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Holistic Exploration of Training Design and Periodisation in Professional Rugby League – A Case Study

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Thesis submitted in fulfilment of the requirements for the degree of

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under the supervision of
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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Joanne Hausler 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 referenced 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.

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PREFACE

This thesis for the degree of Doctor of Philosophy is in the format of Thesis by Compilation following the 'Graduate Research Candidature Management, Thesis Preparation and Submission Procedures'.

This thesis begins with an introduction (Chapter One), which provides background information, highlights the research problem as well as the purpose and significance of the proposed studies. A literature search was segregated into two parts (Chapter Two); a scoping review and narrative review to provide the current knowledge and research gaps in the physical, technical and tactical demands of rugby league training and current periodisation frameworks applied in team sport. The main body of this thesis presents a sequential series of seven studies (Chapters Two – Chapter Eight) following the development of research ideas to address the research problem. Each study follows a similar outline of Introduction, Methods, results, Discussion and Conclusion. All findings are combined into a discussion chapter (Chapter Nine) to integrate the main findings, limitations and practical applications of the thesis. The final chapter (Chapter Ten) provides an overall conclusion of how the thesis contributes to the initial research problem, provides information on the impact of the thesis and recommendations for future research.

Data obtained for this thesis was collected over the entirety of the 2018 National Rugby League (NRL) competition year from a highly successful club (i.e., NRL champions). Furthermore, this club had prior success in the previous year (e.g., preliminary final participants) and in the subsequent year (i.e., NRL and World Club champions). The continued success of the club in combination with the nature of data collected (i.e., tactical demands of rugby league drills and tactical prescription), the publication of data during this time was embargoed by the NRL club. Accordingly, there are currently no publications. However, it is intended to submit the following studies for peer review publication prior to the submission of this thesis:

- Hausler, J. M., Slattery, K. M., & Coutts, A. J., (2022). The physical, technical and tactical demands of on-field training drills in professional rugby league: A scoping review *(Sports Medicine)*
- Hausler, J. M., Slattery, K. M., & Coutts, A. J., (2022). The development and evaluation of the Training Drill Questionnaire for rugby league *(Science and Medicine in Football)*
- Hausler, J. M., Stolp, S. M., Slattery, K. M., & Coutts, A. J., (2022). The physical, technical and tactical demands of on-field training drills in professional rugby league *(Science and Medicine in Football)*
- Hausler, J. M., Stolp, S. M., Slattery, K. M., & Coutts, A. J., (2022). Variation in physical, technical and tactical aspects in professional rugby league training *(Science and Medicine in Football)*
- Hausler, J. M., Stolp, S. M., Slattery, K. M., & Coutts, A. J., (2022). How do coaches prescribe the tactical elements of training in professional rugby league? A case study *(Science and Medicine in Football)*
- Hausler, J. M., Stolp, S. M., Slattery, K. M., & Coutts, A. J., (2022). Developing a Match Difficulty Index for professional rugby league *(Journal of Sports Sciences)*
- Hausler, J. M., Stolp, S. M., Slattery, K. M., & Coutts, A. J., (2022). How do coaches design training to prepare for upcoming oppositions? *(Journal of Sports Sciences)*

ABSTRACT

Coaches and support staff in professional rugby league clubs collaborate to prepare players for the specific physical, technical and tactical elements required for performance. This is achieved through careful prescription and manipulation of training. Due to the perceived importance to successful match performance, coaches emphasise tactics in training where much of practice is focussed on the execution of strategies. Recently, there has been increased interest in periodisation strategies that seek to concurrently develop the multifaceted physical, psychological and technical requirements of competition, while centrally focussing on the tactical elements of performance (i.e., tactical periodisation). When implemented effectively, this approach ensures that training is designed to prepare for moments within the game (i.e., attack, defence and transitions) while adhering to the philosophies, strategy and game style desired by coaches. Anecdotally, this approach is popular within team sports, but to date, due to the dynamic and changing professional rugby league environment, there is little empirical evidence describing or assessing the efficacy of this approach.

While there are many studies describing the physical demands of rugby league performance and others that have highlighted the importance of specific technical and tactical features for successful performance, a scoping review (Chapter Two) identified gaps in understanding the physical, technical and tactical demands of rugby league training. A narrative review also highlighted the lack of empirical evidence investigating tactical periodisation frameworks. Accordingly, it was apparent there had been no investigations on how coaches plan and prescribe the tactical elements of training for preparation according to their desired game style and philosophical approach.

To address these shortcomings, study two (Chapter Three) developed a questionnaire tool to quantify and monitor how coaches prescribe the tactical elements of training. Measures of tactical descriptors, variables and post-training assessment were identified to form a questionnaire and were subsequently applied in study three (Chapter Four) and study five (Chapter Six) of this thesis.

Studies three (Chapter Four) and four (Chapter Five) investigated the multifaceted demands within rugby league training by describing and examining the variability of

physical, technical and tactical components within team-based training drills. These studies were the first to provide descriptions on the various demands of training, discerning eight overarching components and six central types of drills conducted throughout the season.

Study five (Chapter Six) applied the tool developed in study two (Chapter Three) to describe the tactical arrangement of coaches' on-field training prescription during weekly and seasonal cycles. Results revealed two overarching trends of tactical prescription in the weekly lead up to match performance, with only one variable increasing throughout the competition season. Studies six and seven extended on study five by examining the tactical prescription by coaches in relation to difficulty of upcoming opponent, with main findings revealing the majority of tactical variables differed by training day, with only two variables varying for difficulty of upcoming opponent.

Taken collectively, the findings from this thesis contribute new information to facilitate a holistic approach to the preparation for performance in professional rugby league. These studies extend on the previous knowledge base of physical and technical demands of rugby league training and provide novel insights into how coaches tactically plan, prescribe and arrange rugby league training. Accordingly, studies in this thesis deliver an example of how this information can be routinely collected, monitored and measured to assist coaches and support staff in strategically manipulating physical – technical loads and tactical approaches to training. Future investigations are encouraged to examine whether there are physical, technical and tactical factors that underpin the coaches' prescription and assess these relationships within training and performance.

