0.043	0.059
Tackles per Minute	1	-0.002	0.004	406	-0.010	0.007
	2	-0.001	0.004	413	-0.010	0.007
	3	0.004	0.003	391	-0.002	0.011
	4	0.000	0.004	394	-0.007	0.007
	5	0.020	0.004	406	0.012	0.027
	6	0.024	0.001	45	0.022	0.027
Marks per Minute	1	0.287	0.011	405	0.265	0.310
	2	0.195	0.012	405	0.171	0.218
	3	0.093	0.006	386	0.080	0.106
	4	0.108	0.006	385	0.095	0.121
	5	0.056	0.006	383	0.044	0.069
	6	0.029	0.003	43	0.024	0.034

8.5 Discussion

This study was the first to examine individual player behaviour for individual and integrative metrics across changing conditions in professional AFL players. There were either no or negligible relationships with changes in task demands (i.e. different game types) for integrative measures (indegree and outdegree importance). In partial agreement with our hypotheses, individual level behaviours were associated with changes in task constraints. Individual level behaviours demonstrated varied responses across each game type. Specifically, competitive AFL matches revealed the lowest kicks and marks per minute compared to all other conditions, whilst tackles per minute were substantially higher compared to every other condition during match-play. There were varying and inconsistent differences between the different game types for handball and kick proficiency, and goals and handballs per minute. Researchers, practitioners and coaches may use these findings to consider how manipulations to space and condition types may influence individual and integrative level behaviours in Australian football.

Practice design in team sport is challenging. In Australian football, coaches must design practice that attempts to emphasise the dynamic nature of competitive performance (Alexander et al., 2019; Sheehan et al., 2019), whilst still attempting to evaluate players performance over varying and different conditions. The findings from this study confirm individual and (minor) integrative levels of behaviour vary across changes in task constraints, represented by different commonly used SSGs, simulation matches and competition games. For example, players exhibited the lowest kicks and marks per minute in competitive AFL matches compared to every other condition. This partially agrees with previous research where there were lower marks per minute in competitive AFL matches, but higher kicks per minute compared to match simulation activities (Tribolet et al., 2021). Furthermore, whilst the kick volume was lower in AFL matches in this study, players also displayed far lower kick proficiency in conditions involving larger field dimensions and player numbers (conditions 4, 5 and 6). Such an outcome might allude to the fact that larger player numbers, coupled with varying relative spaces per player, may result in individual levels of behaviour that do not self-organise into stable states of behaviour that are resistant to these perturbations (Renshaw et al., 2019). These results do not align with other research in Australian football which has suggested weak associations of space per player and player numbers with disposal frequency and skill proficiency (Teune et al., 2021). These findings however are not surprising given that the differences in conditions measured, the team studied and coaching methodologies between the current study and the study by Teune and colleagues (2021).

In contrast to kicks and marks per minute being significantly lower in AFL matches compared to each other condition, tackles per minute were significantly higher in AFL matches compared to every other condition except for match simulation. This finding differs from previous research, where competitive AFL matches revealed significantly larger rates of tackles per minute compared to match simulations (Tribolet et al., 2021). The changes in relative space and opposition team likely lead to much larger rates of tackles per minute in competitive AFL matches compared to SSGs. This may also be the case because the player numbers are much lower in SSGs, reducing the congestion (i.e. high player numbers in a smaller amount of space). These findings correspond to previous research which reported increased tackles in smaller sized SSG compared to larger sized SSG (Fleay et al., 2017). Indeed, the spatial movements of players are more unpredictable when player numbers are lower (Low et al., 2020), suggesting the larger spaces with a lower number of players and increased unpredictability of movements may make it more difficult for players to make tackles. Coaches and practitioners can use these findings to integrate varying levels of representativeness using the constraints-led approach.

One of the properties attributed to a complex system in dynamical systems theory is system degeneracy (Handford et al., 1997). Degeneracy indicates that performers can vary their behaviour without compromising on the performance outcome, suggesting high levels of adaptability to varying constraints (Seifert et al., 2014). In this study, handballs per minute were significantly higher in condition 2 (9 versus 9 with 1 floater) compared to every other condition. Moreover, condition 2 also demonstrated significantly higher handball proficiency compared to conditions 4 (13v13 SSG) and 5 (15v15 match simulation), but not conditions 1 (7v7 SSG) and 6 (AFL matches). This suggests the constraints in condition 2 led players to self-organise into using more handballs, likely a result of having an outnumber to the attacking team i.e. floater. Consequently, it appears that these behaviours were generally more effective compared to the other conditions observed. Moreover, players are typically instructed to use the outnumber to their advantage in attack, which seemingly occurred in this condition. Indeed, numerical advantages during structured phases of play has shown a greater likelihood of gaining possession from clearances or generating scores in professional AFL matches (Alexander et al., 2021). Consequently, coaches may constrain the environment with an outnumber to the attacking team to probe and encourage degenerate behaviour during practice and further emphasise features in the environment which invite the players to behave functionally (Alexander et al., 2021; Vilar et al., 2013). Whilst this may be valuable for training particular behaviours, coaches need to remain mindful that generating an outnumber in play should be valued more so than purely 'allocating' or prescribing an outnumber during practice.

Whilst some conditions demonstrated higher or lower individual level values in comparison to others, integrative level measures for the most part, did not significantly differ across any condition, largely aligning with our hypotheses. Whilst outdegree importance significantly differed between conditions three (10 versus 10 SSG) and four (13 versus 13 SSG), which is likely a result of handball and kick proficiency being significantly higher in condition three, every other pairwise condition comparison did not significantly differ. The stability of indegree and outdegree importance across each condition may demonstrate a stable behaviour that wasn't perturbed by the changing conditions and changes in relative space per player. Subsequently, it seems larger manipulations to control parameters/constraints are required to alter integrative levels of behaviour. It may also be more difficult for coaches to influence these levels of behaviours as they rely on the cooperative behaviours of other players in the system where the tasks performed are mutually interdependent (Adams et al., 2003). To help increase the effectiveness of skill development, especially for individual and integrative behaviours, coaches may attempt to implement a philosophy of learning where future capabilities are given precedence over present functioning (Ghodsian, Bjork & Benjamin, 1997). This ideology may change during the season, where tangible attempts to improve performance over learning are justifiably implemented by the coaches. For example, coaches provide more prescriptive and directive feedback during competitive matches (Mason et al., 2020), ask less questions of the players and playing group (Mason et al., 2020) and implement less representative practice design (Tribolet et al., 2021). Nonetheless, these results compliment previous research by increasing an understanding on how individual and integrative level changes in behaviour vary across different conditions.

As a proof of concept, the methodology of this manuscript may provide a framework to assess individual and integrative level behaviour changes in different conditions in Australian football. It may further help track individual players involvements and interactions with other players over time and in different interacting constraints. Thus, it may provide information into the emergence and dissipation of coordinative structures and movement behaviours each player exhibits, and under the conditions (i.e. interacting constraints) these behaviours develop or regress. Nonetheless, some limitations must be considered. Firstly, the data was collected in one professional AF team. Consequently, the data may not be generalisable to other teams and individuals. Secondly, the results are preliminary and should be interpreted as observational and for hypothesis testing before being able to predict and solidify future use cases. In addition to this, some influential observations were removed from the data, suggesting that the models and analyses may only be relevant for 'average' and not 'extreme' behaviours. Nonetheless, the method presented here provides the largest sample to investigate this domain of performance to-date and offers a level of objectivity for practitioners and coaches integrating different interacting constraints in team sport. These findings may help measure player skilfulness and how this may develop or regress over time, with future research able to utilise the present results to design appropriate assessments.

8.6 Conclusion

This study examined individual and integrative level behaviours across three different types of conditions: SSGs, match simulation and competitive AFL matches. Estimated marginal means revealed negligible integrative behaviour level changes while identifying varying individual level changes. Coaches and practitioners may have to consider larger manipulations to control parameters to alter integrative level behaviours, as they reflect interdependent cooperative behaviour. Competitive AFL matches displayed the lowest rate of kicks and marks per minute but highest rate of tackles per minute and further, conditions with a higher number of players revealed a lower kick proficiency. These differences suggest varying individual level behaviours are exhibited by professional AF players across different constraints. As such, analysts and sport scientists working with coaches may consider using an assessment tool to objectively monitor the (in)stability of players behaviour across changing interacting constraints. Due consideration of such tasks could be based upon some of the methodologies presented in this study. Consequently, coaches can evaluate the individual and integrative levels of behaviour over time and assess players responses to changing constraints to guide future practice design in an attempt to optimise the training process.

8.7 References

Adams, B.D., Webb, R. & Angel, H. & Bryant, D. (2003), Development of theories of collective and cognitive skill retention, Psychology, Toronto, CA: Department of National Defence.

Alexander, J.P., Spencer, B., Mara, J.K. & Robertson, S.J. (2019), Collective team behaviour of Australian rules football during phases of match play, *Journal of Sports Sciences*, 37(3), 237–243.

Araújo, D. & Davids, K. (2011), What exactly is acquired during skill acquisition, *Journal of Consciousness Studies*, 18(3-4), 7-23.

Bates, D., Maechler, M., Bolker, B. & Walker, S. (2015), Fitting linear mixed-effects models using lme4. J Stat Softw. 67(1):1–48. DOI:10.18637/jss.v067.i01.

Bourbousson, J., Deschamps, T., & Travassos, B. (2014), From players to teams: Towards a multi-level approach of game constraints in team sports. *International Journal of Sports Science & Coaching, 9*(6), 1393–1406.

Bjork, R.A. (1994), Memory and metamemory considerations in the training of human beings. In J. Metcalfe & A. P. Shimamura (Eds.), Metacognition: Knowing about knowing (pp. 185–205). The MIT Press.

Browne, P.R., Woods, C.T., Sweeting, A.J. & Robertson, S.J. (2020), Applications of a working framework for the measurement of representative learning design in Australian football, *PLoS ONE*. DOI: doi.org/10.1371/journal.pone.0242336.

Cohen, J. (1988), Statistical power analysis for the behavioural sciences. 2nd ed. Hillsdale (NJ): Lawrence Erlbaum Associates.

Davids, K., Button, C., & Bennett, S. (2008), *Dynamics of skill acquisition: A constraints-led approach*. Human Kinetics.

Fleay, B., Joyce, C., Banyard, H. & Woods, C.T. (2018), Manipulating field dimensions during small-sided games impacts the technical and physical profiles of Australian footballers, *Journal of Strength and Conditioning Research*, 32(7), 2039-2044.

Fransen, J., Tribolet, R., Sheehan, W.B., McBride, I., Novak, A.R. & Watsford, M.L. (2021), Cooperative passing network features are associated with successful match outcomes in the Australian Football League, *International Journal of Sports Science and Coaching*, DOI: doi.org/10.1177/17479541211052760.

Ghodsian, D., Bjork, R.A. & Benjamin, A.S. (1997), Evaluating training during training: Obstacles and opportunities, Training for 21st Century Technology: Applications of Psychological Research, pp. 63-88. Washington, DC. American Psychological Association.

Gorman, A.D. & Maloney, M.A. (2016), Representative design: Does the addition of a defender change the execution of a basketball shot? *Psychology of Sport and Exercise*, 27, 112-119.

Greenwood, D., Davids, K., & Renshaw, I. (2016), The role of a vertical reference point in changing gait regulation in cricket run-ups, *European Journal of Sport Science*, *16*(7), 794–800.

Guadagnoli, M.A. & Lee, T.D. (2004), Challenge point: a framework for conceptualising the effects of various practice conditions in motor learning, *Journal of Motor Behaviour*, 36(2), 212-224.

Güllich, A. (2018), “Macro-structure” of developmental participation histories and “micro-structure” of practice of German female world-class and national-class football players, *Journal of Sports Sciences*, 37(12), 1347-1355.

Handford, C., Davids, K., Bennett, S., & Button, C. (1997), Skill acquisition in sport: Some applications of an evolving practice ecology. *Journal of Sports Sciences*, *15*(6), 621–640.

Johnston, R.D., Black, G.M., Harrison, P.W., Murray, N.B. & Austin, D.J. (2018), Applied sport science of Australian football: a systematic review. *Sports Medicine*, 48(7), 1673–1694.

Koo, T.K. & Li, M.Y. (2016), A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine.15*(2), 155–63.

Kuznetsova, A., Brockhoff, P.B. & Christensen, R.H.B. (2017), lmerTest package: tests in linear mixed effects models, *Journal of Statistical Software*, 82(13):1–26. DOI: doi:10.18637/ jss.v082.i13.

Lenth, R.V. (2021), emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version, 1.6.3. https://CRAN.R-project.org/package=emmeans

McCalman, W., Crowley-McHattan, Z.J., Fransen, J. & Bennett, K.J.M. (2021), Skill assessments in youth soccer: A scoping review, Journal of Sports Sciences, DOI: 10.1080/02640414.2021.2013617.

Moreira, P. E. D., Barbosa, G. F., Murta, C. D. C. F., Morales, J. C. P., Bredt, S. D. G. T., Praça, G. M., & Greco, P. J. (2019), Network analysis and tactical behaviour in soccer small-sided and conditioned games: Influence of absolute and relative playing areas on different age categories. *International Journal of Performance Analysis in Sport*, *20*(1), 64–77.

Olthof, S. B. H., Frencken, W. G. P., & Lemmink, K. A. P. M. (2019), When something is at stake: Differences in soccer performance in 11 vs 11 during official matches and training games. *Journal of Strength and Conditioning Research*, *33*(1), 167–173.

Otte, F.W., Millar, S-K. & Klatt, S. (2020), Skill training periodisation in "Specialist" sports coaching – An introduction of the "PoST" framework for skill development, *Frontiers in Sports and Active Living,* 1(61), DOI: 10.3389/fspor.2019.00061.

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011), Representative learning design and functionality of research and practice in sport. *Journal of Sport & Exercise Psychology*, *33*(1), 146–155.

R Core Team. (2019), R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna(Austria). Accessed July 2020 https://www.R-project.org

Renshaw, I., Davids, K., Phillips, E. & Kerherve, H. (2011), "Developing Talent in Athletes as Complex Neurobiological Systems." In Talent Identification and Development in Sport: International Perspectives, edited by Joe Baker, Stephen Cobley, and Jorg Schorer, 64–80. London: Routledge.

Renshaw, I., Davids, K., Newcombe, D. & Roberts, W. (2019), The constraints-led approach: Principles for sports coaching and practice design. Routledge.

Robertson, S. (2016), A statistical approach to enhancing player skill in Australian Rules Football: applications to team sport, Conference: The 13th Australasian Conference on Mathematics and Computers in Sport At: Melbourne, Australia.

Robertson, S., Gupta, R., & McIntosh, S. (2016), A method to assess the influence of individual player performance distribution on match outcome in team sports, *Journal of Sports Sciences,* 34(19), 1893–1900.

Robertson, S., Back, N. & Bartlett, J.D. (2016), Explaining match outcome in elite Australian rules football using team performance indicators, *Journal of Sports Sciences*, 34(7), 637-644.

Robertson, S. & Joyce, D. (2018), Evaluating strategic periodisation in team sport, *Journal of Sports Sciences*, 36(3), 279-285.

Sheehan, W. B., Tribolet, R., Watsford, M. L., Novak, A. R., Rennie, M. J., & Fransen, J. (2019). Using cooperative networks to analyse behaviour in professional Australian Football. *Journal of Science and Medicine in Sport*, *23*(3), 291–296.

Stevens, J.P. (1984), Outliers and influential data points in regression analysis, *Psychological Bulletin*, 95(2), 334-344.

Svilar, L., Castellano, J., & Jukic, I. (2019), Comparison of 5v5 training games and match-play using microsensor technology in elite basketball. *Journal of Strength and Conditioning Research*, *33*(7), 1897–1903.

Travassos, B., Duarte, R., Vilar, L., Davids, K. & Araújo, D. (2012), Practice task design in team sports: Representativeness enhanced by increasing opportunities for action, *Journal of Sports Sciences*, 30(13), 1447-1454.

Tribolet, R., Sheehan, W.B., Novak, A.R., Watsford, M.L. & Fransen, J. (2021), Factors associated with cooperative network connectedness in a professional Australian football small-sided game, *Science and Medicine in Football*, DOI: 10.1080/24733938.2021.1991584.

Vilar. L., Araújo, D., Davids, K. & Bar-Yam, Y. (2013), Science of winning soccer: Emergent pattern-forming dynamics in association football, *Journal of Systems Science and Complexity*, 26(1), 73–84.