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LIST OF ABBREVIATIONS

%	Percentage
2D	2-Dimensional
ANOVA	Analysis of Variance
AU	Arbitrary units
AUC	Area under curve
CI	Confidence interval
COD	Change of direction
COREQ	Consolidated Criteria for Reporting Qualitative research
COSMIN	COnsensus-based Standards for the selection of health Measurement INstruments
CV	Coefficient of variation
df	Degrees of freedom
ES	Effect size
ESL	European Super League
Exp(B)	Odds ratio
GAS	General Adaptation Syndrome
GLD	Goal line defence
GPS	Global Positioning Satellite
HMP	High-metabolic power
HSD	High speed distance
HSR	High-speed running
HUF	Hit-up forwards
Hz	Hertz
ICC	Intraclass coefficient correlation
IFT	Intermittent fitness test
IMA	Inertial Movement Analysis
IMU	Inertial Movement Units
kg	Kilogram
km	Kilometre
KPC	Kingston Press Championship
M	Mean
m	Metre
mm	Millimetre
MDI	Match Difficulty Index
min	Minute
n	Sample size
NASA-TLX	NASA task load index
NR	Not reported

NRL	National Rugby League
NYC	National Youth Competition
OB	Outside back
PCA	Principal component analysis
Pred	Predicted
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews
Prob	Probability
PTB	Play-the-ball
QC	Queensland Cup
RHIE	Repeated high-intensity effort bouts
RPE	Rating of perceived exertion
s	Second
SAP	Skill Acquisition Periodisation
SD	Standard deviation
SE	Standard error
SPSS	Statistical Package for the Social Sciences
sRPE	Session RPE
SSG	Small-sided games
SWC	Smallest worthwhile change
TAD	Transition from attack to defence
TDA	Transition from defence to attack
TMT	Tactical metabolic training
USB	Universal Serial Bus
VAS	Visual Analogue Scale
VHSR	Very high-speed running
W	Watts
WRF	Wide-running forwards
comp	Competition
F	Forwards
g	G-force
NR	Not reported
Semi-pro	Semi-professional
VHSD	Very high speed distance

CHAPTER ONE

Introduction

1.1 Background

An important role of sport scientists working in high performance team sport is to deliver evidence-based practices that assist in improving athletic performance, preparation and management processes. Following the principles of evidence-based practice, relevant research is utilised to integrate and challenge coaching philosophies, assist training decisions and evaluate performance [1]. In professional team sports, coaches and support staff carefully prescribe training to prepare players for the specific demands of competition; including developing training drills specific to the varying roles within a team and organising team structures against varying match scenarios and oppositions. To achieve this, collaboration between high performance coaches and support staff is required to ensure training is designed to meet and prepare athletes for specific demands and improve performance in competition. Accordingly, it is essential that sports scientists understand the various demands of match performance to inform training design and the implementation of training frameworks to ensure robust preparation and promote improvements in performance (figure 1.1).

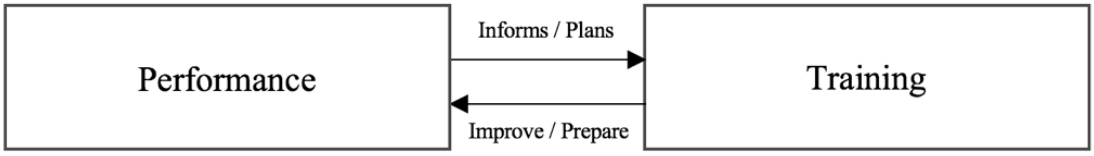


Figure 1.1 Relationship between match performance and training in team sport.

Rugby league is a contact sport where team players cooperatively interact with each other in related 'moments' of attack, defence and transitions to score more points than the opposition through scoring tries and kicking goals. When in attack, teams have six consecutive plays (i.e., 'set') to establish as much field territory as possible and score a try before surrendering possession to the opposition [2]. When in defence, teams seek to present an organised line of defence and protect field position and conceded tries. When an attacking ball carrier and defending players meet in the field of play, they engage in contact activities such as wrestling and tackling. In addition to players requiring the ability to withstand collision demands, players are also required to intermittently perform high-intensity physical activity such as running, accelerating, decelerating and agility manoeuvres such as changing direction [3]. Players must also possess a high level of technical skill as they tackle, pass, kick and receive the ball [4, 5]. Ultimately, rugby league performance is reliant on the collective physical, technical (individual skill) and tactical

(interaction with other individuals) abilities of team members. Accordingly, understanding these multifaceted demands within training and competition is a fundamental part of developing evidence-based practice. The physical, technical and tactical demands of rugby league match-play have previously been investigated in the literature, providing thorough descriptions of the physical demands [3, 6], and technical and tactical characteristics of successful performance [7-9]. However, there have been proportionally fewer studies describing the physical demands of training drills, many of which provide observations of physical measures (e.g., distance and high-speed running) across shorted periods (i.e., pre-season phases) [10-12] and a small selection of training drills [13-15]. Only a few studies have described the technical demands in rugby league training [14-19]. However, these studies are limited as they have assessed one broad category of training drill (i.e., small-sided games), and none have described the tactical approaches applied within these drills. Investigating the multifaceted demands of rugby league training accounting for tactical approaches would provide important information for developing and implementing strategies (e.g., distribution of training drills) to form appropriate training models.

To develop physical, technical and tactical capabilities, rugby league teams undertake specific and deliberate training. In addition to team-based training, players also complete specific (isolated) training sessions focussing on skills such as wrestling and kicking. Overarching to the planning process, coaches spend considerable time developing a tactical periodisation model (i.e., how they want to play) to implement according to the desired style-of-play, player capabilities and tactical principles. Tactical periodisation models are based on the principle that the multifaceted components (i.e., physical, technical, tactical and psychological) of performance are always integrated within training design but also places tactics as the central focus within training [20]. This model has become popular among high performance coaches in team sport as it encompasses a holistic approach to preparing the multifaceted demands of performance. As such the importance of tactics is emphasised for preparation within these models, rather than a ‘physical-led’ periodisation approach [20]. While key principles and approaches such as incorporating game style and preparing for all moments of the game (attack, defence and transition) have been noted in tactical periodisation models, there is currently no empirical evidence investigating this framework. Accordingly, how coaches plan, prescribe and assess the tactical elements of training remains unknown. Investigating these aspects could

provide novel insight into the prescription approaches used by coaches that could be utilised to inform and model future training.