Woods, C., McKeown, I., Rothwell, M., Araújo, D., Robertson, S. & Davids, K. (2020), Sport practitioners as sport ecology designers: How ecological dynamics has progressively changed perceptions of skill 'acquisition' in the sporting habitat, *Frontiers in Psychology*, 24(11), DOI: 10.3389/fpsyg.2020.00654.

Chapter 9 | General Discussion

This thesis contains a series of studies that investigated current practice structures in professional Australian football (AF), in addition to examining the factors that influence how much augmented feedback coaches provide during practice. An ecological dynamics approach was used to explore an interdisciplinary method to understand performance in professional AF via collective skill acquisition and performance analysis. Specifically, the research investigated how coaches implemented practice activities (Chapter Four) and provided augmented feedback to the team (Chapter Five) and subsequently related these to optimal provisions based on skill acquisition literature. Cooperative passing behaviours were measured and explored to help determine how coaches and practitioners could manipulate constraints to help influence favourable cooperative passing behaviours (Chapter Six). Furthermore, match simulation practice and competitive matches were compared at a cooperative passing behaviour level, team skill level and task constraint level to ascertain any differences (Chapter Seven). Finally, an observational design which manipulated space per player (m^2) assessed the adaptability of individual players across six different conditions with differing task demands (Chapter Eight). Importantly, the studies in this thesis used ecological dynamics, the constraints-led approach and experiential knowledge from professional coaches and practitioners to guide study design and optimise the translation of results to the field. This blended approach represents an optimal model of ecological validity, with due attention paid to a range of approaches and considerations.

Consequently, the generation of five research questions sought to address the aims of this thesis. There is further application and discussion of these key questions to contexts outside of professional male AFL, namely women's and youth team sport. Additionally, the results are also presented in light of alternative skill acquisition frameworks (e.g. information processing theories, Fitt's stage theory). The research questions asked were:

1) How do coaches currently design practice across a season and what value do they place on different practice types?
2) Which factors explain the duration of augmented feedback coaches provide to the team during practice?
3) Which factors can coaches manipulate during practice using the constraints-led approach to influence favourable collective tactical behaviour metrics?

4) Which differences exist (if any) between the most representative form of practice i.e. match simulation, and competitive AFL matches?
5) In which way do professional Australian football players change their cooperative and individual behaviours when space per player (m^2) is manipulated during practice?

The five studies presented throughout this thesis aimed to answer these questions, build on current literature and provide data to improve the integration of empirical knowledge with experiential knowledge for practice design in professional AF. This discussion chapter provides an overview of the implications arising from each study with due consideration paid to the limitations and delimitations evident within the research. Further, the overall contribution of the sequence of studies is discussed along with the practical applications and outcomes for the specific partner organisation involved in the research and various team sports in general.

How do coaches currently design practice across a season and what value do they place on different practice types?

The findings of this thesis build on previous literature in other team sports documenting how coaches implement different practice types and activities (Ford, Yates & Williams, 2010; Roca & Ford, 2020; Williams & Hodges, 2005). Specifically, *Study One* provided insight into how coaches prescribe more representative practice during the in-season phase as indicated by an increased amount of practice in match simulation and position-specific practices. This provides support for the specificity of practice hypothesis (Proteau, 1992) and importantly provides empirical evidence for the fact that coaches generally employ a skill acquisition periodisation framework (Robertson & Farrow, 2017), regardless of whether this implementation leads to accelerated skill learning, which remains unknown. Similarly, coaches implement more training-form type practice activities in the pre-season phase. One of the major contributions of this body of work is the insight it provides on how coaches value different practice types across a full season in a professional sport setting. Skill type practice activities (e.g. isolated game events, no to minimal defenders when disposing possession) were the most frequently performed practice type across pre- and in-season periods which suggests the coaches were primarily concerned with improving the athletes skill proficiency. Whilst relevant, the ecological dynamics literature highlights that as a performer increases their skill over time, more specific information in the environment is required to further improve the performers skill (Fajen et al., 2008; Farrow et al., 2013). Consequently, the ecological dynamics framework suggests these practice types may not be the most optimal to improve the transfer of skill to competition. Alternatively, the implementation of the ecological dynamics framework in this context may require considerations that integrates these findings, in addition to previous research documenting how AF practice significantly differs to competition (Browne et al., 2020; Corbett et al., 2017; Ireland et al., 2019). Here, the current evidence suggests a misalignment between empirical data and experiential knowledge.

The results of *Study One* provide wider implications for the progression of skill acquisition in the field. Importantly, the findings suggest that there are opportunities for skill acquisition specialists to integrate empirical knowledge in the AF context. Skill acquisition specialists can work with coaches to create a system and method to implement and optimise practice design according to effective pedagogical principles (Fransen, Pepping & MacMahon, 2021b). The effectiveness of this approach relies on the integration between empirical and experiential knowledge however. Whilst the coaches in the current study were not homogenous to coaching groups at other AFL clubs, historical precedence and emulating the past may allude to these common implementations of practice that does not fully represent competition. Whilst current practice design procedures definitely have merit, further examinations of coaching philosophies are warranted. Specifically, future research may examine why coaches implement the practice activities they do and the context of those decisions. Here, qualitative research would help provide great insight and allow researchers to provide greater detail to improve the integration of the ecological dynamics framework as a pedagogical tool for learning in team sport.

Which factors explain the duration of augmented feedback coaches provide to the team during practice?

One of the most common forms of interaction between athletes and coaches in team sport is via verbal augmented feedback. Augmented feedback in team sport is a common and powerful way to enhance learning outcomes (Anderson et al., 2019) and is defined as feedback that either replace or supplement a player's intrinsic feedback mechanisms (Magill, 1994). Whilst there are many laboratory-based studies examining the effect of augmented feedback in motor tasks (Edwards, 2010; Swinnen et al., 1990) and more recent studies assessing competitive contexts and augmented feedback (Halperin et al., 2016; Mason et al., 2020), relatively little is known about the factors that contribute to augmented feedback provision in team sport practice. *Study*

Two aimed to address this and explore the factors associated with the duration of augmented feedback during each practice type and activity forms defined and classified in *Study One*. Furthermore, additional factors such as season phase, practice time, previous match result and the number of feedback interventions were also investigated. The results showed a practice time*feedback intervention frequency interaction explained 65% of the variance in terminal augmented feedback durations provided across the whole season. Furthermore, when exploring previous in-season competitive match result, a practice time*match result interaction and a match result*feedback intervention frequency explained 99% of the variance in terminal augmented feedback duration.

The results of *Study Two* suggest the duration of terminal augmented feedback provided during practice is largely related to the duration of the practice activity. I.e. when coaches are afforded more time with the players, they provide more feedback. Additionally, augmented feedback duration was also related to the total number of feedback interventions performed by the coach and the previous match result. These results were in contrast to what was hypothesised, as it was expected practice type, activity form and season phase would contribute to the results, in which they did not.

The findings from *Study Two* suggest that an increased practice activity duration possibly presents more opportunities to provide feedback to the team. Moreover, this may suggest the relationship between coach interventions and complex cooperative team behaviour is mediated by time. Descriptively, coaches did spend a higher proportion of practice time providing feedback in playing form activities (more complex) compared to training form activities (less complex). These results confirm that coaches provide more information in more complex practice types. Another key finding of *Studies One* and *Two* was that coaches implemented longer practice durations in more complex practice types, but in doing so, implicitly tend to provide increased augmented feedback durations. The integration of findings from *Study One* and *Study Two* may reflect the value coaches have in traditional pedagogical methods, where outside of the design of specific practice types, their main coaching tool is the provision of verbal augmented feedback. For example, *Study One* highlights the value coaches place on technical and closed-type practice types, compared to more open and complex practice types.
The more complex practice types hypothetically have increased transfer as there is greater similarity of perception-action responses to that of competitive matches (Maloney et al., 2018; Pinder et al., 2011). Related to the current research question however, the factors that help

explain terminal augmented feedback during practice may suggest coaches implicitly implement augmented feedback ad-hoc and without an appropriate framework to help support their decision-making on this pedagogical tool. This may provide an opportunity for skill acquisition specialists to help guide coaches on how to optimise their provision of augmented feedback during practice.

Nonetheless, both *Study One* and *Study Two* were exploratory in nature, and no causal inferences about the role played by augmented feedback in the acquisition of AF specific skill can be made. Nonetheless, they have helped provide insight in the practice structures that coaches implement over a full AFL season and the factors which help explain the duration of terminal augmented feedback during these practice structures. This sort of feedback is valuable to coaches who can then reconcile their feedback intentions with objective information and be accountable for the duration and subsequent use of feedback during training.

Which factors can coaches manipulate during practice using the constraints-led approach to influence favourable collective tactical behaviour metrics?

According to the constraints-led approach, skilled behaviour emerges under the interaction of individual, environmental and task constraints (Davids et al., 2008). Coaches play an important role in this approach and aim to design practice in a way that improves the development and skilfulness of both the players and team. From a collective team perspective, coaches must manipulate specific constraints to help teams produce functional movement solutions similar to those observed in competitive matches. Connectedness is a global cooperative passing network metric that reflects the bi-directional interactivity amongst the players in a passing network. High connectedness values have been associated with the probability of winning competitive AFL matches (Fransen et al., 2021a). Thus, *Study Three* aimed to determine which constraints and metrics could help explain connectedness values in a small-sided game (SSG) routinely performed across the season. The results showed the number of team shots at goal and the time on task both positively contributed to connectedness scores and explained 65% of connectedness variance. While no causal inferences can be drawn from this study, further research should explore if these metrics may be used as indicators to elicit higher or lower connectedness scores and how coaches can use these metrics to objectively guide practice design. In association football, Mendes and colleagues (2019) revealed positive associations with network density and goals scored and negative associations between network density and goals conceded across different competition levels and cohorts of association football teams. In addition to *Study Three, Study One* and *Study Two* can help objectively guide practice design by first determining what activities coaches value and at which points in the season. The results can then help guide which activities may be more thoroughly assessed in relation to tactical behaviours and how they can be influenced using the constraints-led approach.

The results from Mendes et al. (2019) highlight that specific cooperative network properties lead to favourable outcomes in competition. Moreover, the findings from *Study Three* compliment previous literature by establishing the trainability of cooperative networks in professional AF practice, something that has not been established previously. Whilst research has established that some key performance indicators (e.g. inside 50's, number of kicks) are significantly different between competitive AFL matches won or lost (Fahey-Gilmour et al., 2019; Robertson et al., 2016; Young et al., 2020), these studies results cannot articulate how to create practice interventions that aim to create cooperative behaviour change that transfers to competitive matches whereas this study begins to establish how it could be implemented using cooperative passing networks.

In contrast to the hypotheses, field dimensions (length and width) and space per player did not contribute any explanatory power to the model. These findings from *Study Three* contrast previous research in association football where Moreira and colleagues (2019) reported that reductions in the spacings per player increased the level of interaction between players. This was likely due to an increased physical proximity to other players, making them more easily reachable. This also demonstrates that even though AF and association football share some similarities e.g. team evasion sports, spatiotemporal characteristics etc, the behaviours of AF players and association football players may not be similar. Whilst not in agreement with the hypotheses, the major goal of *Study Three* was to determine which factors coaches can manipulate during practice to enhance favourable cooperative passing behaviours (i.e. increased connectedness; Fransen et al., 2021a). The results confirmed the positive contribution of shots at goal and the time on task for increasing connectedness values. Using the constraints-led approach, coaches and practitioners could influence these values through such things as manipulating task rules or creating specific outnumbers in zones on the field. *Study Three* confirmed cooperative passing networks can be integrated into practice analyses to help support decision-making for practice design.

Which differences exist (if any) between the most representative form of practice i.e. match simulation, and competitive AFL matches?

In team sport, the constraints and practice environments provide specific aspects of information to facilitate the players decision making and skill execution (Davids et al., 2008; Pinder et al., 2011). Here, coaches and practitioners must consider which aspects of competition they sample in practice and understand the potential consequences if they fail to do so e.g. omit key constraints that the team and players interact with during competition (Maloney, 2018). The collective results from *Studies One* and *Two* demonstrated that coaches valued match simulation activities over the season by allocating more practice time to it and also providing more feedback in it. Consequently, an examination of constraints and subsequent behaviours in match simulation would help inform how representative this activity is in relation to competitive matches. The findings from *Study Four* build on existing literature showing differences in practice environments to competitive match environments (Browne et al., 2020; Corbett et al., 2017; Ireland et al., 2019). The major contributions of this body of work are establishing the dissonance between the constraints and behaviours players interact with during practice being substantially different to the constraints and behaviours they interact with and exhibit during competitive matches. The findings from this thesis extend on this in two ways. Firstly, *Study One* established that over longer time periods, coaches do not implement representative constraints across the entire season. Rather, they emphasise more representative practice types in-season compared to pre-season. Secondly, *Study Four* demonstrated that what is typically thought to be the 'most representative' practice activity, match simulation, has substantial differences for team skill and tactical metrics compared to competitive AFL matches. Specifically, match simulation practice had a higher number of goals scored per minute with less passing actions (kicks and handballs per minute) and a greater reliance on relatively few key players to receive and distribute possession, whilst competitive AFL matches had higher tackles and turnovers per minute.

These findings correspond to previous research, where a lower degree of physical contact is commonly prescribed during practice (Dawson et al., 2004). Thus, in relation to the research question, it is important to consider a continuum along which representative learning design exists. Specifically, coaches may implement a high level of representativeness in match simulation and subsequently have a higher number of tackles and turnovers per minute, which would likely increase the pressure on the ball disposal and reduce the number of passes per minute, however, these changes would likely increase the amount of physical contact and blunt force trauma players are exposed to (Rennie, 2017). Hence, it may lead to a larger risk of injury and a subsequent reticence to incorporate the 'most' representative practice design that is most similar to competition.

Study Four confirms recent research in association football (Olthof et al., 2019), basketball (Svilar et al., 2019) and AF (Browne et al., 2020) whereby match simulation activities contain substantial differences to competition matches. The extent of these differences presented in *Study Four* provides important insight for practitioners and coaches whilst concurrently stimulating discussion with researchers on the best approach to achieve the collective task goals, increase the similarity of match simulation to competitive matches and ensure injury risk isn't too high that it compromises player availability for competition.

In which way do professional Australian football players change their cooperative and individual behaviours when space per player (m^2) is manipulated during practice?

Expert team sport athletes must be adaptable and be able to perform and use their skills across a variety of contexts (Renshaw et al., 2019). In fact, skilled behaviour could be considered to reflect the ability to perform a skill under varying constraints. To help athletes develop adaptable skillsets and behaviours, coaches commonly manipulate features in the practice environment. Thus, coaches', analysts' and sport scientists' must consider methods to analyse how player behaviours can be assessed across practice and whether these behaviours transfer to competition. The results from *Study One* helped establish the practice activities the coaches implement across a whole season. Working with the coaches' and attaining insights into which practice activities they valued permitted our research group with an ability to assess which practice activities would be the most beneficial to potentially use within a methodology to answer this question. Furthermore, *Study Three and Four* provided insight into which metrics may show differences at an individual and integrative level across different manipulations to constraints and across different game types. Consequently, *Study Five* sought to build on the previous studies in this thesis by integrating empirical and experiential knowledge into an observation of player behaviours across practice and competitive match conditions.

The results from *Study Five* suggest integrative levels of behaviour, for the most part, do not change across changing conditions and task demands. Integrative levels of behaviour represent how a single player is embedded within a larger collective (Adams et al., 2003). For example, receiving a pass from a teammate relies on the teammate successfully passing the ball to them. Only one condition comparison showed significant differences for outdegree importance. As these behaviours rely on cooperative interdependence with other players (Adams et al., 2003), it seems that larger manipulations to constraints/control parameters are required to perturb the stability of these behaviours. Consequently, these findings have implications for how coaches may expect manipulations to influence integrative level changes in professional AF players. Moreover, these results may inform practitioners on the emergence and dissipation of successful and unsuccessful coordinative behaviours that individuals may exhibit, and under which conditions they exhibit them. The findings help inform ecological dynamics theory and how it may be applied in team sport practice and how it may help inform practice design. Whilst previous research has shown team-level changes in cooperative behaviour to changes in constraints (Frencken et al., 2013; Moreira et al., 2019), this research is the first to demonstrate the (lack of) integrative level behavioural changes across changing conditions and task demands.

Individual level behaviours are those that directly relate to the actions of an individual independent to those of the collective. For example, the number of kicks a player performs in one game. The results from *Study Five* demonstrate variable and inconsistent responses across changing conditions. For example, tackles per minute were higher in condition 6 (competitive AFL matches) than conditions 1-4 (SSGs) but not different to condition 5 (match simulation). Comparatively, condition 6 had the lowest rates of kicks and marks per minute. These results suggest the condition type and consequently, task demands, perturb the stability of individual behaviours significantly enough to change these behaviours. Furthermore, kick proficiency was significantly lower in conditions with larger field dimensions and a greater number of players (conditions 4, 5 and 6). The greater complexity, indicated by a larger number of players and more space, may make it more difficult for players to stabilise these behaviours (Handford et al., 1997). Indeed, it is a challenge for coaches' to assess how complex and difficult to make practice. These findings have implications for such concepts as explorative behaviour, learning versus performance and pattern formation and self-organisation under constraints, to name a few. The results and implications from *Study Five* seem to misalign with recent research in AF. Specifically, Teune and colleagues (2021) alluded to weak associations between space per player and player numbers with disposal frequency and skill proficiency. It seems future research is required to validate these results across different teams and cohorts.

Nonetheless, coaches may also use specific results within *Study Five* to observe system degeneracy, a key component of dynamical systems theory (Handford et al., 1997). For example, condition 2 had a consistent outnumber to the attacking team. As a result, condition 2 had significantly higher handball proficiency compared to other conditions. Here, it appears a numerical advantage can help develop effective passing behaviours, potentially helping players stabilise these behaviours across changing constraints. Previous research has confirmed the importance of an outnumber in competitive AFL matches (Alexander et al., 2021) whilst system degeneracy has shown beneficial outcomes in association football (Vilar et al., 2013). Here, degeneracy signifies that an individual or team can vary their motor behaviour without compromising on function (Mason, 2010), suggesting that evidence may entail adaptive coordinative patterns in order to satisfy changing task constraints. Degeneracy also suggests that there is an interchangeability of different components that is able to help achieve the task goal (Araujo & Davids, 2016). Seifert and colleagues (2014) showcase degeneracy properties in professional swimmers. Specifically, the swimmers were able to swim at the same target speed without extra energy expenditure across two different conditions of instruction, signifying degeneracy, where the swimmers achieve the same outcome through different forms of organisation and under different constraints (Seifert et al., 2014). The degenerate properties showcase being able to vary behaviour without compromising on the task outcome or goal, highlighting how adaptability is important to satisfy the interacting constraints (Davids et al., 2003; Handford et al., 1997; Seifert et al., 2013; Seifert et al., 2014).

Collectively, the findings from *Study Five* provide implications for practitioners' and coaches' attempting to monitor and influence individual and integrative metrics across changing conditions and task demands. Additionally, the methods described may be used to help evaluate players individual and cooperative behaviour under different constraints, and under which constraints these behaviours are stable or not. These findings provide important implications for guiding practice design in AF and team sport in general.

As a reflection of the current literature and synthesising the current thesis' collective findings, considerations are proposed to the framework to help improve the integration of empirical and experiential knowledge to design practice. Whilst previous models proposed have outlined skill periodisation (Farrow & Robertson, 2017; Otte et al., 2019) and measuring representative learning design via constraint interactions (Browne et al., 2020), the findings presented by this thesis integrate insight into what skill periodisation empirically looks like in professional AF (*Study One* and *Study Two*) while simultaneously presenting methods to measure collective team behaviour through the constraints-led approach, cooperative passing networks and skill metrics (*Study Three, Study Four* and *Study Five*). These methods can be applied in both practice and competitive matches to support decision-making on practice design. Consequently, considerations to the current framework and conceptual model to optimise practice design are presented (Figure 9.1.1).

Within this conceptual model (Figure 9.1.1.), the constraints-led approach provides a tangible framework to incorporate ecological dynamics concepts into practice design. These considerations and findings from this thesis are designed to help inform coaches, practitioners and researchers on how the constraints-led approach can be observed and assessed to then inform representative learning design. Specifically, monitoring current practice implementation and the feedback coaches provide can help determine the value coaching groups place on particular activities and how much interaction they may have in them, respectively. Additionally, practitioners and researchers can observe and determine which constraints they can manipulate to alter cooperative passing network behaviours during practice using the constraints-led approach. Lastly, an improved integration of empirical and experiential knowledge via an interdisciplinary approach to measure individual performance can help inform representative learning design to improve the level of skill transfer.

Consequently, practitioners can work with coaches to help support decisions made on practice design to improve the level of representativeness (action fidelity and functionality). That is, are the constraints coaches manipulating making the team organise and behave in a way where they use similar information in practice to what they do in competition and as a result, do they perform similar behaviours and actions to competitive matchplay.

This framework can help answer questions such as:

- What constraints can coaches manipulate or target that change the behavioural organisation of the system (i.e. control parameters)?
- Is this change in the systems organisational behaviour favourable to matchplay behaviours?
- Is behaviour within a certain practice activity stable and effective (consistent behaviour with increased transfer to match performance), or stable and ineffective (consistent behaviour with less transfer)?
- If constraints have been manipulated and team behaviour plateaus (as observed by the team interaction and skill metrics), what changes could coaches make to continue progression using the constraints-led approach?

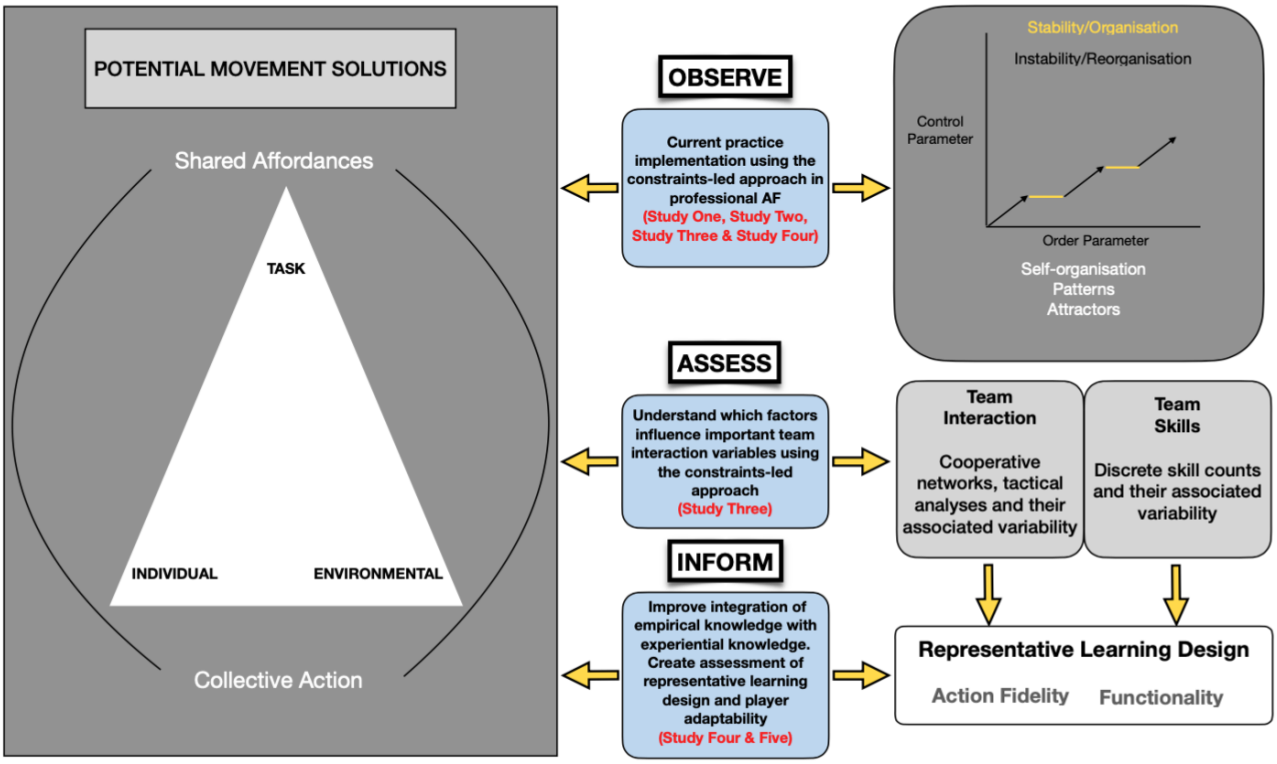

Figure 9.1.1. Integration of research studies into an adapted framework for practice design in team sport.

Contribution of thesis

This thesis proposed a framework and sequence of studies to assist with understanding what is currently being implemented by professional AFL coaches in practice and how this relates to empirical knowledge in skill acquisition. Moreover, it was the aim of the thesis' studies to re-evaluate an existing empirical framework, ecological dynamics, and investigate its suitability for the ‘real-world’ application of training and match-play. In doing so, this work provides some considerations for practitioners and researchers implementing it.

Specifically, this thesis examined the practice structures coaches implement across an AFL season whilst concurrently exploring the factors that explained augmented feedback provided by coaches during practice. Moreover, the thesis investigated the factors that lead to favourable tactical outcomes and made comparisons between match simulation practice and competitive matches. Consequently, this research proposed simple objective methods to monitor and compare practice activities to competition to help promote an integration of empirical knowledge with experiential knowledge. With some adjustments to specific metrics and contextual information relating to match-play, these methods can be applied to any team sport, competition or cohort.

The research in this thesis examined changes in behaviour that occur across different types of practice constraints. Furthermore, study 5 investigated changes in skill frequencies and outcomes in addition to cooperative passing network metrics. The task constraint space per player (m^2) was experimentally manipulated to provide a global manipulation that can be performed across sports and cohorts and can further manage different player availability numbers. These investigations provide preliminary evidence into how behaviours may change across differing task constraints.

Collectively, the findings of these studies support the previously discussed considerations of the ecological dynamics framework to assess practice in AF but can be applied across team sports generally. The findings of the thesis studies are in general agreement with current literature, where practice does not correspond to empirical ‘best practice’ practice design. Nonetheless, the thesis outlined tangible outcomes using the constraints-led approach to skill acquisition. Here, an integration of empirical data collection led to multiple outcomes: i) the establishment of factors that influence favourable tactical metrics in competitive matches, ii) understand where key differences exist between match simulation and competition and iii) how practitioners can incorporate an assessment of player adaptability in practice.

Practical applications

- Practitioners should monitor practice through the time spent in the activity type and how frequently activities are prescribed by coaches. Consequently, practitioners such as performance analysts, skill acquisition specialists and sport scientists can assess how coaches' value different activities and monitor their level of similarity to competitive matches across the season.
- An *in-situ* measurement of augmented feedback during practice can help practitioners working with coaches understand when and how often coaches may provide feedback to the team. Resultantly, practitioners can understand how the feedback presented may have implications on how quick the activity is understood by the team, the effectiveness of the feedback and how this may change across the season.
- Performance analysts working in AF can use the number of shots on goal and the time in the activity as indicators of the level of connectedness a team displays during practice. This reduces the number of variables that an analyst has to code whilst still providing insight into tactical behaviour during practice.
- If coaches and support staff wish to increase the level of representativeness of match simulation to competitive AFL matches, players must tackle more often to induce more turnovers. Coaches may reduce the size of the field or give one team an outnumber to do so.
- Individual and integrative level behaviours can be monitored to help inform how players behaviours may change (effectively or ineffectively) under different constraints and task demands. An evaluation of integrative metrics, including indegree and outdegree importance, with individual level metrics, including kicks, marks, handballs, tackles and goals per minute, and handball and kick proficiency, can help examine how cooperative behaviours emerge or dissipate across different constraints in individuals.

Chapter 10 | Summary and Future Directions

Summary

This thesis provided contemporary considerations to an established framework (Figure 9.1.1) to assess practice in team sport. Guided by ecological dynamics, the considerations integrate findings from the thesis, along with discussions with key personnel within the football club and supervisory team. Practitioners working with coaches' in attempts to optimise individual and team skilled behaviour can use the current framework and contemplate these considerations to help guide decision making when designing practice. Despite the collection of longitudinal data across multiple seasons with the AFL team, practitioners' and coaches' must always consider that the goal and intention of the activity is one of the most important considerations to make when designing practice. Nonetheless, the main findings from the thesis include:

- Practitioners' can monitor the exposure (time and frequency) that players and team spend in different activities across an AFL season to help understand what activities coaches value the most
- Coaches place a great emphasis on training form activities during practice, and skill type activities in particular, even though they may not demonstrate high levels of representativeness. This contrasts empirical frameworks and suggests the framework must consider this evidence
- An *in-situ* measurement of augmented feedback during practice can provide clarity on how much interaction coaches have with the team
- There is a complex interaction of factors that help explain augmented feedback duration in practice. As such, coaches and practitioners working with coaches must acknowledge that these factors have an impact on skill acquisition, and with the help of skill acquisition specialists, a context-appropriate pedagogical framework can be integrated
- Time in the practice activity and the number of shots at goal explain 65% of the variance in the cooperative passing metric, connectedness
- Coaches' can use the constraints-led approach to influence collective team behaviour during practice in an attempt to optimise the transfer of cooperative skill to matches
- Match simulation practice differs to competitive matches for task constraints, skill metrics and cooperative passing metrics. Specifically, match simulation has more goals per minute with less passing actions compared to AFL matches

- Competitive matches have significantly more turnovers and tackles per minute, whilst match simulation also had a number of players that were relied upon to receive and distribute possession compared to AFL matches
- Integrative level behaviours (behaviours or metrics that reflect how an individual is embedded in a collective) showed no or negligible changes across changing conditions (small-sided games, match simulation and competitive matches) and task demands. This type of behaviour may need larger manipulations to constraints to perturb the stability and self-organisation tendencies
- Individual level behaviours (the actions of an individual independent to those of the collective) showed variable and inconsistent responses across changing conditions and task demands. The results suggest these behaviours are not stable across different conditions. Additionally, this result has implications for system degeneracy, with players potentially being able to achieve the same solution in a different way. As such, coaches must be mindful of these implications when designing practice.

Future Directions

This thesis has provided considerations to the ecological dynamics framework to help integrate empirical data into practice design. In doing so, it has opened up avenues for future research that are beyond the scope of this thesis. Some of these avenues include:

1. The inherent nature of professional sport means research is typically conducted within a single cohort of athletes in one team. This is also reflective of the coaching group. Therefore, things such as coaching philosophies, the playing group and their availability and the playing style and tactics can all influence the results and applicability of the thesis' findings. Future research should consider data across multiple cohorts and clubs across multiple seasons. This would provide greater surety of the results and ultimately enhance the application and generalisability across AF.

2. Whilst this thesis was able to establish where differences exist in team skill and tactical metrics between practice and competitive matches, it would be useful to assess the interaction of these differences that exist in addition to the constraint interactions that may differ. Future work can help determine whether the complex interactions of competitive matches are represented and preserved during practice.

3. The team skill and tactical metrics used throughout this thesis represent key performance indicators in AF. Nonetheless, there may be alternative metrics that may better encapsulate performance in AF. Therefore, whilst the metrics may provide an overall indication, integrating subjective coach ratings of things like skilfulness, adaptability or decision-making, to name a few, during practice and across competitive matches will likely improve the validity of these results. These ratings can provide a complementary perspective to objective and empirical data.

4. Performance in team sport is comprised of physical, skill and tactical components. This thesis did not integrate any physical metrics or components, with the view of establishing findings in skill and tactical outcomes as the priority. Nonetheless, future research should aim to integrate physical, skill and tactical variables as a holistic perspective of performance and assess their trainability and similarity to competition when integrated together.

5. The naturalistic nature of data collection within this thesis meant the data was descriptive and observational. Future research should incorporate intervention studies that further integrate empirical and experiential knowledge. This will ensure skill acquisition sciences continues to develop and be utilised in the real world.

6. An evaluation of practice is difficult without understanding what measures may contribute to performance during practice. Whilst different focus points may exist and need to be established during the practice session (e.g. performance or learning focus), some specific performance outcomes should be investigated to help understand how to best assess practice activities. Future work should aim to integrate coach perspectives for player and team evaluation during practice.

Chapter 11 | References

Adams, J. A. (1971), A closed-loop theory of motor learning, *Journal of Motor Behaviour*, 3, 111-150.

Adams, B.D., Webb, R. & Angel, H. & Bryant, D. (2003), Development of theories of collective and cognitive skill retention, Psychology, Toronto, CA: Department of National Defence.

Afonso, J., Esteves, F., Araújo, R., Thomas, L. & Mequita, I. (2012), Tactical determinants of setting zone in elite men's volleyball, *Journal of Sports Science and Medicine*, 11, 64-70.