To assist with training prescription and periodisation, it is commonplace for sports scientists to carefully monitor athletes to provide objective and subjective evidence to coaches surrounding appropriate training dose and recovery [21]. These athlete monitoring systems are often used to collect data relating to the external and internal loads and skill requirements within training, utilising tools such as global positioning satellite (GPS) units, rating of perceived exertion (RPE) scales and notational analysis of training vision [22]. Indeed, monitoring physical loads via GPS tools such as velocity (e.g., distance, high-speed running) and acceleration-based movements is common practice, with many indicators achieving scientific validation. However, there are currently no tools available to measure and quantify the tactical elements of training including the training prescription by coaches. Obtaining this data would promote a holistic approach to training data collection by quantifying the physical, technical and tactical training completed, understanding training periodisation models and used to plan future training.

1.2 Statement of the Problem

Despite prevalent literature examining the multifaceted demands of rugby league performance, a greater understanding of the physical, technical and tactical demands is required within training. With the current lack of evidence investigating the technical and tactical demands of rugby league training and absence of team-based training drills included within available studies, there is a limited understanding on the holistic demands and preparation approach for rugby league performance. Furthermore, there are currently no investigations on how coaches plan and prescribe training to ensure tactical preparation within all moments of the game according to their desired game style and philosophical approach. Accordingly, investigations are needed to examine if the coaches' tactical prescription can be measured and monitored.

Examining these aspects within professional rugby league can provide objective evidence to assist in informing training prescription and periodisation in accordance with implemented tactical periodisation frameworks and contribute to a holistic understanding and assessment of the preparation process for performance (figure 1.2).

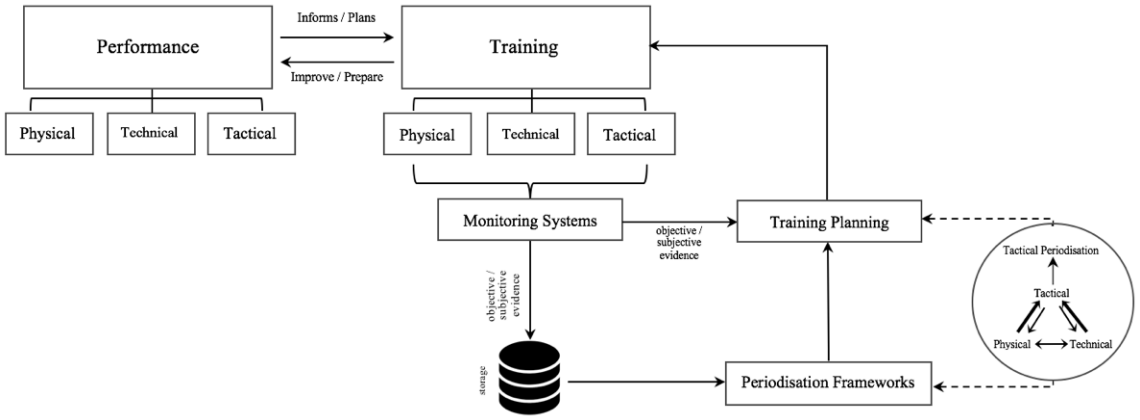


Figure 1.2 Investigated holistic framework utilised to support training, periodisation and performance within professional rugby league in this thesis.

1.3 Research Objectives

This thesis aims to examine, describe and quantify an implemented training and periodisation framework within professional rugby league to provide evidence and contribute to a holistic understanding of the preparation process. The overall objectives of this thesis are to:

- Understand the multifaceted physical, technical and tactical demands of professional rugby league training.
- Provide empirical evidence on how coaches plan training according to their current tactical periodisation framework to better understand how rugby league players are prepared for performance.
- Investigate the coaches' prescription and training framework considering the upcoming opposition.
- Provide a conceptual training framework that can be employed by future sports scientists and coaches that encompasses a holistic approach to the preparation of rugby league players.

To fulfil these objectives, one data collection period over an entire competition season was implemented from one professional club within the National Rugby League (NRL). Findings from this collection period were divided into seven studies to investigate the implementation of training periodisation frameworks (in particular, tactical periodisation)

within professional rugby league training (figure 1.3). Broadly, study one was implemented to scope the current literature on the physical, technical and tactical (multifaceted) demands of rugby league training. A subsequent narrative review was conducted to identify current training and periodisation frameworks commonly implemented within team sports. Based on the identified gaps within the literature (i.e., limited understanding of the multifaceted demands in rugby league training and how coaches plan and prescribe the tactical elements of training), study two (Chapter Three) was implemented to identify how the tactical elements of training were prescribed by interviewing high performance coaches, and a practical tool to measure and describe these aspects was developed. Study three (Chapter Four) and study four (Chapter Five) were implemented to describe the multifaceted demands of training. Study five (Chapter Six) aimed to implement the tool developed in study two (Chapter Three) and examine how coaches design training according to tactical periodisation frameworks. Studies six (Chapter Seven) and seven (Chapter Eight) extend on this investigation by developing a predicted Match Difficulty Index model and comparing coaches' prescription against oppositions of varying predicted difficulty.