Aguiar M, Gonçalves B, Botelho G, Lemmink K, Sampaio J. (2015), Footballers' movement behaviour during 2-, 3-, 4-and 5-a-side small-sided games, *Journal of sports sciences*, 33(12), 1259-66.

Alexander, J.P., Spencer, B., Sweeting, A.J., Mara, J.K. & Robertson, S. (2019a), The influence of match phase and field position on collective team behaviour in Australian rules football, *Journal of Sports Sciences*, 37(15), 1699-1707.

Alexander, J.P., Spencer, B., Mara, J.K. & Robertson, S. (2019b), Collective team behaviour of Australian rules football during phases of match play, *Journal of Sports Sciences*, 37(3), 237-243.

Alexander, J., Bedin, T., Jackson, K.B. & Robertson, S. (2021), Team numerical advantage in Australian rules football: A missing piece of the scoring puzzle?, *PLos ONE*, 16(7).

Amorose, A.J. (2007), Coaching effectiveness: Exploring the relationship between coaching behaviour and self-determined motivation. In M. S. Hagger & N. L. D. Chatzisarantis (Eds.), Intrinsic motivation and self-determination in exercise and sport. Human Kinetics.

Anderson, D. I., Rymal, A. M., & Ste-Marie, D. M. (2014), Modelling and feedback. In A. Papaioannou & D. Hackfort (Eds.), The Routledge handbook of sport and exercise psychology (pp. 272–288). New York: Routledge.

Anderson, D.I., Magill, R.A., Mayo, A.M. & Steel, K.A. (2019), Enhancing motor skill acquisition with augmented feedback, Skill Acquisition in Sport: Research, Theory and Practice, 3rd Ed. Routledge London.

Anson, G., & Elliott, D. (2005). Information processing and constraints-based views of skill acquisition: divergent or complementary? *Motor control*, 9(3), 217-241.

Araújo, D., Davids, K., Bennett, S.J., Button, C. & Chapman, G. (2004), Emergence of sport skills under constraints, Emergence of sport skills under constraints. Skill Acquisition in Sport: Research, Theory and Practice. 409-433.

Araújo, D., Davids, K. & Hristovski, R. (2006), The ecological dynamics of decision making in sport, *Psychology of Sport and Exercise*, 7(6), 653-676.

Araújo, D. & Davids, K. (2011). What exactly is acquired during skill acquisition, *Journal of Consciousness Studies*, 18(3-4), 7-23.

Araújo, D., Silva, P. & Ramos, J.P. (2014), Affordance-based decisions guide team synergies during match performance, *Research in Physical Education, Sport and Health*, 3(1), 19-26.

Araújo, D., Silva, P., and Davids, K. (2015). Capturing group tactical behaviours in expert team players, *Routledge Handbook of Sport Exercise*, eds J. Baker, and D. Farrow, (London: Routledge), 209–220.

Araújo, D. & Davids, K. (2016), Team synergies in sport: Theory and measures, *Frontiers in Psychology*, 21(7).

Badami, R., VaezMousavi, M., Wulf, G. & Namazizadeh, M. (2012), Feedback about more accurate versus less accurate trials: Differential effects on self-confidence and activation, *Research Quarterly for Exercise and Sport,* 83(2), 1-8.

Baker, J., Côté, J. & Abernethy, B. (2003), Learning from the experts: Practice activities of expert decision makers in sport, *Research Quarterly for Exercise and Sport*, 74(3), 342-347.

Baker, J., & Farrow, D. (2015). Routledge handbook of sport expertise. Routledge.

Bates, D., Maechler, M., Bolker, B. & Walker, S. (2015), Fitting Linear Mixed-Effects Models Using lme4, *Journal of Statistical Software*, 67(1), 1-48. DOI:10.18637/jss.v067.i01.

Batista, J., Goncalves, B., Sampaio, J., Castro, J., Abade, E. & Travassos, B. (2019), The influence of coaches' instruction on technical actions, tactical behaviour, and external workload in football small-sided games, *Montenegrin Journal of Sports Science and Medicine*, 1, 29-36.

Bennett, K.J.M. & Fransen, J. (2022), The difference between technique and skill in sports practice, *The Journal of Sport and Exercise Science*, *In Review*.

Ben-Shachar, M.S., Makowski D. & Lüdecke, D. (2020), Compute and interpret indices of effect size. CRAN. Available from https://github.com/easystats/effectsize.

Bernstein, N.A. (1967). The control and regulation of movements. London: Pergamon Press.
Bompa TO. (1999), Periodization Training: Theory and Methodology, (4th ed.). Champaign, IL: Human Kinetics.

Bonney, N., Berry, J., Ball, K., & Larkin, P. (2020), Can match play kicking and physical performance outcomes be replicated in an Australian football small-sided game? *Science and Medicine in Football*, 4(4), 314–321.

Bourbousson, J., Deschamps, T., & Travassos, B. (2014), From players to teams: Towards a multi-level approach of game constraints in team sports, *International Journal of Sports Science & Coaching*, 9(6), 1393–1406.

Braham, C. & Small, M. (2018), Complex networks untangle competitive advantage in Australian football, *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 28(5).

Browne, P.R., Sweeting, A.J., Davids, K. & Robertson, S. (2019), Prevalence of interactions and influence of performance constraints on kick outcomes across Australian Football tiers: Implications for representative practice designs, *Human Movement Science*, 66, 621-630.

Browne, P.R., Woods, C.T., Sweeting, A.J. & Robertson, S.J. (2020), Applications of a working framework for the measurement of representative learning design in Australian football, *PLoS ONE*, 15(11).

Brunswik, E. (1956). Perception and the representative design of psychological experiments. Univ of California Press.

Brunswik, E. (1952). The conceptual framework of psychology. Psychological Bulletin, 49(6), 654-656.

Causer, J., & Williams, A. M. (2013). Improving anticipation and decision making in sport. In T. McGarry, P. O'Donoghue, & J. Sampaio (Eds.), Routledge handbooks. Routledge handbook of sports performance analysis (p. 21–31). Routledge/Taylor & Francis Group.

Chiviacowsky, S., Wulf, G., Wally, R. & Borges, T. (2009), Knowledge of results after good trials enhances learning in older adults, *Research Quarterly for Exercise and Sport*, 80(3), 663-668.

Chow, J.Y., Davids, K., Button, C., Shuttleworth, R., Renshaw, I. & Araújo, D. (2007), The role of nonlinear pedagogy in physical education, *Review of Educational Research*, 77(3), 251-278.

Chow, J.Y., Davids, K., Button, C. & Renshaw, I. (2016), *Nonlinear Pedagogy in Skill Acquisition: An Introduction,* Routledge, New York.

Clark, J.E. (1995), On becoming skilful: Patterns and constraints, *Research Quarterly for Exercise and Sport,* 66(3), 173-183.

Clemente, F.M., Owen, A., Serra-Olivares, J., Correia, A., Sequeiros, J.B., Silva, G.M.F. & Martins, F.M.L. (2018), The effects of large-sided soccer training games and pitch size manipulation on time–motion profile, spatial exploration and surface area: Tactical opportunities, *Journal of Sports Engineering and Technology*, 232(2), 1-20.

Cohen, J. (1988). Statistical power analysis for the behavioural sciences (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

Corbett, D. M., Bartlett, J. D., O'Connor, F., Back, N., Torres-Ronda, L., & Robertson, S. (2017), Development of physical and skill training drill prescription systems for elite Australian rules football. *Science and Medicine in Football*, 2(1), 51–57.

Correira, V., Araujo, D., Craig, C. & Passos, P. (2011), Prospective information for pass decisional behaviour in rugby union, *Human Movement Science*, 30, 984-997.

Côté, J., Baker, J. & Abernethy, B. (2003), Sport specific training, deliberate practice and the development of expertise in team ball sports, *Journal of Applied Sport Psychology*, 15, 12–25.

Côté, J., Baker, J., & Abernethy, B. (2007). Practice and play in the development of sport expertise. In G. Tenenbaum & R. C. Eklund (Eds.), *Handbook of sport psychology* (p. 184–202; 3RD Ed.). John Wiley & Sons Inc.

Côté, J. & Gilbert, W. (2009), An integrative definition of coaching effectiveness and expertise, *International Journal of sports Science and Coaching*, 4(3), 307-323.

Cushion, C.J., Armour, K.M. & Jones, R.L. (2003), Coach education and continuing professional development: Experience and learning to coach, *Quest*, 55(3), 215-230.

Davids, K., Araújo, D., Shuttleworth, R. & Button, C. (2003a), Acquiring skill in sport: A constraints-led perspective, *International Journal of Computer Science in Sport*, 3(3), 31-39.

Davids, K., Glazier, P., Araújo, D. & Bartlett, R. (2003b), Movement systems as dynamical systems: The functional role of variability and its implications for sports medicine, *Sports Medicine*, 33(4), 245-260.

Davids, K., Button, C., & Bennett, S. (2008). Dynamics of skill acquisition: A constraints-led approach. Champaign, IL: Human Kinetics.

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

Dawson, B., Hopkinson, R., Appleby, B., Stewart, G., & Roberts, C. (2004), Player movement patterns and game activities in the Australian Football League, *Journal of Science and Medicine in Sport*, 7(3), 278–291.

Duarte, R., Araújo, D., Correira, V., Davids, K., Marques, P & Richardson, M.J. (2013), Competing together: Assessing the dynamics of team-team and player-team synchrony in professional association football, *Human Movement Science*, 32, 555-566.

Edwards, W.H. (2010). Motor Learning and Control: From Theory to Practice, Wadsworth, OH: Cengage Learning.

Ericsson, K. A., & Smith, J. (Eds.). (1991), Toward a general theory of expertise: Prospects and limits. Cambridge University Press.

Ericsson, K.A., Krampe, R.T. & Tesch-Römer, C. (1993), The role of deliberate practice in the acquisition of expert performance, *Psychological Review*, 100(3), 363–406.

Esteves, P.T., Araújo, D., Davids, K., Vilar, L., Travassos, B. & Esteves, C. (2012), Interpersonal dynamics and relative positioning to scoring target of performers in 1 vs. 1 sub-phases of team sports, *Journal of Sports Sciences*, 30(12), 1285-1293.

Expert, P., Evans, T.S., Blondel, V.D., Lambiotte, R. (2011), Uncovering space-independent communities in spatial networks, *Proceedings of the National Academy of Sciences of the United States of America*, 108(19), 7663-7668.

Fahey-Gilmour, J., Dawson, B., Peeling, P., Heasman, J. & Rogalski, B. (2019), Multifactorial analysis of factors influencing elite Australian football match outcomes: a machine learning approach, *International Journal of Computer Science in Sport*, 18(3), DOI: https://doi.org/10.2478/ijcss-2019-0020.

Fajen, BR., Riley, M.A. & Turvey, M.T. (2008), Information, Affordances, and the control of action in sport, *International Journal of Sport Psychology*, 40, 79-107.

Farrow, D., Pyne, D.B. & Gabbett, T. (2008), Skill and physiological demands of open and closed training drills in Australian football, *International Journal of Sports Science and Coaching*, 3(4), 485-495.

Farrow, D., Baker, J. & MacMahon, C. (2013), *Developing sport expertise: Researchers and coaches put theory into practice*, London: Routledge.

Farrow, D. & Robertson, S. (2017), Development of a Skill Acquisition Periodisation Framework for High-Performance Sport, *Sports Medicine,* 47(6), 1043-1054.

Fitts, P. M., & Posner, M. I. (1967). Human performance. Oxford, England: Brooks/Cole.

Fewell, J.H., Armbruster, D., Ingraham, J., Peterson, A. & Waters, J.S. (2012), Basketball Teams as Strategic Networks, *PLoS ONE*, 7(11).

Fleay, B., Joyce, C., Banyard, H. & Woods, C.T. (2018). Manipulating field dimensions during small-sided games impacts the technical and physical profiles of Australian footballers, *Journal of Strength and Conditioning Research*, 32(7), 2039-2044.

Folgado, H., Lemmink, K.A.P.M., Frencken, W., & Sampaio, J. (2014), Length, width and centroid distance as measures of team's tactical performance in youth football, *European Journal of Sport Science*, 14(1), 487-492.

Ford, P.R., Yates, I. & Williams, A.M. (2010), An analysis of practice activities and instructional behaviours used by youth soccer coaches during practice: Exploring the link between science and application, *Journal of Sports Sciences*, 28(5), 483-495.

Fransen, J., Pepping, G.J. & MacMahon, C. (2021), Introductory statement for The Journal of Sport and Exercise Science special issue: Skill acquisition – research and practice, *The Journal of Sport and Exercise Science*, 5(1), 1-2.

Fransen, J., Tribolet, R., Sheehan, W.B., McBride, I., Novak, A. & Watsford, M.L. (2021), Cooperative passing network features are associated with successful match outcomes in the Australian Football League, *International Journal of Sports Sciences and Coaching*, 10.1177/17479541211052760.

Ghodsian, D., Bjork, R.A. & Benjamin, A.S. (1997). Evaluating training during training: Obstacles and opportunities, Training for 21st Century Technology: Applications of Psychological Research, pp. 63-88. Washington, DC. American Psychological Association.

Gibson, J.J. (1979), The Ecological Approach to Visual Perception. Boston: Houghton Mifflin.

Gilbert, W.D. and Trudel, P., (2004), Analysis of Coaching Science Research Published from 1970-2001, *Research Quarterly for Exercise and Sport*, 75, 388-399.

Gladwell, M. 2005, Blink: The Power of Thinking Without Thinking, Back Bay Books, New York.

Goldhammer, F., Naumann, J., Stelter, A., Tóth, K., Rölke, H. & Eckhar, K. (2014), The Time on Task Effect in Reading and Problem Solving Is Moderated by Task Difficulty and Skill: Insights from a Computer-Based Large- Scale Assessment, *Journal of Educational Psychology*, 106(3), 608-626.

Gonçalves, B., Coutinho, D., Santos, S., Lago-Penas, C., Jiménez, S., Sampaio, J., & Hayasaka, S. (2017), Exploring team passing networks and player movement dynamics in youth association football, *PLoS One*, 12(1).

Gorman, A.D. & Maloney, M.A. (2016). Representative design: Does the addition of a defender change the execution of a basketball shot? *Psychology of Sport and Exercise*, 27, 112-119.

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

Gray, R. (2020), Comparing the constraints led approach, differential learning and prescriptive instruction for training opposite-field hitting in baseball, *Psychology in Sport & Exercise*, DOI:10.1016/j. psychsport.2020.101797.

Greenwood, D., Davids, K. & Renshaw, I. (2012), How elite coaches experiential knowledge might enhance empirical research on sport performance, *International Journal of Sport Science and Coaching*, 7(2), 411-422.

Greenwood, D., Davids, K., & Renshaw, I. (2016), The role of a vertical reference point in changing gait regulation in cricket run-ups, *European Journal of Sport Science*, 16(7), 794–800.

Groom, R. & Nelson, L. The application of video-based performance analysis: the coach supporting athlete learning. In: P Potrac, W Gilbert and J Denison (eds) Routledge handbook of sports coaching. Oxon: Routledge, 2013, pp.96–107.

Grund, T.U. (2012), Network structure and team performance: the case of English premier league soccer teams. *Social Networks*, 34(4), 682–690.

Guadagnoli, M.A. & Lee, T.D. (2004), Challenge point: a framework for conceptualising the effects of various practice conditions in motor learning, *Journal of Motor Behaviour*, 36(2), 212-224.

Gudmundsson, J. & Horton, M. (2017), Spatio-temporal analysis of team sports. ACM Computer Science (CSUR). 50(2), 22.

Güllich, A. (2018), “Macro-structure” of developmental participation histories and “micro-structure” of practice of German female world-class and national-class football players, *Journal of Sports Sciences*, 37(12), 1347-1355.

Halperin, I., Chapman, D.W., Martin, D.T., Abbiss, C. & Wulf, G. (2016), Coaching cues in amateur boxing: An analysis of ringside feedback provided between rounds of competition, *Psychology of Sport and Exercise*, 25, 44-50.

Handford, C., Davids, K., Bennett, S., & Button, C. (1997), Skill acquisition in sport: Some applications of an evolving practice ecology, *Journal of Sports Sciences*, 15(6), 621-640.

Harrison, X.A., Donaldson, L., Correa-Cano, M.E., Evans, J., Fisher, D.N., Goodwin, C.E.D., Robinson, B.S., Hodgson, D.J. & Inger, R. (2018), A brief introduction to mixed effects modelling and multi-model inference in ecology, *PeerJ*, DOI: doi.org/10.7717/peerj.4794.

Helsen, W.F., Starkes, J.L., & Hodges, N.J. (1998), Team sports and the theory of deliberate practice, *Journal of Sport and Exercise Psychology*, 20, 12-34.

Henderson, M., Fransen, J., McGrath, J.J., Harries, S.K., Poulos, N. & Coutts, A.J. (2019), Situational factors affecting rugby sevens match performance, *Science and Medicine in Football,* 3(4), 275-280.

Hill-Haas, S.V., Dawson, B., Impellizeri, F.M. & Coutts, A.J. (2011), Physiology of small-sided games training in football: A systematic review, *Sports Medicine*, 41(3), 199-220.

Hodges, N.J., & Williams, A.M. (2012). Skill acquisition in sport: Research, theory and practice. 3rd Ed. London, UK: Routledge.

Hoffman, D. T., Dwyer, D. B., Bowe, S. J., Bowe, S. J., Clifton, P., & Gastin, P. B. (2019), Is injury associated with team performance in elite Australian football? 20 years of player injury and team performance data that include measures of individual player value, *British Journal of Sports Medicine*, 54(8), 475–479.

Impellizeri, F.M., Rampinini, E. & Marcora, S.M. (2005), Physiological assessment of aerobic training in soccer, *Journal of Sports Sciences,* 23(6), 583-592.

Ireland, D., Dawson, B., Peeling, P., Lester, L., Heasman, J. & Rogalski, B. (2019), Do we train how we play? Investigating skill patterns in Australian football, *Science and Medicine in Football*, 3(4), 265-274.

Isabel, M., Antonio, S., Antonio, R., Felismina, P. & Michel, M. (2008), A systematic observation of youth amateur volleyball coaches behaviours, *International Journal of Applied Sports Sciences*, 20(2), 37-58.

JASP Team (2020). JASP (Version 0.13.1)[Computer software].

Johnston, R.D., Black, G.M., Harrison, P.W., Murray, N.B. & Austin, D.J. (2018), Applied sport science of Australian football: A systematic review, *Sports Medicine*, 48(7), 1673-1694.

Kahneman, D. & Klein, G. (2009), Conditions for Intuitive Expertise: A failure to disagree, *American Psychologist*, 64(6), 515-526.

Kay, B.A. (1988), The dimensionality of movement trajectories and the degrees of freedom problem: A tutorial, *Human Movement Science*, 7, 343-364.

Keele, S.W., & Posner, M.I. (1968). Processing of feedback in rapid movements, *Journal of Experimental Psychology*, 77, 353-363.

Kelso, J.A.S. (1981). *Contrasting perspectives on order and regulation in movement*. In J. Long & A. Baddeley (Eds.), Attention and performance IX (pp. 437-458). Hillsdale, NJ: LEA.

Kelso, J.A.S. (1984), Phase transitions and critical behaviour in human bimanual coordination, *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology,* 246, R1000-1004.

Kelso, J.A. (2012), Multistability and metastability: understanding dynamic coordination in the brain, *Philosophical Transactions of the Royal Society of London*, 367(1591), 906-918.

Kugler, P.N., Kelso, S.J.A. & Turvey, M.T. (1980), On the concept of coordinative structures as dissipative structures: I. Theoretical lines of convergence, *Advances in Psychology*, 1, 3-47.

Koo, T.K. & Li, M.Y. (2016), A guidelines of selecting and reporting intraclass correlation coefficients for reliability research, *Journal of Chiropractic Medicine*, 15, 155-163.

Kugler, P.N., Kelso, S.J.A. & Turvey, M.T. (1980), On the concept of coordinative structures as dissipative structures: I. Theoretical lines of convergence, *Advances in Psychology*, 1, 3-47.

Kuznetsova, A., Brockhoff, P.B. & Christensen, R.H.B. (2017), lmerTest Package: Tests in Linear Mixed Effects Models, *Journal of Statistical Software*, 82(13), 1-26. DOI: 10.18637/jss.v082.i13 (URL: https://doi.org/10.18637/jss.v082.i13).

Lazarus, B.H., Hopkins, W.G., Stewart, A.M. & Aughey, R.J. (2017), Factors affecting match outcome in elite Australian football: A 14-year analysis, *International Journal of Sports Physiology and Performance*, 13(2), 140-144.

Lenth, R.V. (2021). emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version, 1.6.3. https://CRAN.R-project.org/package=emmeans

Low, B., Coutinho, D., Gonçalves, B., Rein, R., Memmert, D. & Sampaio, J. (2019), A Systematic Review of Collective Tactical Behaviours in Football Using Positional Data, *Sports Medicine*, 50, 343-385.

Lyle, J. & Cushion, C. (2010), Sports Coaching: Professionalisation and practice, 1st Ed. Churchill Livingstone.

Madden, C. C. (1995). The Nature and Relative Importance of Coaching Communications in Australian Rules Football, *International Journal of Sport Psychology*, 26(4), 524–540.

Magill, R.A. (1994), The Influence of Augmented Feedback on Skill Learning Depends on Characteristics of the Skill and the Learner, *Quest*, 46, 314-327.

Magill & Anderson, (2014), Motor Learning and Control: Concepts and Applications, 10th Ed. McGraw-Hill Australia.

Mahmoud, M.S. (1977), Multilevel systems control and applications: A survey, *Institute of Electrical and Electronics Engineers*, 7(3), 125-143.

Maloney, M. A., Renshaw, I., Headrick, J., Martin, D. T., & Farrow, D. (2018), Taekwondo fighting in training does simulate the affective and cognitive demands of competition: Implications for behaviour and transfer, *Frontiers in Psychology*, 9(25).

Markland, R. & Martinek, T.J. (1988), Descriptive analysis of coach augmented feedback given to high school varsity female volleyball players, *Journal of Teaching in Physical Education*, 7, 289-301.

Mason, P.H. (2010), Degeneracy at multiple levels of complexity, *Biological Theory*, 5, 277-288.

Mason, R.J., Farrow, D. & Hattie, J.A.C. (2020), An analysis of in-game feedback provided by coaches in an Australian Football League competition, *Physical Education and Sport Pedagogy,* 25(5), 464-477.

McCalman, W., Crowley-McHattan, Z.J., Fransen, J. & Bennett, K.J.M. (2021), Skill assessments in youth soccer: A scoping review, *Journal of Sports Sciences*, 40(6), 667-695.

Mendes, B., Clemente, F.M. & Maurício, N. (2018), Variance in prominence levels and in patterns of passing sequences in elite and youth soccer players: A network approach, *Journal of Human Kinetics*, 61, 141-153.

Moreira, A., Bilsborough, J.C., Sullivan, C.J., Ciancosi, M., Aoki, M.S. & Coutts, A.J. (2014), The training periodisation of professional Australian football players during an entire AFL season, *International Journal of Sports Physiology and Performance,* 10(5), 566-571.

Moreira, P.E.D., Barbosa, G.F., Murta, C.D.C.F., Morales, J.C.P., Bredt, S.D.G.T., Praça, G.M. & Greco, P.J. (2019), Network analysis and tactical behaviour in soccer small-sided and conditioned games: influence of absolute and relative playing areas on different age categories, *International Journal of Performance Analysis in Sport*, 20(1), 64-77.

Newell, K.M., Morris, L.R. & Scully, D.M. (1985), Augmented information and the acquisition of skill in physical activity, *Exercise and Sport Sciences Reviews*, 13, 235-261.

Newell, K. M. (1986), Constraints on the development of coordination. In M. G. Wade, & H. T. A. Whiting (Eds.). Motor development in children: aspects of coordination and control (pp. 341–360). Dordrecht, The Netherlands: Martinus Nijhoff.

Nicholson, D.E. & Schmidt, R.A. (1991), Feedback schedules to enhance training effectiveness, Proceedings of the Human Factors Society, 35th Annual Meeting, Santa Monica, CA.

Olthof, S. B. H., Frencken, W. G. P., & Lemmink, K. A. P. M. (2019), When something is at stake: Differences in soccer performance in 11 vs 11 during official matches and training games, *Journal of Strength and Conditioning Research*, 33(1), 167–173.

Ometto, L., Vasconcellos, F.V.A., Cunha, F.A., Teoldo, I., Souza, C.R.B., Dutra, M.B., O'Sullivan, M. & Davids, K. (2018), How manipulating task constraints in small-sided and conditioned games shapes emergence of individual and collective tactical behaviours in football: A systematic review, *International Journal of Sports Science and Coaching*, 13(6), 1200-1214.

Otte, F.W., Millar, S-K. & Klatt, S. (2020), Skill training periodisation in "Specialist" sports coaching – An introduction of the "PoST" framework for skill development, *Frontiers in Sports and Active Living*, 1(61), DOI: 10.3389/fspor.2019.00061.

Partington, M., Cushion, C.J., Cope, E. & Harvey, S. (2015), The impact of video feedback on professional youth football coaches' reflection and practice behaviour: a longitudinal investigation of behaviour change, *Reflective Practice*, 16(5), 700-716.

Passos, P., Araújo, D., Davids, K. & Shuttleworth, R. (2008), Manipulating constraints to train decision making in rugby union, *International Journal of Sports Science and Coaching*, 3(1), 125-140.

Passos, P., Araújo, D. & Davids, K. (2013), Self-organisation processes in field-invasion team sports: Implications for leadership, *Sports Medicine*, 43, 1-7.

Pill, S. (2013), Developing theoretically informed practice: the forward press in Australian football as an example of the dynamics of a complex system, Proceedings of the 28th ACHPER International Conference, Melbourne 2013.

Pill, S. (2014), Informing Game Sense pedagogy with constraints led theory for coaching in Australian football, *Sports Coaching Review*, 3(1), 46-62.

Pill, S. (2015), Using Appreciative Inquiry to explore Australian football coaches' experience with game sense coaching, *Sport, Education and Society*, 20(6), 799-818.

Pinder, R. A., Renshaw, I., & Davids, K. (2009), Information-movement coupling in developing cricketers under changing ecological practice constraints, *Human Movement Science*, 28(4), 468–479.

Pinder, R.A., Davids, K., Renshaw, I. & Araújo, D. (2011), Representative learning design and functionality of research and practice in sport, *Journal of Sport and Exercise Psychology*, 33, 146-155.

Proteau, L. (1992). On the specificity of learning and the role of visual information for movement control. In L. Proteau & D. Elliott (Eds.), *Vision and motor Control* (pp. 67- 103). Amsterdam: North Holland.

R Core Team. R: A language and environment for statistical computing. *R Foundation for Statistical Computing.* 2019; Vienna(Austria): https://www.R- project.org/.

Rangeon, S., Gilbert, W., Trudel, P. and Côté, J., Coaching Science in North America, Paper Presented at the 12th ISSP World Congress of Sport Psychology, Marrakesh, Morocco, 2009, June.

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

Rennie, M.J., Watsford, M.L., Kelly, S.J., Bush, S., Spurrs, R.W., & Austin, D.J. (2020), Phases of match play in professional Australian football: Distribution of physical and technical performance, *Journal of Sports Sciences*, 38(14), 1682-1689.

Renshaw, I., Chow, J.Y., Davids, K. & Hammond, J. (2010), A constraints-led perspective to understanding skill acquisition and game play: a basis for integration of motor learning theory and physical education praxis? *Physical Education and Sport Pedagogy*, 15(2), 117-137.

Renshaw, I., Davids, K., Phillips, E. & Kerherve, H. (2011), "Developing Talent in Athletes as Complex Neurobiological Systems." In Talent Identification and Development in Sport: International Perspectives, edited by Joe Baker, Stephen Cobley, and Jorg Schorer, 64–80. London: Routledge.

Renshaw, I., Araújo, D., Button, C., Chow, J.Y., Davids, K. & Moy, B. (2015), Why the constraints-led approach is not teaching games for understanding: A clarification, *Physical Education and Sport Pedagogy*, 21(5), 459-480.

Renshaw, I., & Gorman, A. D. (2015), Challenges to capturing expertise in field settings. In J. Baker & D. Farrow (Eds.), Routledge handbook of sport expertise (pp. 282–294). Routledge/Taylor & Francis Group.

Renshaw, I., Davids, K., Newcombe, D., & Roberts, W. (2019), The Constraints led approach: Principles for sports coaching and practice design, Routledge, 2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN.

Ribeiro, J., Silva, P., Duarte, R., Davids, K. & Garganta, J. (2017), Team Sports Performance Analysed Through the Lens of Social Network Theory: Implications for Research and Practice, *Sports Medicine*, 47(9), 1-8.

Robertson, S., Gupta, R., & McIntosh, S. (2016), A method to assess the influence of individual player performance distribution on match outcome in team sports, *Journal of Sports Sciences,* 34(19), 1893–1900.

Robertson, S., Back, N. & Bartlett, J.D. (2016), Explaining match outcome in elite Australian rules football using team performance indicators, *Journal of Sports Sciences*, 34(7), 637-644.

Robertson, S. & Joyce, D. (2018), Evaluating strategic periodisation in team sport, *Journal of Sports Sciences*, 36(3), 279-285.

Robertson, S., Spencer, B., Back, N. & Farrow, D. (2019), A rule induction framework for the determination of representative learning design in skilled performance, *Journal of Sports Sciences*, 37(11), 1280-1285.

Roca, A. & Ford, P.R. (2020), Decision-making practice during coaching sessions in elite youth football across European countries, *Science and Medicine in football*, 4(4), 263-268.

Salmoni, A.W., Schmidt, R.A. & Walter, C.B. (1984), Knowledge of results and motor learning: A review and critical appraisal, *Psychological Bulletin*, 95(3), 355-386.

Schmidt, R.A. (1982). Motor control and learning: A behavioural emphasis. Champaign, IL: Human Kinetics Publishers.

Schmidt, R. (1991), Frequent Augmented Feedback Can Degrade Learning: Evidence and Interpretations, Tutorials in Motor Neuroscience, Stelmach, G.E. & Requin, J. Dordrecht Kluwer.

Schmidt, R. & Wrisburg, C.A. (2000), Motor learning and performance: A problem-based learning approach. Champaign, IL: Human Kinetics.

Schmidt, R., & Wrisberg, C.A. (2004), Motor learning and performance (3rd Ed.). Champaign, IL: Human Kinetics.

Seifert, L., Button, C. & Davids, K. (2013), Key properties of expert movement systems in sport: An ecological dynamics perspective, *Sports Medicine*, 43, 167-178.

Seifert, L., Komar, J., Crettenhead, F. & Millet, G. (2014), Coordination pattern adaptability: Energy cost of degenerate behaviours, *PLoS One*, 25(9).

Sheehan, W.B., Tribolet, R., Watsford, M.L., Novak., A.R., Rennie, M.J. & Fransen, J. (2019), Using cooperative networks to analyse behaviour in professional Australian football, *Journal of Science and Medicine in Sport*, 23(3), 291-296.

Sheehan, W.B., Tribolet, R., Watsford, M.L., Novak, A.R., Rennie, M. & Fransen, J. (2020), Improving the interpretation of skill indicators in professional Australian Football, *Journal of Science and Medicine in Sport*, 23(9), 872-878.

Sheehan, W. B., Tribolet, R., Watsford, M. L., Novak, A. R., Rennie, M. J., & Fransen, J. (2021a), Tactical analysis of individual and team behaviour in professional Australian football, *Science and Medicine in Football*, 6(2), 172-180.

Sheehan, W. B., Tribolet, R., Watsford, M. L., Novak, A. R., Rennie, M. J., & Fransen, J. (2021b), An assessment of physical and spatiotemporal behaviour during different phases of match play in professional Australian football, *Journal of Sports Sciences*, 39(19), 2232-2241.

Silva, P., Garganta, J., Araújo, D., Davids, K. & Aguiar, P. (2013), Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports, *Sports Medicine*, 43, 765-772.

Silva, P., Duarte, R., Sampaio, J., Aguiar, P., Davids, K., Araújo, D. & Garganta, J. (2014), Field dimensions and skill level constrain team tactical behaviours in small-sided and conditioned games in football, *Journal of Sports Sciences*, 32(20), 1-9.

Silva, P., Vilar, L., Davids, K., Araújo, D. Garganta, J. (2016), Sports teams as complex adaptive systems: manipulating player numbers shapes behaviours during football small-sided games, *SpringerPlus*, 5, 1-10.

Sparrowe, R.T., Liden, R.C., Wayne, S. & Kraimer, M.L. (2001), Social Networks and the Performance of Individuals and Groups, *The Academy of Management Journal*, 44(2).

Steel, K.A., Harris, B., Baxter, D., King, M. & Ellam, E. (2014), Coaches, athletes, skill acquisition specialists: A case of misrecognition, *International Journal of Sports Science and Coaching*, 9(2), 376-378.