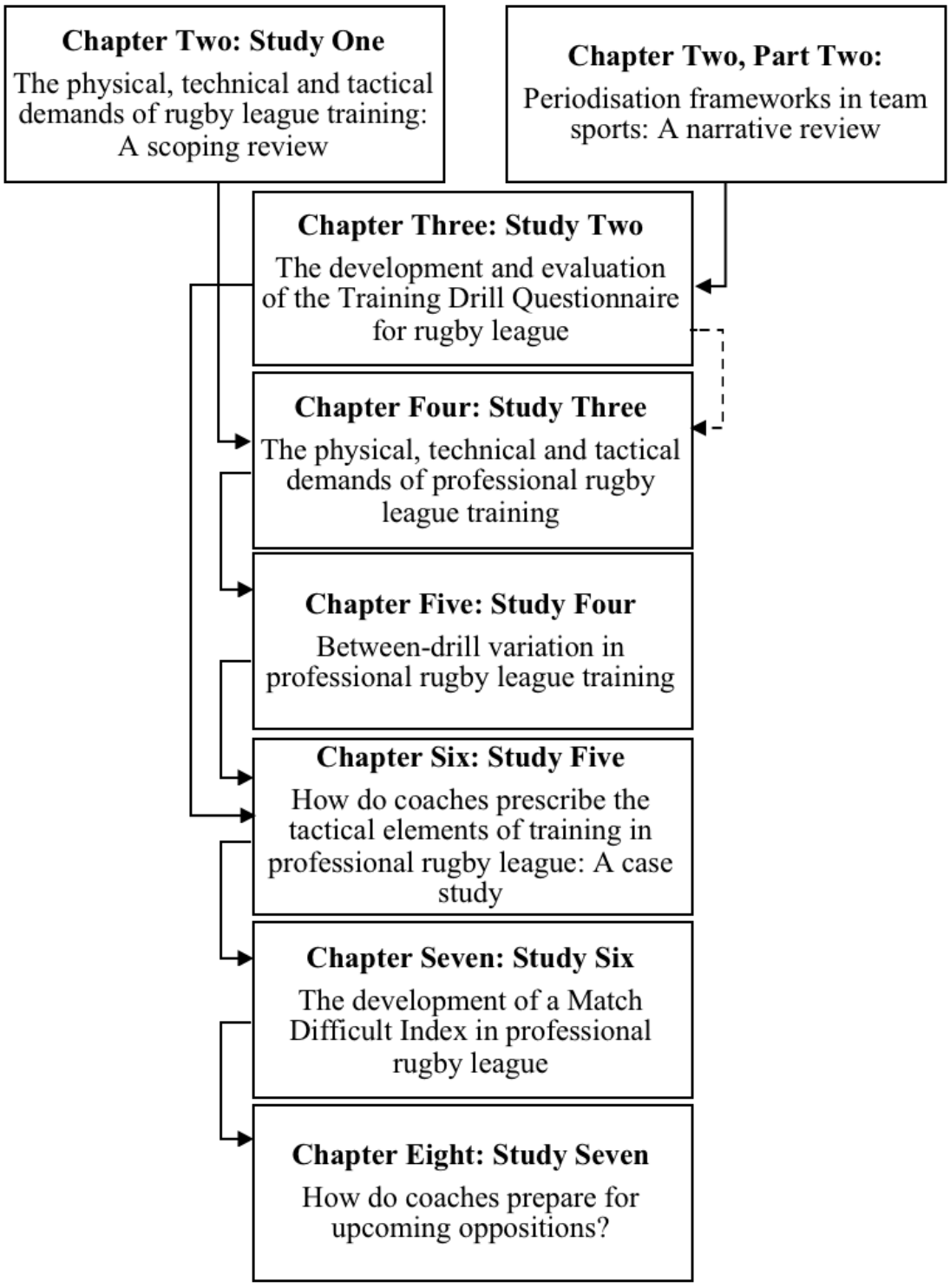


Figure 1.3 Process and links of the research studies involved in this thesis.

1.3.1 Study One: The physical, technical and tactical demands of on-field training drills in professional rugby league: A scoping review

Aims: The aim of study one is to scope peer-reviewed literature on the physical, technical and tactical demands of rugby league training to identify the quantity of research, key concepts and research gaps.

Significance: To date, there are no reviews on the multifaceted (i.e., physical, technical and tactical) demands of professional rugby league training. Accordingly, study one provides the first review to identify key concepts and research gaps within this area to steer future research directions and designs.

1.3.2 Study Two: The development and evaluation of the Training Drill Questionnaire for rugby league

Aims: Study two follows an exploratory research design to provide information on how coaches plan the tactical elements of training. Accordingly, the aims of this investigation is to interview high-performance coaches to identify possible themes for tactical arrangement of on-field training drills and develop an assessment tool to measure and quantify the prescription of these factors.

Hypothesis: Due to the exploratory nature of this study, there are no prior assumptions or hypotheses.

Significance: Tactical periodisation frameworks are implemented by coaches to ensure all training drills are designed to meet the tactics, strategy and game style desired by preparing the multifaceted physical, technical and tactical aspects of performance [20]. While key principles of this framework have been noted [23-25], there is a lack of understanding in how coaches plan, prescribe and assess the tactical elements within rugby league training. Moreover, these studies are limited as there are no tools available to describe these aspects. Therefore, this study is novel as it is the first to develop a training assessment tool, integrating coaching philosophies, tactical strategies, and perceptions of performance.

1.3.3 Study Three: The physical, technical and tactical demands of on-field training drills in professional rugby league

Aims: The aim of study three is to implement a descriptive study design to gather information on the multifaceted demands of professional rugby league training. Specifically, the aim is to describe the physical, technical and tactical demands of on-field training drills that are designed for team preparation. Additionally, this study intends to classify these drills based on the similarities of physical, technical and tactical properties via a data reduction and cluster analysis approach.

Hypothesis: The findings of the study will provide a method to classify training drills in rugby league that considers the multifaceted physical, technical and tactical demands.

Significance: Considering the collective relationship between physical, technical and tactical aspects within team sports and its recognition within recent periodisation and planning approaches, it is important to investigate the multifaceted demands of training drills to provide a holistic understanding towards preparation in team sports such as rugby league. Additionally, this study provides a new classification method for rugby league training drills based on the similarities of physical, technical and tactical properties.

1.3.4 Study Four: Between-drill variation in professional rugby league training

Aims: Study four builds on study three by utilising the derived physical, technical and tactical components and clusters to gather further information on the characteristics of training drills within professional rugby league. Accordingly, the aim of study four is to investigate the between-drill variability of physical, technical and tactical measures.

Hypothesis: With knowledge from previous case studies identifying large variations in physical and technical aspects between rugby league [26] and Australian Football [27] match performance, and the anecdotal process of training planning by coaches, it is hypothesised that variability in physical, technical and tactical measures between training drills will be present.

Significance: Study four provides additional information to understand the holistic characteristics of professional rugby league training. While previous investigations of

physical and technical variability can be utilised to assist with interpreting physical and technical performance changes in team sport, no studies have investigated this within training drills. Accordingly, this is the first study to provide evidence of the variability of multifaceted constructs within training drills.