Stevens, J.P. (1984), Outliers and influential data points in regression analysis, *Psychological Bulletin*, 95(2), 334-344.

Stewart, M.F., Mitchell, H. & Stavros, C. (2007), Moneyball Applied: Econometrics and the Identification and Recruitment of Elite Australian Footballers, *International Journal of Sport Finance*, 2(4), 231-248.

Sullivan, C., Bilsborough, J.C., Cianciosi, M., Hocking, J., Cordy, J.T. & Coutts, A.J. (2014), Factors affecting match performance in professional Australian football, *International Journal of Sports Physiology and Performance,* 9(3), 561-566.

Svilar, L., Castellano, J., & Jukic, I. (2019), Comparison of 5v5 training games and match-play using microsensor technology in elite basketball, *Journal of Strength and Conditioning Research*, 33(7), 1897–1903.

Swinnen, S., Schmidt, R.A., Nicholson, D.E. & Shapiro, D.C. (1990), Information feedback for skill acquisition: Instantaneous knowledge of results degrades learning, *Journal of Experimental Psychology: Learning, Memory and Cognition*, 16, 706-716.

Taylor, N., Gastin, P.B., Mills, O. & Tran, J. (2020), Network analysis of kick-in possession chains in elite Australian football, *Journal of Sports Sciences*, 38(9), 1053-1061.

Teune, B., Spencer, B., Sweeting, A. J., Woods, C. W., Inness, M., & Robertson, S. (2021), Application of a continuous pressure metric in Australian football, *Journal of Sports Sciences*, 39(13), 1548–1554.

Tinning, R. (1982). Improving coaches' instructional effectiveness, *Sports Coach*, 5(4), 37-41.

Todorov, E. & Jordan, M.I. (2002), Optimal feedback control as a theory of motor coordination, *Nature Neuroscience*, 5(11), 1226-1235.

Travassos, B., Duarte, R., Vilar, L., Davids, K. & Araújo, D. (2012), Practice task design in team sports: Representativeness enhanced by increasing opportunities for action, *Journal of Sports Sciences*, 30(13), 1447-1454.

Travassos, B., Vilar, L., Araújo, D., & McGarry, T. (2014), Tactical performance changes with equal vs unequal numbers of players in small-sided football games, *International Journal of Performance Analysis in Sport*, 14, 594-605.

Tribolet, R., Sheehan, W. B., Watsford, M. L., & Fransen, J. (2021), How does practice change across the season? A descriptive study of the training structures and practice activities implemented by a professional Australian football team, *International Journal of Sports Science & Coaching*. 17(1), 63-72.

Tribolet, R., Sheehan, W.B., Novak, A.R., Watsford, M.L. & Fransen, J. (2021), Factors associated with cooperative network connectedness in a professional Australian football small-sided game, *Science and Medicine in Football*, 6(4), 511-518.

Turvey, M. T. (1990), Coordination, *American Psychologist*, 45(8), 938–953.

Turvey, M.T. and Shaw, R. (1999) Ecological Foundations of Cognition I: Symmetry and Specificity of Animal-Environment Systems, *Journal of Consciousness Studies*, 6, 95-110.

Verhoeff, W.J., Millar, S.K., Oldham, A.R.H. & Cronin, J. (2020), Coaching the power clean: A constraints-led approach, *Strength and Conditioning Journal*, 42(2), 16-25.

Walsh, J. & Jureidini, J. (2016). Language as a Key Resource for the Football Coach: A Case Study of In-Game Coaching at One Australian Rules Club, *The Discourse of Sport: Analyses from Social Linguistics*, edited by D. Caldwell, J. Walsh, E. W. Vine, and J. Jureidini, 13–33. Oxon: Routledge. Challenging tradition, *Journal of Sports Sciences*, 23(6), 637-650.

Williams, A.M. (2000), Perceptual skill in soccer: Implications for talent identification and development, *Journal of Sports Sciences*, 18, 737-750.

Williams, A.M. & Hodges, N.J. (2005), Practice, instruction and skill acquisition in soccer: Challenging tradition, *Journal of Sports Sciences*, 23(6), 637-650.

Williams, A.M., Fawver, B. & Hodges, N.J. (2017), Using the 'Expert Performance Approach' as a Framework for Improving Understanding of Expert Learning, *Frontline Learning Research,* 5(3), 139-154.

Woods, C.T., Robertson, R. & Collier, N.F. (2017), Evolution of game-play in the Australian Football League from 2001 to 2015, *Journal of Sports Sciences*, 35(19), 1879-1887.

Woods, C. T., McKeown, I., Shuttleworth, R. J., Davids, K., & Robertson, S. (2019a), Training programme designs in professional team sport: An ecological dynamics exemplar, *Human Movement Science*, 66(66).

Woods, C.T., Jarvis, J. & McKeown, I. (2019b), Differences between Elite and Semi-Elite Australian Football Conceptualised through the Lens of Ecological Dynamics, *Sports*, 7(7).

Woods, C. T., McKeown, I., O'Sullivan, M., Robertson, S., & Davids, K. (2020a), Theory to practice: Performance preparation models in contemporary high-level sport guided by an ecological dynamics framework, *Sports Med Open*, 6(1).

Woods, C., McKeown, I., Rothwell, M., Araújo, D., Robertson, S. & Davids, K. (2020b), Sport practitioners as sport ecology designers: How ecological dynamics has progressively changed perceptions of skill 'acquisition' in the sporting habitat, *Frontiers in Psychology*, 24(11), DOI: 10.3389/fpsyg.2020.00654.

Wulf, G., McConnel, N., Gartner, M. & Schwarz, A. (2002), Enhancing the learning of sport skills through external-focus feedback, *Journal of Motor Behaviour*, 34(2), 171-182.

Wulf, G. & Lewthwaite, R. (2016), Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning, *Psychonomic Bulletin and Review*, 23(5), 1382-1414.

Voss, M.W., Kramer, A.F., Basak, C., Prakash, R.S., & Roberts, B. (2010), Are expert athletes' 'expert' in the cognitive laboratory? A meta-analytic review of cognition and sport expertise, *Applied Cognitive Psychology, 24*(6), 812–826.

Young, C.M., Luo, W., Gastin, P., Tran, J. & Dwyer, D.B. (2019), The relationship between match performance indicators and outcome in Australian football, *Journal of Science and Medicine in Sport*, 22(4), 467-471.

Young, C.M., Luo, W., Gastin, P.B. & Dwyer, D.B. (2020), Understanding the relative contribution of technical and tactical performance to match outcome in Australian football, *Journal of Sports Sciences*, 38(6), 676-681.

Yue, Z., Broich, H., Seifriz, F., & Mester, J. (2008), Mathematical Analysis of a Soccer Game. Part I: Individual and Collective Behaviours. *Studies in Applied Mathematics*, 121(3), 223–243.

Chapter 12 | Appendices

Appendix A: University Ethics Approval

Dear Applicant,

Thank you for your response to the Committee's comments for your project titled, "**A constraints-led approach to practice in Australian Football**". The Committee agreed that this application now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy (http://www.gsu.uts.edu.au/policies/research-management-policy.html).

Your approval number is UTS HREC REF NO. ETH19-3597.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

• Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.

• The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat (Research.Ethics@uts.edu.au).

• The Principal Investigator will notify the UTS HREC of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions can be found at https://staff.uts.edu.au/topichub/Pages/Researching/Research%20Ethics%20and%20Integrity/Human%20research%20ethics/Post-approval/post-approval.aspx#tab2.

• The Principal Investigator will promptly report adverse events to the Ethics Secretariat (Research.Ethics@uts.edu.au). An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.

• The Principal Investigator will report to the UTS HREC annually and notify the HREC when the project is completed at all sites. The Principal Investigator will notify the UTS HREC of any plan to extend the duration of the project past the approval period listed above through the progress report.

• The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).

• The Principal Investigator will notify the UTS HREC of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

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

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

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

Yours sincerely,

A/Prof Beata Bajorek
Chairperson
UTS Human Research Ethics Committee
C/- Research Office
University of Technology Sydney
E: Research.Ethics@uts.edu.au

Appendix B: Published Manuscripts

Check for updates

Original Investigation

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How does practice change across the season? A descriptive study of the training structures and practice activities implemented by a professional Australian football team

Rhys Tribolet, William Bradshaw Sheehan, Andrew Roman Novak, Mark Langley Watsford and Job Fransen

Abstract

There is limited research investigating objective practice monitoring in team sports. This observational study examined the practice activities used by eight professional coaches across 72 different practice sessions in one season within a professional Australian football team. This study aimed to evaluate the extent to which these practice types differed from those shown to facilitate skill acquisition in team sports. Across the whole season (pre-season and in-season), coaches implemented seven practice types which were categorised into training-form and playing-form. Practice type frequencies were different between pre- and in-season (v^2 ¼ 109.6, p < 0.001). Significant differences were reported for practice type duration between pre-season and in-season (p ¼ 0.023, d¼–0.17), where in-season activities were longer. Coaches implemented a higher percentage of practice time to playing-form activities in-season (62.0 ± 25.4) compared to pre-season (52.4 ± 19.8) [95%CI: –2.35:21.4]. Coaches were more likely to alter the frequency of practice types, rather than the exposure time. Players performed more training-form activities during pre-season than in-season (v^2 ¼ 30.8, p < 0.001). There were no differences in playing-form activities between pre- and in-season. This study provides insights into the practice activities implemented by professional Australian football coaches and discusses the extent to which they represent best practice in the context of skill acquisition.

Keywords

Constraints-led approach, representative learning design, skill acquisition, training

Introduction

Experts exhibit superior execution, perceptual-motor proficiency and information processing abilities with respect to skill in team sports.[1,2] The amount of time spent in practice has historically been associated with the above characteristics e.g. Ericsson and colleagues[3] hypothesised improvements in skill were primarily related to the amount of time spent in deliberate practice.[3] However, contemporary research suggests that the development of skilled performance is more complex. Recent research has demonstrated a range of constraints that impact skill development and proficiency. For example, although Baker and Cobley[4] note individual proficiency when performing a skill may originate from the relationship between the amount of practice and performance, it is the type of practice

Reviewer: Danielle Ireland (University of Western Australia, Australia)
Thomas McGuckian (Australian Catholic University, Australia)

Faculty of Health, School of Sport, Exercise and Rehabilitation, Human Performance Research Centre, University of Technology Sydney, Ultimo, Australia

Corresponding author:
Rhys Tribolet, Faculty of Health, School of Sport, Exercise and Rehabilitation, Human Performance Research Centre, University of Technology Sydney, Ultimo, Australia.
Email: Rhys.Tribolet@uts.edu.au

(i.e. high validity environments and the information available within them) that can further differentiate expert performers from non-experts.[5,6] Different practice environments in team sport lead to different behaviours emerging.[7] Thus, the consequence of the interaction of the constraints imposed on the skill is fundamental to how skill emerges and develops.[8] Consequently, an awareness of the specific environments implemented for skill acquisition and expertise development is useful for practice design. In part, this will enhance coach's awareness for skill acquisition and development and its usefulness for future refinement of practice design.

According to the constraints-led approach to skill acquisition, skilled behaviour emerges through the interaction of individual, environmental and task constraints.[9,10] Due to the complexity of team sport performance, performers interact and adapt to an array of interacting constraints to collectively achieve a common goal.[9,11] Consequently, coaches aim to design practice that represents the performance contexts and the information sources that are present during competition.[12] Task constraints are commonly implemented by coaches[13] and involve changing the field size, the number of players, or task goals, to name a few. Coaches often manipulate task constraints during practice to elicit specific behaviours from their performers. Nonetheless, these constraints may not always be manipulated deliberately, and in reality are often the result of ad-hoc implementations by coaches (e.g. the players are not sufficiently pressured, so the surface area in a small-sided game is adapted during training). It is this exposure to specific practice contexts that allows performers to adapt their behaviour to the environmental information more effectively over time. This concept is referred to as perceptual attunement and is commonly associated with expertise in human movement.[14,15] This mutuality between the performer and the performance environment is adequately described in the ecological dynamics approach to skill acquisition in team sport.[15,16] To effectively train collective and individual behaviour in team sports, exposure to practice contexts that replicate the coupling of perception and action is needed. Interestingly, the specific practice activities implemented by coaches throughout the season at the professional or amateur level has yet to be documented in the scientific literature.

A common approach within team sports training is to increase specificity as competition approaches.[17,18] In the Australian Football League (AFL), particular attention is payed to periodisation and the specific activities players perform across pre-season and in-season. For example, Moreira and colleagues[19] reported higher physical training loads for all training activities during the pre-season compared to in-season. The emphasis for practitioners is to physically 'peak' the players for the competitive in-season period, which is commonplace amongst physical performance programs in the AFL.[19,20] Consequently, practitioners and coaches must simultaneously prepare players physically, but also skilfully and tactically. The subsequent structure of practice and how much time is spent practicing certain activities then becomes a considerable concern. Importantly, when and how this shift in practice occurs often demonstrates a different collective focus for teams and likely reveals the value coaches place on physical, skill or tactical development throughout the season. Guided by physiology periodisation, Farrow and Robertson[21] and Otte and colleagues[22] provided conceptual frameworks for skill acquisition development in team sport and skill development for 'specialist' coaches, respectively. Both frameworks consider traditional coaching features that can be observed to indicate skill acquisition periodisation, such as the progression of practice (e.g. less to more representative practice), incorporating more specific practice closer to competition and how to overload the organisation of the team and individuals. Whilst these frameworks propose guidelines for skill acquisition periodisation, no literature exists to determine whether coaches implement such guidelines. It is generally coaches relying on their experience, expertise and philosophies when designing and implementing practice. Hence, it would be beneficial to notate and measure the types and duration of practice coaches implement to help enhance our understanding of how much value coaches place on specific types of practice and when this changes throughout the season. There is currently an absence of research illustrating the types of practices professional teams perform in a full season across any sport.

The AFL is the professional competition of Australian Football (AF) that involves 18 competing teams based around Australia. The complex nature is demonstrated through dynamic environments and emergent patterns of behaviour.[23,24] Moreover, coordinative team behaviour in AF is predicated on functional behaviours based on the spatiotemporal relations between performers, as they continuously adapt to their teammates and the opposition's movements.[25] This exemplifies that AF players perceptually attune to relevant sources of information in games and take advantage of shared affordances, i.e. collective opportunities for action[7] to produce actions that increase the team's likelihood of winning. As such, representative sources of information and action should be reflected in practice contexts through representative learning design.[12] Recent research in professional AF highlights the discord between the constraints encountered in training environments and competitive matches.

These studies provide clarity for practitioners aiding practice design. For example, Ireland and colleagues[26] described conflicting temporal and situational constraints when disposing possession in competitive matches compared to practice. Specifically, defensive pressure applied to kicking disposals was significantly higher in matches compared to practice contexts. Similarly, Browne and colleagues[27] compared the frequency and interaction of constraints across match simulation, small-sided games and competitive matches. The authors reported disparity between each context, especially in regard to the disposal type i.e. kick or handball, and the proceeding disposal effectiveness. Here, the sequence of an effective third disposal was lower in matches and match simulations compared to the observed small-sided games. Thus, understanding and implementing representative learning design is crucial and can assist coaches to provide practice environments that are more likely to increase the transfer of practice to game performance.[6,12]

To date, no studies have documented the practice activities that professional AFL teams perform throughout a complete season. This study aimed to describe the practice activities implemented by AF coaches throughout a competitive season, with an emphasis on quantifying the exposure (time and frequency) to certain types of practice. It was hypothesised that coaches would implement a higher proportion of more representative activities, termed playing-form activities, during the in-season phase. Additionally, it was hypothesised that coaches would employ a higher proportion of less representative activities, termed training-form practices, in the pre-season compared to in-season.

Materials and methods

Participants

One professional AF club agreed to be involved in the research. Specifically, the coaching group and head of performance agreed for this research to be executed. The team consisted of 48 male professional Australian footballers (age: 23.28 ± 4.35 years) and they participated in their normal training across one entire season. The pre-season phase lasted four months from November to March, whilst the in-season phase lasted 6 months from March to September. The eight senior and development coaches within the professional club had an average of 6.8 ± 6.5 years of AFL coaching experience, in addition to an average of 11.5 ± 5.1 years of playing professional level AF. Training occurred without intervention from researchers. Ethics approval was obtained for this study from the University's ethics committee.