1.3.5 Study Five: How do coaches prescribe the tactical elements of training in professional rugby league? A case study

Aims: Study five aims to implement the assessment tool developed in study two to describe and quantify the tactical arrangement of on-field training and its distribution during a competition season in professional rugby league. Specifically, this study aims to examine any changes in tactical aspects of training within training weeks and also seasonal variations.

Hypothesis: It is hypothesised that coaches implement a tactical periodisation template by consistently arranging and manipulating the tactical elements of training drills.

Significance: As coaching practices have evolved, there has been an increased need to assess and understand tactical performance in team sports within research. However, there is a lack of understanding surrounding training context and coaches' intention within rugby league. This study is the first to integrate coaching philosophies, tactical strategies, and perceptions of performance within current athlete monitoring and training periodisation processes. Furthermore, it is the first to provide empirical evidence on tactical periodisation and planning frameworks implemented within team sport such as rugby league. This study contributes new information on implemented tactical periodisation frameworks and holistic preparation in rugby league training.

1.3.6 Study Six: Developing a Match Difficulty Index for professional rugby league

Aims: The aim of study six is to replicate previous work in Super Rugby and Australian Football and develop a Match Difficulty Index (MDI) model to predict the difficulty of regular competition season matches in professional rugby league by examining the influence of external factors to match outcome.

Hypothesis: Based on previous research it is hypothesised that the developed MDI model would demonstrate an ability to predict match outcome, with factors such as opposition rank and match location displaying large contributions to determining match difficulty.

Significance: As standard practice, coaches and players study the opposition to identify supposed strengths, weaknesses and current form to assess the difficulty of upcoming matches. This information is often used to guide training plans and periodisation strategies. While investigations on the influence of contextual factors on match difficulty have been conducted in team sports such as Australian Football [28] and rugby union [29], no studies have developed this within rugby league. It is anticipated that with the development of a MDI specific to rugby league, coaches and support staff can strategically manipulate physical and technical loads and tactical approaches to training.

1.3.7 Study Seven: How do coaches design training to prepare for upcoming oppositions?

Aims: Study seven aims to extend on study five by utilising the MDI model developed in study six and examine how coaches prepare and manipulate training for upcoming oppositions by comparing the differences in tactical prescription with training day and difficulty of upcoming opponents.

Hypothesis: It is hypothesised that coaches alter and manipulate their training prescription based on the difficulty of the upcoming opponent.

Significance: It is currently unknown if tactical periodisation approaches remain consistent in preparation for varying upcoming oppositions. Such information would add evidence informing on the efficacy of tactical periodisation frameworks that can be used for decision making and training design to prepare for performance. Accordingly, study seven extends on study five to be the first to establish contextual factors that may be used to influence the design and planning of a tactical periodisation approach.

1.4 Project Limitations and Delimitations

This project acknowledges the following limitations and delimitations in its research design:

Equipment

- The use of Optimeye S5 GPS units (Catapult Sports, Melbourne, Australia) sampling at 10-Hz and firmware version. This equipment was contractually utilised by the industry partner prior to and during the data collection period.
- The number of available satellites, horizontal dilution of precision and associated software and firmware versions for data collection.
- The use of SportsCode Elite video-coding software (Hudl, Sydney, Australia) and firmware version for data collection. This equipment was contractually utilised by the industry partner prior to and during the data collection period.

Data collection

- Data collection from the 2018 competition season from one competitive National Rugby League (NRL) team. Accordingly, implications may only be applicable to this population and not representative of the wider rugby league community.
- Player injuries obtained throughout the season that may reduce data samples in training.

Limitations imposed through collaboration with industry partner

- Thresholds of GPS parameters were determined by the industry partner.
- Internal load (e.g., heart rate, RPE), psychological and subjective measures (e.g., daily wellness questionnaires) were not collected as part of this research project. While it is acknowledged these measures contribute to the holistic preparation of players in rugby league, they were not collected either due to the inability to access the data or to reduce the volume of measures collected (i.e., degrees of freedom). Accordingly, this thesis aims to provide a holistic understanding to rugby league preparation through the use of objective measures, before integrating subjecting measures.

CHAPTER TWO

A Preface to the Literature Review

The overarching aim of rugby league is to score more points than the opposition by scoring tries and kicking goals. This is achieved through obtaining and maintaining optimal field position during attack, defence and transition moments and causing disruption of the opposition's defence line to reveal try scoring opportunities [30-32]. To meet these team objectives, players work collectively and perform intermittent high-intensity activities (i.e., accelerating and high-speed running) and engage in collision events such as tackling and wrestling [3, 6, 33]. They also perform various technical skills as they pass, kick and receive the ball to evade the opposition, gain field territory and perform key events such as scoring points [31, 34]. Accordingly, rugby league performance is reliant on the combination of physical, technical and tactical elements.

The physical demands of rugby league match-play has been thoroughly described within literature [3, 6, 33], and utilised to guide performance strategies (e.g., player interchange during match-play [3]) and inform training approaches including player development pathways [6]. Recent research has also investigated the technical and tactical demands of match-play, including identifying profiles and indicators between successful and less-successful teams [9, 35-37]. Anecdotally, coaches and high-performance staff design and implement detailed training plans to best prepare players for these multifaceted demands of rugby league. Accordingly, this literature review sought to understand how players prepare for professional rugby league performance. This was achieved in two parts; we first conducted a scoping review of the physical, technical and tactical demands of rugby league training and, secondly, provided a narrative review of common periodisation and training frameworks implemented within team sports.

The first part of this review systematically identified 21 papers eligible for inclusion. Of these 21 papers, 20 examined the physical demands of training, six papers examined the technical demands and no papers examined the tactical demands of rugby league training. Five papers included both physical and technical demands of rugby league training within their investigations.