Practice activities

In total, 37 pre-season and 35 in-season training sessions were recorded across the data collection period, resulting in an entire sample of 72 sessions. The data for each training session was collected at the team level. Practice sessions were planned by the coaching group in conjunction with physical performance staff to determine player availability (which players can participate in which drills). The club utilises a long-term planning framework to guide practice design, while also accommodating for variation based on player availability e.g. if less players were available than expected, then an activity tended to be conducted with slightly smaller field dimensions. For each field session, details of practice activities were recorded and activities were filmed. Filming was captured using a combination of handheld and remote video cameras (Axis Q6128-E Network, Axis, Lund, Sweden and Canon Legria HFG30, Canon, Tokyo, Japan). One was placed perpendicular to the direction of play at the side-line, and the other behind the goals. Both cameras were placed at elevated positions. Training footage was manually coded for time spent in each practice and one investigator notated the start and finish of each practice.

All practice types were categorised into one of seven classifications by the coaching staff: fundamentals, fitness, skills, breakdown, transition, line specific and match simulation (Table 1). These practices were classified by the research team as either training-form or playing-form, as per the methods of Ford and colleagues.[28] Training-form practice types were performed in isolation or in small groups. They generally involved simplified practices[29] and are repetitive in nature. Playing-form practice categories have a game-related focus and emphasise certain phases in a game (i.e. stoppages) or relate to transitioning between certain phases (e.g. attack to defence). This practice includes position-specific set ups and break downs. All practices sessions were annotated by the same experienced observer, who had annotated more than 200 h of AF training and match-play. Coding reliability was assessed using an intra-class correlation coefficient (3, k).[30]

Data analysis

The time spent in each practice activity type was calculated over the whole season, and separately for pre-season and in-season phases. Cross-tabulations and chi-square tests of independence (χ^2) were used to investigate the relationship between practice categorisations (practice types and practice forms), and season phases (pre- and in-season). Practice type proportions were expressed as a percentage of total time spent in

Table 1. Training activity categories and their definitions.

Practice activity	Definition
Training-form	
Fundamentals	Drills that focus on kicking, handballing, marking, tackling technique and handwork Generally performed in small groups that are repetitive and blocked and have unopposed skill repetition
Fitness	Activities aimed at improving game-related fitness qualities (e.g. aerobic capacity, repeat speed ability etc.)
Skills	Consists of various practices They largely involve ball movement (cone to cone), chaotic handball practices with outnumbered situations (e.g. 4v3), goal kicking and crumbing Tend to re-enact isolated game incidents
Playing-form	
Breakdown	Part-practice activities that involve a certain phase of game play E.g. stoppages or exiting the defensive 50 Generally, these practices have limited/reduced opposition
Transition	Activities such as small-sided games that aim to simulate the continual adaptation between attack, contested play and defence seen in match-play
Line-specific	Practices that are run by each line coach and are positional and craft specific For example, midfielders may work on the centre bounce clearance whereas defenders and forwards may work on 1 on 1 marking contests
Match Simulation	Involves representative game play/simulation This involved anywhere between 13–18 players on each team

practice by dividing the time spent in the activity by the total time spent in practice for the whole season and then for pre- and in-season individually, and then multiplying this number by 100. The time in each practice activity type between pre-season and in-season was compared using a paired samples t-test. Additionally, comparing the duration of time spent in playing-form activities from pre-season to in-season was analysed using a paired samples t-test. The data was normalised by calculating the percentage of session duration players spent in playing-form activities to prevent violating the statistical assumption of independence. Similar methods normalising playing-form activities have been used previously.[28,31] Effect size statistics were used to quantify the magnitude of difference between the groups, with interpretation of magnitudes being <0.19 = trivial, 0.2–0.49 = small, 0.5–0.79 = moderate, >0.8 = large.[32] The alpha level for significance was set at $p < 0.05$. All statistical analyses were conducted using JASP Team.[33]

Results

The intra-class correlation coefficients between test 1 and test 2 demonstrated excellent reliability (r = 0.97–0.99) for the annotations of practice types and time spent in each practice type.

Practice type and practice form frequencies

Table 2 demonstrates the chi-square contributions for each practice type and practice activity form. The chi-square test of independence comparing in-season practice type frequencies to pre-season practice type frequencies demonstrated significantly different frequency distributions in different phases of the season (χ^2=109.6, $p < 0.001$). Table 2 presents the observed and expected counts for each practice type and shows the contribution to the final chi-squared value. The large chi-square value is largely caused by not performing any fitness sessions in-season, moving to a very low amount of fundamentals in-season and an increased number of line specific practice drills in-season. Pre-season included more breakdown (+8), fitness (+63), fundamentals (+105), skill (+14) and transition (+10) type practice. Higher amounts of line specific (+14) and match simulation (+4) practice types were performed in-season. Furthermore, the chi-square test of independence demonstrated a significant difference between training-form and playing-form activities when comparing pre- and in-season frequencies ($\chi^2 = 30.8$, $p < 0.001$). Table 2 presents the observed and expected counts for each practice form and their respective contribution to the final chi-squared value. There was no change in the frequency of playing-form activities between pre- and in-season. However, the relative contribution to chi-square values is caused by a large difference in the frequency of training-form practice between pre- and in-season. Training-form practice was performed more frequently during pre-season (+182). Playing-form practice frequency was equal between pre- and in-season (82).

Practice activity duration

The average practice activity time for a drill in pre-season was 7.0 ± 0.8 mins. While the average practice activity time in-season was 8.0 ± 0.4 mins. There was a significant difference between practice activity duration between pre-season and in-season (t (177) = –2.286, p = 0.023, d = –0.17 [95% CI: –0.319 to –0.023]).

Table 2. Cross tabulations and chi-square contributions for each practice type and practice form.

Practice type and form	Season phase	Observed counts	Expected counts	Sums	Squared difference (Observed-Expected)	Chi squared contribution
Breakdown	Pre-season	23	255	38	6	024
	In-season	15	125			048
Fitness	Pre-season	63	422	63	4328	1026
	In-season	0	208			2080
Fundamentals	Pre-season	117	864	129	9363	1084
	In-season	12	426			2198
Line specific	Pre-season	13	268	40	1902	710
	In-season	27	132			1440
Match simulation	Pre-season	19	281	42	8	296
	In-season	23	139			601
Skill	Pre-season	97	1206	180	5551	460
	In-season	83	594			934
Transition	Pre-season	27	295	44	61	021
	In-season	17	145			042
					Total χ^2	1096
Training-form	Pre-season	277	2492	372	7752	31
	In-season	95	1228			63
Playing-form	Pre-season	82	1098	164	7752	71
	In-season	82	542			143
					Total χ^2	308

χ^2=chi-square value.

Subsequently, the in-season phase had longer practice activity durations with lower variation.

Time-use analyses

Table 3 outlines the time spent in each practice type separated by season phase. Figure 1 illustrates the proportion of time and the proportion of frequencies in each practice type between pre- and in-season. Since practice activity time differed across pre-season and in-season, a paired samples t-test was used to determine the difference in percentage of session duration spent in playing-form activities. The average percentage of time spent in playing-form activities for pre-season was 52.4 $\pm$ 19.8, whilst for in-season it was 62.0 $\pm$ 25.4. The difference in proportions between pre-season and in-season was insignificant ($t=(27)$ -1.641, $p=0.112$, $d=-0.31$ [95% CI: -0.687:0.072). Across the whole season, a higher proportion of time was spent in training-form activities compared to playing-form activities. In pre-season, a higher proportion of training time was spent in training-form compared to playing-form activities, whilst a higher amount of time was spent in playing-form activities in-season, compared to training-form activities.

Across the whole season, the proportion of time in training was the largest for skill, followed by match simulation, fundamentals, transition, line specific, fitness and breakdown. In pre-season, skill type practices composed the largest proportion of training, followed by fundamentals, fitness, transition, breakdown, match simulation and line specific. The greatest proportion of training in-season was spent in skill, followed by match simulation, line specific, transition, breakdown and fundamentals. All of the relevant proportions (in percentages) are reported in Table 3.

Discussion

This descriptive study examined the practice contexts that coaches implemented in a professional AF team with a view to facilitating optimal skill acquisition principles. Practice type frequencies between pre-season and in-season were different. The difference largely originated from no specific fitness drills being performed in-season, a low amount of fundamental practice types being performed in-season and an increase in line specific practice in-season. Moreover, coaches more frequently implemented training-form practice during pre-season than in-season. The significant chi-square indicates larger contributions from the observed playing-form frequencies compared to what was expected for both in-season and pre-season. There were no differences detected between in-season and pre-season for playing-form practice frequency (82 each). There was a significant difference between practice type duration between pre-season and in-season, with drills typically being of longer duration

Table 3. Practice types and the average and total time and subsequent proportion spent in each, according to whole season, pre-season and in-season.

Practice type	Average duration (mins)	N	Total time in practice type (mins)
Whole season			
Training-form	**5.9 ± 2.8**	**372**	**2207**
Playing-form	**12.9 ± 5.1**	**164**	**2114**
Breakdown	10.9 ± 5.5	38	414
Fitness	6.8 ± 4.0	63	431
Fundamentals	4.4 ± 2.1	129	569
Line Specific	12.1 ± 4.0	40	485
Match Simulation	15.8 ± 3.4	42	664
Skill	6.7 ± 2.2	180	1207
Transition	12.2 ± 5.7	44	551
Pre-season			
Training-form	**5.8 ± 3.0**	**277**	**1609**
Playing-form	**14.8 ± 4.6**	**82**	**1220**
Breakdown	13.5 ± 4.9	23	310
Fitness	6.8 ± 4.0	63	431
Fundamentals	4.2 ± 2.1	117	495
Line Specific	15.0 ± 4.0	13	194
Match Simulation	15.8 ± 4.2	19	301
Skill	7.0 ± 2.3	97	683
Transition	15.0 ± 5.1	27	415
In-season			
Training-form	**6.3 ± 2.0**	**95**	**598**
Playing-form	**10.9 ± 4.7**	**82**	**894**
Breakdown	7.0 ± 3.9	15	104
Fitness	0 ± 0	0	0
Fundamentals	6.1 ± 1.4	12	74
Line Specific	10.8 ± 3.2	27	291
Match Simulation	15.8 ± 2.8	23	363
Skill	6.3 ± 2.0	83	524
Transition	8.0 ± 3.7	17	136

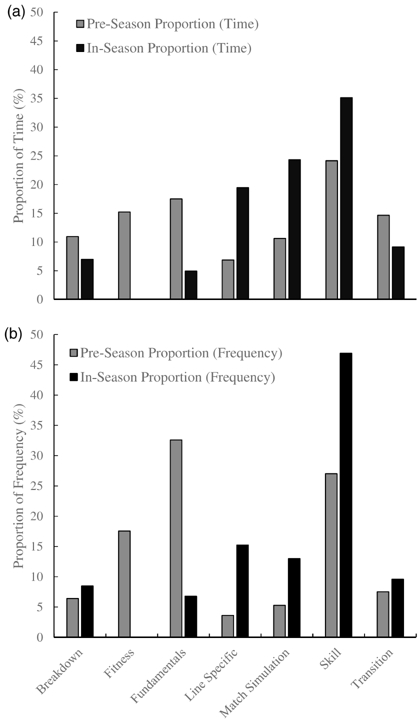

Figure 1. Proportion of practice types for time (a) and frequency (b) between pre- and in-season.

in-season. Furthermore, the mean percentage of time spent in playing-form in-season (62.0 ± 25.4) did not significantly differ compared to pre-season (52.4 ± 19.8). Collectively, these results suggest that coaches prefer to implement higher exposures, via frequency, to more practice types rather than a longer exposure to a specific, and smaller amount of practice types. For example, within one training week the coaches may implement 12 different variations of these practice classifications, with each lasting 6 min in duration. This would be in contrast to the coaches implementing 6 practice drills lasting 12 min each. The variation and differences within each practice type between pre- and in-season could also reflect variations between the intensity of these training activities. There are several conceivable reasons for these outcomes including the requirement to meet the physical requirements determined by physical performance staff, the implicit provision of more opportunities to expose players to the same problem in different contexts, or providing the coaches a platform to observe, refine and correct performance more often.

The highest pre-season proportions of training were skill (24.2%), fundamentals (17.5%) and fitness (15.2%) practice types. In contrast, in-season training time proportions were skill (35.1%), match simulation (24.3%) and line specific (19.5%) practice types. These results clearly demonstrate that coaches replace fundamentals and fitness with match simulations as they move to in-season training. This alludes to the specificity of practice hypothesis.[34] Coaches seem to implement more representative practice with reduced available time for training in-season. The match simulation may be implemented as it provides players with the ability to use more appropriate information from the environment to support actions,[12] showcasing to coaches whether the collective and individual perceptual and motor processes are desirable and align with specific tactics and outcomes they are wanting to observe. From an ecological view, it aims to create shared affordances and for the players to become attuned to these shared affordances that would also be present in competitive matches. The collective and cyclical relationship between shared affordances and shared action exposes players to behaviours, constraints and information that can be observed in match-play.[7] Hence, match simulation may provide the most representative and manipulatable degree of perception-action coupling that can seemingly be achieved in practice. Specific constraints, like space (m^2) per player, using a scoreboard and assigning specific criteria to be met and achieved during match simulation, can be manipulated to optimise collective adaptations during practice.

Skill type practice was the most frequently performed in both the pre- and in-season phases. Moreover, the tendency for an increase of training time proportion performing skill type practice in-season compared to pre-season (+10.9%) indicates that coaches appear to implement a strategy that changes from general to more specific training throughout the season. This aligns with skill periodisation ideas proposed previously.[21,22] Interestingly, in-situ skill periodisation is not as complicated as that proposed in the models and is largely implemented ad-hoc. Nonetheless, the large proportion of time spent performing skill type activities suggests coaches are primarily concerned with improving their athletes' skill proficiency. According to the literature, this approach to training may not be the best approach to achieve that goal.[12,34] This practice type largely involved isolated game incidents that removed a continuation of play. Accordingly, this practice type may remove key perception and action responses for subsequent phases of play. For skill to improve and transfer to competitive match-play to occur, high validity environments, where performer-environment interactions represent those experienced during game play, are needed.[12] Here, we advocate increased opportunity for skill acquisition specialists in professional sport to play a key role in continually developing expertise. As Steel and colleagues[35] describe, "skill acquisition specialists are sport scientists who examine the theories, principles and processes of motor and perceptual learning". Thus, a complimentary role between coaches, who make decisions based on experiential knowledge, and skill acquisition specialists, who make decisions based on both empirical and experiential knowledge can lead to beneficial outcomes for practice design, feedback and instruction. Furthermore, the complimentary role skill acquisition specialists can play ensures the continual development of perceptual-motor learning based on scientific principles. A good example of how the cross-disciplinary nature of a skill acquisition specialist can help improve practice design has been documented by Ireland and colleagues.[26] These authors reported that kicking disposal constraints relating to space and time were underrepresented during practice compared to professional AF matches. For expert performers to improve skill, informational sources used to regulate behaviour need to be very specific[6] and as such, it is likely that until coaches use and develop practice activities that truly resemble conditions from match-play, skill proficiency will not be optimised, or will remain at a level below that required for successful performance in competition. A simple method to enhance skill development in experts is to perform the skill at speeds similar to game play so the performers can process relevant information and execute skills at the required pace.[36] However, rather than mimicking actual game-play pace, coaches often choose to train skilled behaviour and decision making at a proportional pace of that experienced during competition (e.g. match simulation run-throughs at 60% of maximal velocity).

Similar to previous research assessing coaching and youth practice contexts in elite association football,[1,28,31] these findings indicate an insignificant difference but higher proportion of time in-season vs pre-season is spent performing playing-form activities. Moreover, the greatest contributor to the chi-squared value (χ^2=30.8) assessing the practice form activity frequencies was the difference between expected and observed frequencies of playing form activities in-season. That is, the frequency of playing-form activities in-season was much larger than expected. This may indicate an increased and implicit awareness of representative practice from coaches, or an enhanced understanding of transferable practice due to their experience and philosophies. Additionally, these results may highlight the multidimensionality of practice design concerns for professional coaches. For example, other factors such as training load management e.g. reduce the number of defenders to reduce the number of change of direction efforts, the players and teams experience, the number of days between competitive games in-season e.g. less days between games means more time is focussed towards recovery and not training, meaning the most relevant activities must be performed, or the upcoming opposition e.g. positional requirements across different phases of play. Nonetheless, playing-form activities are deemed more relevant as they generally contain more specific informational sources such as pressure from defenders, spacing and game speed. However, these proportions differed in pre-season for the current data i.e. training-form encompassed 56.9% of total training time.