Papers describing the physical demands of rugby league training provide information on velocity and acceleration derived global positioning satellite (GPS) variables, with the majority (12 out of 20) of papers providing observations over shortened periods (i.e., pre-

season phases) [10-12, 14, 38-45]. Five studies investigated the physical demands of training across the whole season (i.e., pre-season and competition phases) [46-50] reporting reductions in distance and high speed running distance within competition phases compared to pre-season and a further reduction was also observed in the latter stage of the competition season [46]. Only one study compared the physical demands of rugby league training to matches discerning game-based drills exceed the running, repeat high intensity effort bouts and moderate collision demands compared to those completed within matches [48]. A large proportion of studies (14 out of 20) investigated the physical demands within various training drills [10, 12, 14, 18, 39-45, 48, 50, 51], with eight of these investigating the physical demands within small sided-games (SSG) to examine the effect of implemented constraints such as contact, on-side and off-side rules, field size and task load [14, 18, 39-43, 51]. While these studies can be collectively useful to inform physical periodisation models and conditioning programs, they predominately adopt a one-factored approach to describing the demands of rugby league training and do not encompass the technical and tactical aspects of performance which are also considered critical to success [9]. Furthermore, these studies failed to provide a detailed description within the numerous team-based drills prescribed by coaches for tactical preparation and do not examine between drill variations that may exist as a result of manipulations of prescription and external influences (e.g., upcoming opposition, number of days between matches).

The technical demands of rugby league training drills have not been well described, with a limited number of empirical studies available. Only six studies have examined the technical demands within rugby league training [14, 16, 18, 39, 41, 51], with five of these studies included as part of investigations on the effects of constraints in SSG (i.e., 'onside' or 'offside' rules, contact demands, target task loads) [14, 18, 39, 41, 51]. Currently only one study has compared the technical demands of SSG and match-play revealing a greater frequency of offensive, defensive and total skill involvements within SSG [16]. Collectively these studies are limited to describe the technical demands of rugby league training, as their study design involves one category of training drill (i.e., SSG). Therefore, future research should investigate the technical demands of various team-based drills designed and implemented within training.

Despite its purported importance to rugby league performance, there have been no reports investigating the tactical demands of rugby league training drills. Additionally, it is unknown how coaches consider, manipulate and meet their tactical objectives within team training drills. Accordingly, how teams tactically prepare within training drills remains unknown and warrants further exploration.

Planning and monitoring the physical aspects of training has become a focal point for athlete management and injury prevention [52, 53]. Consistent and systematic monitoring of the physical demands has allowed large data sets to be utilised for planning and periodising training in accordance with proposed models and frameworks. Models such as the general adaptation syndrome (GAS) [54], fitness and fatigue [55] and tactical metabolic training (TMT) [56] have been proposed, however they all inform a physical-led approach that neglects to incorporate technical and tactical elements of performance. Additionally, a skill acquisition framework (SAP) has been developed to assist in the measurement, monitoring and evaluation of skill training to assist coaches in the technical design and prescription of drills [57]. While this framework can be tailored to meet the specific technical needs of individual players, its application is independent of any physical or tactical components and thereby adopts a reductionist approach. Ideally, future research should integrate a holistic monitoring framework comprising of the physical, technical and tactical elements of performance.

Gaining increased attention is the Tactical Periodisation framework. This framework seeks to shift away from a reductionist approach to periodisation and is designed to consider all physical, technical, tactical and physiological aspects present within team sports, and treats tactics as the supra-dimension or focal point in its design. This framework seeks to align and maintain the game model, principles and style of play coaches desire to implement [20, 23, 24]. While the framework has been outlined and key principles have been proposed, there is a poor understanding and lack of empirical evidence investigating this concept and how coaches implement this paradigm [20]. As such, there are no investigations of tactical periodisation within professional rugby league. The match difficulty index (MDI) has been suggested to inform strategic planning and periodisation based on external influences to assist coaches in assessing the potential difficulty of upcoming matches [28, 29], however it doesn't provide the fundamental tactical

performance indicators required to implement within training sessions. Furthermore, no investigations of how coaches utilise this information to design training and tactically prepare the team have been conducted. Future work adopting and refining methods to examine tactical periodisation approaches may allow the assessment of various game-styles and tactical approaches within rugby league. Identifying valid and reliable monitoring methods to create a holistic, multi-dimensional approach to periodisation and preparation will enhance our understanding of rugby league training and performance.

Currently, there are no studies investigating the multifaceted physical, technical and tactical demands of rugby league training within various team-based training drills coaches design and implement for tactical preparation. Despite an increased recognition in tactical periodisation frameworks, there is a lack of understanding of how coaches plan and prescribe the tactical elements of training drills. Future work investigating this is encouraged and would provide a holistic and robust approach to rugby league preparation and provide a framework for the integration of coaching and sports science departments for the planning and preparation process.

Part One

Study One: The Physical, Technical and Tactical Demands of Rugby League Training: A Scoping Review

2.1 Introduction

Developing and delivering evidence-based practices to assist in improving athletic preparation, performance and athlete management processes is central role of sports scientists working in high performance settings [1]. Following the evidence-based approach, relevant research is utilised to integrate and challenge coaching philosophies and assist the decision-making process of training design and individual needs [1, 22]. To be effective, it is fundamental that sports scientists understand the training and competition demands experienced by athletes. Accordingly, knowledge of the competition demands allows specific and relative training strategies to be planned and implemented to improve and prepare for match performance (figure 2.1). As part of this approach, athlete monitoring has become common practice in high performance sport (e.g., athlete wearable technologies and notational analysis). This monitoring is used to systematically identify and analyse objective and subjective indicators (e.g., muscle soreness, fatigue) regarding each athlete's training, performance and their individual responses to prescribed training loads. The information is then used to identify changes in athlete training 'readiness' and performance capacity [58], and inform decisions on prescribed training [59].

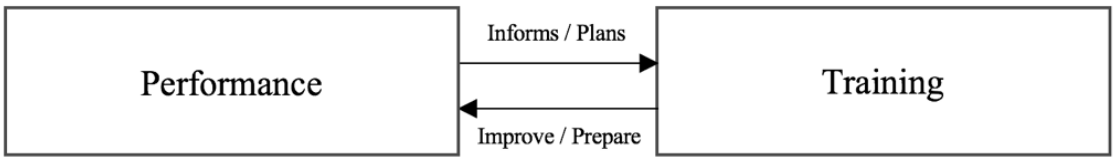


Figure 2.1 Relationship between match performance and training in team sport.

Rugby league is a team sport that requires players to intermittently engage in collision events (i.e., tackles) and perform high-intensity activities (i.e., running and accelerating) separated by bouts of rest (i.e., standing still, walking and jogging) over an ~80-minute period [3, 6, 33]. The ability to achieve high speeds, accelerate, decelerate and change direction allows attacking players to gain on-field metres and evade the approaching line of defence from the opposition. These qualities are also essential within defence to protect field position and reduce field metres gained by attacking players. When defending players meet an attacking ball-carrier within the field of play, they engage in collision events such as tackling and wrestling [60, 61]. Attacking players attempt to withstand these physical collisions to obtain further field position closer to the oppositions try-line [60]. In addition to these physical requirements, players must possess a high level of technical skill to tackle,

pass, kick and receive the ball [31]. Like all team sports, rugby league players must cooperatively interact with each other to develop a style-of-play and structured network to respond cohesively to the opposition during attack, defence and transition moments [30-32]. In attack, teams have 6 consecutive plays (i.e., 'set') to score a try before surrendering possession to the opposition (unless a repeat set is granted because of opposition error). Depending on where field possession is obtained, attacking teams will dedicate plays to either establish optimum field position for subsequent sets (by gaining as many field metres as possible) or seek try scoring opportunities by attempting to cause disorganisation of the defence line. A try (equates to four points) is scored when a player places the ball in a controlled manner over the opposition goal line. After scoring a try, the attacking team has the opportunity to add two points by successfully kicking an uncontested field goal. To ultimately score more points than the opposition, coaches implement a specific game plan and tactical approach based on offensive and defensive principles, strategy and performance moments (i.e., attack, defence and transitions) [24, 30]. Although coaches may modify their tactical approach based on perceived player strengths, capabilities and the opposition, players are required to conform to the desired tactical approach to create an organised system [31]. Ultimately, team performance in rugby league is reliant on the collective physical, technical (individual skill) and tactical (interaction with other individuals) abilities of team members (figure 2.2) [62]. Accordingly, training is deliberately designed to develop, prepare and improve these areas of performance [63].

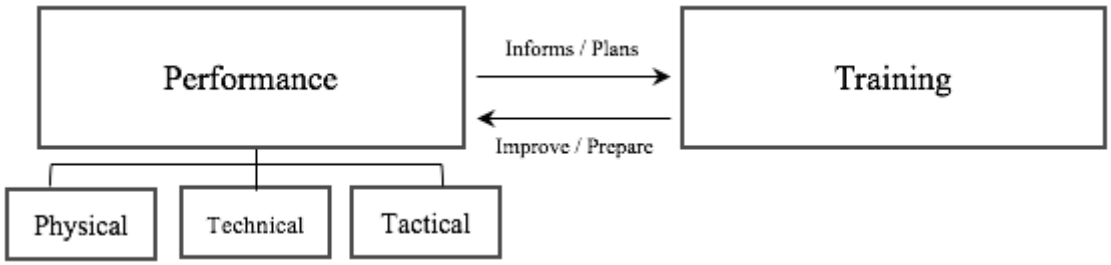


Figure 2.2 The multifaceted constructs of performance embedded within the relationship between match performance and training within professional rugby league.

At the professional level, rugby league coaches and support staff carefully prescribe training to prepare players for the specific demands of competition and for upcoming oppositions [64]. Training drills are designed, implemented and manipulated to develop

the desired style of play and practice the physical, technical and tactical elements required to execute the necessary strategies. Accordingly, strategic actions such as player positioning and running patterns are carefully planned within these training drills. To assist with training prescription, sports scientists implement athlete monitoring systems to provide objective evidence of performance and recovery to coaches [22, 65, 66]. Indeed, as sports scientist have gained better integration within coaching departments, there is a shift for monitoring systems to not only account for the physical work completed, but also provide information relating to the skill requirements and tactical approaches within training [22]. For example, a common role of sport scientists is to provide coaches objective feedback on individual and team technical performance via notational analysis and semi-automated coding video-playbacks [57]. Notational analysis can be used to provide information on the outcome of events (e.g., successful vs. non-successful) or provide the quantity of technical performance indicators (e.g., passes, possession, errors, penalties) within training and performance. This data can be used to quantify and evaluate training and athlete's responses in relation to implemented periodisation frameworks.

Rugby league performance is composed of physical, technical and tactical capabilities [2, 9, 67]. Training is designed to prepare players to withstand these demands and effectively execute necessary actions within these constructs. Understanding the training demands provides important insight into how teams prepare for the multifaceted demands of performance. Coaches and sports scientists could both benefit from this information to assist in training design and adopt a holistic approach to training prescription and preparation. However, at present, the available literature regarding the physical, technical and tactical demands within rugby league training has not been reviewed. For these reasons, a scoping review was conducted to systematically search the available literature on the physical, technical and tactical demands of rugby league training. The main objectives were to examine the extent and nature of studies investigating this topic, summarise key findings and identify any existing gaps in knowledge [68].

2.2 Methods

2.2.1 Design and Search Strategy

The protocol for this scoping review was pre-registered on the Open Science Framework (https://osf.io/m5pfw) and followed the Preferred Reporting Items for Systematic reviews

and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist [68]. A systematic online search of electronic databases (Scopus, PubMed, MEDLINE, and SPORTDiscus) was performed from earliest record to 5th October 2021. The search strategy combined terms relevant to rugby league training ("rugby league", "training", "rugby league training"), and terms relevant to the physical, technical and tactical demands of rugby league: "physical demands", "physical exertion", "physical performance" OR "technical demands", "skill demands", "technical performance", OR "tactical demands", "tactics", "tactical performance". The online search was supplemented by manually exploring the reference lists of selected articles.

2.2.2 Study Selection

Retrieved studies from the online search were downloaded to Endnote (X9.3.3, Clarivate Analytics, Australia) and duplicates were removed. Titles and abstracts were independently reviewed by two researchers (JH, AC) against the eligibility criteria (table 2.1). Articles which could not be eliminated by the title or abstract were retrieved and evaluated for inclusion via a full-text review against the eligibility criteria. Disagreements between researchers were consulted and resolved via a third researcher (KS) throughout the study selection process.

Table 2.1 Applied inclusion and exclusion criteria.