A conservative view may suggest slightly decreasing the proportion of training-form activities, whilst slightly increasing playing-form activities.[28] This may be an ambitious suggestion in practice, but this approach considers that expert performers are systematically characterised by enhanced domain-specific perceptual-cognitive abilities such as enhanced scanning and pattern recognition, anticipation and decision making[37] whilst measures of basic visual and cognitive function (i.e. domain-general skills) do not differ.[38] Thus, expert performers, as showcased here through a professional AF team, require consistent exposure to specific training to enhance adaptations related to their domain-specific expertise. Consequently, an integrated approach to increase playing-form practice types would be recommended across the whole season. Nonetheless, the overall proportion of training-form to playing-form was very similar (51.1% and 48.9%, respectively) over the whole season. Regular assessments and continued monitoring by performance analysts can provide feedback to coaches and assist their quest to optimise practice contexts.

Fundamental type practice constituted 13.2% (preseason: 17.5%, in-season: 5%) of total training time across the whole season. These training-form practices incorporate basic variations of closed skill performances (e.g. groundballs, handballing, kicking, marking, tackling and handwork). The performance of the skill is generally completed in a decontextualized manner where skill execution is independent of the context it is required in. As such, it may not provide the specific information that experts use to regulate match behaviour and decision-making or may lack processing requirements that develop domain-specific skill.[6] This practice type also requires little cognitive attention as the athletes tend to be extremely proficient at the movement solutions. Additionally, because team sport experts differ to non-experts regarding pattern recognition, automatic movement control, anticipation and coping with constraints,[6] repeated exposures to simple closed skill performances are less representative of the domain-specific exercises required for experts to learn and keep improving. Although it can be utilised as a 'get hands on the footy' exercise, from a skill acquisition perspective for experts, it likely offers very little. For example, Farrow and colleagues[2] reported higher cognitive complexity (and thus, engagement) in open type skill contexts. Thus, closed skill practice contexts likely do not cognitively engage the players and do not challenge the players. It appears that the utility of such exercises and practice contexts for expert performers is not warranted and time could be better utilised engaging in other practice types.

Whilst this was the first study to report on practice types and contexts implemented by expert coaches in a professional AF team, some limitations must be considered. Specifically, the data was collected from one professional AF team and therefore may lack generalizability to other professional AF teams' programs or more broadly to other team sports. However, the methodology presented in this study may be useful for other researchers and practitioners to adopt and investigate their own practice environments. Additionally, as these results are clearly preliminary and rely somewhat on the descriptive information on each practice type, future research is required to strengthen the interpretation and extrapolation to more teams and indeed different sporting contexts. This will assist researchers and practitioners understand how expert performers can continue to develop and refine their performance, whilst further understanding where research efforts are required. Nonetheless, the longitudinal collection over one full season using professional athletes presented here strengthens the interpretation of the data and the ecological validity.

Conclusion

This study provided information on the training structures and practice contexts that coaches implement in a professional AF team. There were seven practice types the coaches implemented throughout the season which were different between pre- and in-season phases. Skill practice was most prominent throughout the whole season but was performed more frequently in preseason compared to in-season. This signifies the value coaches place on developing skill proficiency in professional AF players before competitive matches begin. Coaches also tended to emphasise training-form activities in the pre-season and playing-form activities in-season. This likely reflects coaches' willingness to implement practice that transfers into completive play by providing activities with more representative learning design in-season. While these coaches' practices generally correspond with scientific knowledge surrounding optimal practice design, some training activities, including the large proportion of time spent performing closed-natured skills, and practices performed unopposed, may indicate the opportunity for skill acquisition specialists to aid in optimising practice design. Skill acquisition specialists can play an important complimentary role to help coaches design practice and provide feedback and instruction. Additionally, they can implement pedagogical frameworks across an organisation through evidence-based practice.

The information from this study can be used to monitor the type of practice being performed and used to determine the duration and exposures to certain practice types. Collectively, future research and daily practice in sport may warrant these analyses to be used alongside the constraints-led approach and in conjunction with collective behavioural measures to determine behavioural responses to practice in Australian football.

Declaration of Conflicting Interests

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ORCID iDs

Rhys Tribolet https://orcid.org/0000-0001-9252-1900
Andrew Roman Novak https://orcid.org/0000-0002-2949-4150

References

1. Williams AM and Hodges NJ. Practice, instruction and skill acquisition in soccer: challenging tradition. *J Sports Sci* 2005; 23: 637–650.
2. Farrow D, Pyne DB and Gabbett T. Skill and physiological demands of open and closed training drills in Australian football. *Int J Sports Sci Coach* 2008; 3: 485–495.
3. Ericsson KA, Krampe RT and Tesch-Römer C. The role of deliberate practice in the acquisition of expert performance. *Psychol Rev* 1993; 100: 363–406.
4. Baker J, Schorer J and Cobley S. *Talent identification and development in sport: international perspectives*. London: Routledge, 2012.
5. Kahneman D and Klein G. Conditions for intuitive expertise: a failure to disagree. *Am Psychol* 2009; 64: 515–526.
6. Farrow D, Baker J and MacMahon C. *Developing sport expertise: researchers and coaches put theory into practice*. London: Routledge, 2013.
7. Silva P, Garganta J, Araújo D, et al. Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Med* 2013; 43: 765–772.
8. Newell KM. Constraints on the development of coordination. In: Wade MG and Whiting HTA (eds) *Motor development in children: aspects of coordination and control*. Dordrecht: Martinus Nijhoff, 1986, pp.341–360.
9. Davids K, Araújo D, Shuttleworth R, et al. Acquiring skill in sport: a constraints-led perspective. *Int J Comput Sci Sport* 2003; 3: 31–39.
10. Davids K, Button C and Bennett S. *Dynamics of skill acquisition: a constraints-led approach*. Champaign: Human Kinetics, 2008.
11. Handford C, Davids K, Bennett S, et al. Skill acquisition in sport: some applications of an evolving practice ecology. *J Sports Sci* 1997; 15: 621–640.
12. Pinder RA, Davids K, Renshaw I, et al. Representative learning design and functionality of research and practice in sport. *J Sport Exerc Psychol* 2011; 33: 146–155.
13. Ometto L, Vasconcellos FVA, Cunha FA, et al. How manipulating task constraints in small-sided and conditioned games shapes emergence of individual and collective tactical behaviours in football: a systematic review. *Int J Sports Sci Coach* 2018; 13: 1–15.
14. Gibson JJ. *The ecological approach to visual perception*. Boston: Houghton Mifflin, 1979.
15. Araújo D, Davids K and Hristovski R. The ecological dynamics of decision making in sport. *Psychol Sport Exerc* 2006; 7: 653–676.
16. Davids K, Araújo D, Vilar L, et al. An ecological dynamics approach to skill acquisition: implications for development of talent in sport. *Talent Dev Excel* 2013; 5: 21–34.
17. Bompa TO. *Periodization training: theory and methodology*. 4th ed. Champaign: Human Kinetics, 1999.
18. Impellizzeri FM, Rampinini E and Marcora SM. Physiological assessment of aerobic training in soccer. *J Sports Sci* 2005; 23: 583–592.
19. Moreira A, Bilsborough JC, Sullivan CJ, et al. The training periodisation of professional Australian football players during an entire AFL season. *Int J Sports Physiol Perform* 2015; 10: 566–571.
20. Robertson S and Joyce D. Evaluating strategic periodisation in team sport. *J Sports Sci* 2018; 36: 279–285.
21. Farrow D and Robertson S. Development of a skill acquisition periodisation framework for high-performance sport. *Sports Med* 2017; 47: 1043–1054.
22. Otte FW, Millar SK and Klatt S. Skill training periodisation in "specialist" sports coaching – an introduction of the "PoST" framework for skill development. *Front Sports Act Living* 2019; 1: 1–17.
23. Alexander JP, Spencer B, Mara JK, et al. Collective team behaviour of Australian rules football during phases of match play. *J Sports Sci* 2019; 37: 237–243.
24. Sheehan WB, Tribolet R, Watsford ML, et al. Using cooperative networks to analyse behaviour in professional Australian football. *J Sci Med Sport* 2020; 23: 291–296.
25. Silva P, Vilar L, Davids K, et al. Sports teams as complex adaptive systems: manipulating player numbers shapes behaviours during football small-sided games. *SpringerPlus* 2016; 5: 10.
26. Ireland D, Dawson B, Peeling P, et al. Do we train how we play? Investigating skill patterns in Australian football. *Sci Med Football* 2019; 3: 265–274.
27. Browne PR, Woods CT, Sweeting AJ, et al. Applications of a working framework for the measurement of representative learning design in Australian football. *PLoS ONE* 2020; 15: e0242336.
28. Ford PR, Yates I and Williams AM. An analysis of practice activities and instructional behaviours used by youth soccer coaches during practice: Exploring the link between science and application. *J Sports Sci* 2010; 28: 483–495.
29. Edwards WH. *Motor learning and control: from theory to practice*. Wadsworth: Cengage Learning, 2010.
30. Koo TK and Li MY. A guidelines of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med* 2016; 15: 155–163.

31. Roca A and Ford PR. Decision-making practice during coaching sessions in elite youth football across European countries. *Sci Med Football* 2020; 4: 263–268.
32. Cohen J. *Statistical power analysis for the behavioural sciences*. 2nd ed. Hillsdale: Lawrence Earlbaum Associates, 1988.
33. JASP Team 2020. JASP (Version 0131)[Computer software].
34. Proteau L. On the specificity of learning and the role of visual information for movement control. In: Proteau L and Elliott D (eds) *Vision and motor control*. Amsterdam: North Holland, 1992, pp.67–103.
35. Steel KA, Harris B, Baxter D, et al. Coaches, athletes, skill acquisition specialists: a case of misrecognition. *Int J Sports Sci Coach* 2014; 9: 376–378.
36. Reimer T, Park ES and Hinsz VB. Shared and coordinated cognition in competitive and dynamic task environments: an information-processing perspective for team sports. *Int J Sport Exerc Psychol* 2006; 4: 376–400.
37. Williams AM, Fawver B and Hodges NJ. Using the 'Expert Performance Approach' as a framework for examining and enhancing skill learning: Improving understanding of how experts learn. *Frontline Learn Res* 2017; 5: 139–154.
38. Voss MW, Kramer AF, Basak C, et al. Are expert athletes' 'expert' in the cognitive laboratory? A meta-analytic review of cognition and sport expertise. *Appl Cognit Psychol* 2010; 24: 812–826.

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A descriptive and exploratory study of factors contributing to augmented feedback duration in professional Australian football practice

Rhys Tribolet, William Bradshaw Sheehan, Andrew Roman Novak, Mark Langley Watsford and Job Fransen

Abstract

Augmented feedback supplements or replaces task-intrinsic feedback and is common in team sports, however, no studies have reported on augmented feedback provision in professional Australian Football (AF) practice. This study investigated the effects of practice characteristics (feedback intervention frequency, practice time, practice type, season phase, practice activity form and competitive match result) on the duration of feedback provided by professional AF coaches. Two linear mixed-effects models were constructed. The first examined the collective associations between these practice characteristics and feedback durations while the second model investigated the associations between the same practice characteristics and previous match result. Results showed the feedback intervention frequency, practice time and a practice time*feedback intervention frequency interaction explained 65% of feedback duration whenever feedback was provided. Additionally, practice time, feedback intervention frequency, a practice time*match result interaction and a match result*feedback intervention frequency interaction explained 99% of feedback duration in-season. Important factors that were hypothesised to affect feedback durations in AF such as practice type, practice activity form or season phase did not contribute any explanatory power. This study provides information on how professional AF coaches provide augmented feedback in-situ and provides opportunities for skill acquisition specialists to aid coaches when delivering augmented feedback.

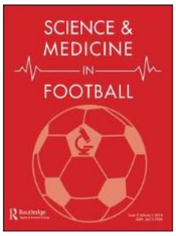
Keywords

Practice, skill acquisition, team sport, training

Reviewer: Alexandru Lascu (University of Canberra, Australia)
Will Vickery (Deakin University, Australia)

Human Performance Research Centre, School of Sport, Exercise and Rehabilitation, Faculty of Health, University of Technology Sydney, Sydney, Australia

Corresponding author:
Rhys Tribolet, Human Performance Research Centre, School of Sport, Exercise and Rehabilitation, Faculty of Health, University of Technology Sydney, UTS/Rugby Australia Building, Corner of Driver Av and Moore Park Road, Moore Park, 2021 New South Wales, Sydney, Australia.
Email: Rhys.Tribolet@uts.edu.au



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Factors associated with cooperative network connectedness in a professional Australian football small-sided game

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Factors associated with cooperative network connectedness in a professional Australian football small-sided game

Rhys Tribolet, William B. Sheehan, Andrew R. Novak, Mark L. Watsford and Job Fransen

Human Performance Research Centre, School of Sport, Exercise and Rehabilitation, Faculty of Health, University of Technology Sydney, Sydney, Australia

ABSTRACT

Objectives: Connectedness is a cooperative network measure that describes how well players in the team bi-directionally connect and how easily reachable they are to other players. It has been associated with an increased probability of winning competitive matches in professional Australian Football (AF), although applications towards training have not been reported. Therefore, this study investigated associations between constraints manipulated by professional AF coaches and the connectedness of cooperative passing networks during a small-sided game (SSG).
Design: Data were collected describing the task constraints manipulated by professional coaches across one SSG performed on multiple occasions. The SSG focused on transitioning between defence and attack and was performed fifteen times across a whole season, resulting in 36 observations of team connectedness.
Method: A linear mixed-effects model was constructed to examine the collective influence of constraints manipulations made by professional coaches (e.g. field size) and team skill characteristics (e.g. kick efficiency) on connectedness scores.
Results: The number of team shots on goal and the time on task both positively contributed to connectedness scores, explaining 65% of its variance.
Conclusion: The findings show that the number of shots on goal and the time on task may be used to elicit higher or lower connectedness scores in AF SSGs. Skill acquisition specialists, in conjunction with coaching staff, can use these metrics to aid practice design in professional AF or indeed other invasion-style team sports.

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KEYWORDS
Constraints-led approach; coaching; small-sided games; passing networks

CONTACT Rhys Tribolet Rhys.Tribolet@student.uts.edu.au Human Performance Research Centre, School of Sport, Exercise and Rehabilitation, Faculty of Health, University of Technology Sydney. UTS/Rugby Australia Building, Corner of Driver Av and Moore Park Rd Moore Park, Sydney, NSW 2021, Australia

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Match simulation practice may not represent competitive match play in professional Australian football

Rhys Tribolet, William B. Sheehan, Andrew R. Novak, Michael J. Rennie, Mark L. Watsford & Job Fransen

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Match simulation practice may not represent competitive match play in professional Australian football

Rhys Tribolet[a,b], William B. Sheehan[a], Andrew R. Novak[a], Michael J. Rennie[b], Mark L. Watsford[a] and Job Fransen[a]

[a]Human Performance Research Centre, School of Sport, Exercise and Rehabilitation, Faculty of Health, University of Technology Sydney, Moore Park, Australia; [b]Football Department, Sydney Swans Football Club, Sydney, Australia

ABSTRACT

Match simulation in team sport should sample representative constraints and behaviours to those observed in competitive matches to enhance near skill transfer. This study compared task constraints (field length, field width, length per width ratio, space per player), time-standardised skill metrics (goals, shots on goal, handballs, kicks, marks, turnovers, tackles, handball proficiency, kick proficiency) and cooperative passing metrics (connectedness, indegree variability and outdegree variability) between match simulation practice and competitive Australian Football League (AFL) games for one professional team. MANOVAs identified activity-related differences for task constraints, skill metrics and cooperative passing networks. During match simulation, goals were scored more frequently, but with less passing actions per minute. Receiving and distributing passing networks were more centralised (reliance on fewer key individuals), with less turnovers and tackles per minute compared to AFL matches. If match simulation is designed to reflect competition, then player and team skill preparation may be compromised. Furthermore, the competing demands in high-performance sport may restrict the degree of representativeness that can be achieved during practice. These findings provide valuable insight and may assist practitioners and/or coaches to understand the value of match simulation practice and to maximise near skill transfer from match simulation to competition.

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KEYWORDS
Task fidelity; representative learning design; team sport; constraints-led approach

CONTACT Rhys Tribolet Rhys.Tribolet@student.uts.edu.au Human Performance Research Centre, School of Sport, Exercise and Rehabilitation, Faculty of Health, University of Technology Sydney, UTS/Rugby Australia Building, Corner of Driver Av and Moore Park Rd, Moore Park 2021, Australia

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