Inclusion Criteria	**Exclusion Criteria**
• Male participants • All levels of competition (junior, semi-professional, professional) • All Australian and overseas competitions • On-field rugby league training sessions or training drills • >1 physical (measured by GPS), technical or tactical outcome measure	• Reviews, opinion pieces, conference articles • Non-English papers • Unable to retrieve full-text articles • No GPS, technical or tactical on-field measures reported as part of a testing battery investigations • Outcome measures reported to describe testing battery protocol

> more than, GPS Global positioning satellite

2.2.3 Data Extraction and Categorisation

For the purpose of this scoping review, primary categories were formed based on the distinct, but interrelated physical, technical and tactical elements present in team sport

performance [62]. Accordingly, studies were first organised within each category as per the following descriptions:

- Physical: external load (i.e., work completed) by an individual or team
- Technical: acquisition and execution of rugby league related individual or team skills e.g., passing, tackling, kicking, play-the-balls
- Tactical: interactions with other team members to execute strategic actions

Subcategories were successively formed based on observation period and types of training drills (indicated by study aims) included within their design to highlight how research has addressed these areas within rugby league training. All eligible articles were reviewed and categorised by authors (JH, AC) with any disagreements resolved via the third researcher (KS). General characteristics of each study including; publication year, cohort competition, number of participants, sample size, observation period, number of files, GPS device / method and geography were extracted. Data relating to the aims, outcome measures and key findings of each study were also extracted for each study.

2.2.4 Data Charting and Synthesis

Extracted data regarding was compiled into an Excel spreadsheet (version 16.16.27, Microsoft Office, Australia) and data charts were formed. Continuous data such as publication year was charted using line charts and categorical data such as cohort competition and geography was charted as pie charts to display quantity and proportion. Data charts were created according to each theme (i.e., physical, technical and tactical).

Characteristics, main outcomes and a summary of the key findings were tabularised for each theme via an Excel spreadsheet (version 16.16.27, Microsoft Office, Australia) Where appropriate, data is expressed as mean ± standard deviation (SD), mean (95% confidence intervals (CI)) or mean (range) unless otherwise stated. No further analysis or conversion of outcome metrics was conducted.

2.3 Results

2.3.1 Search and Selection of Studies

The primary search of literature examining the physical, technical and tactical demands of training captured 722 papers with seven additional papers identified through other sources (n = 729). Following the removal of duplicates and ineligible manuscripts, 20 papers were

included in this review (figure 2.3). Of these studies, 14 (70%) exclusively examined the physical demands of training, one (5%) exclusively examined the technical demands of training, five (25%) studies included both physical and technical demands, and no studies examined the tactical demands of training.

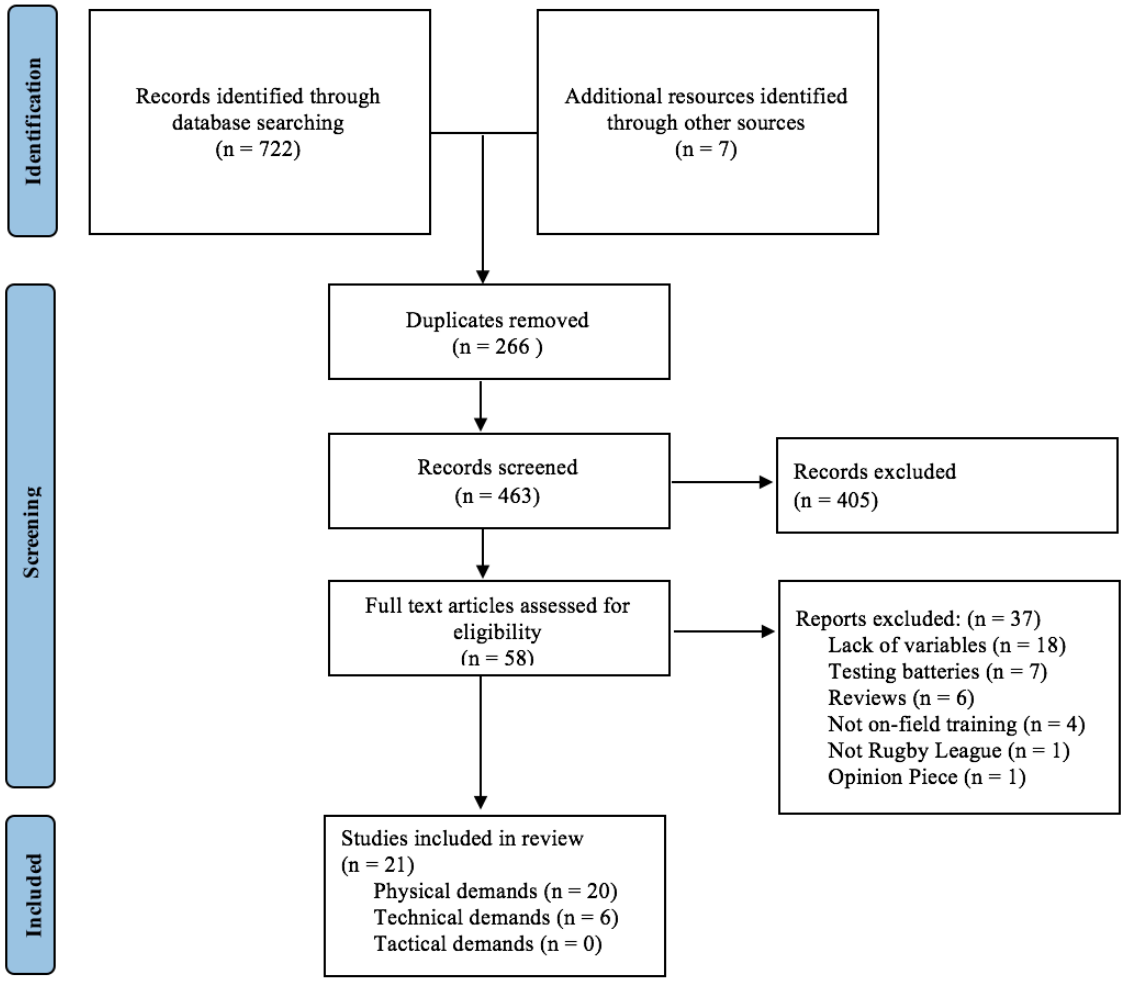


Figure 2.3 Selection process of eligible studies for this review.

2.3.2 General Characteristics

Figure 2.4 demonstrates the number of publications of studies examining the physical, technical and tactical demands of rugby league training with the first publication dated back to 2010. The number of publications examining the physical demands peaked (n = 4) in 2012, with an average of one to two studies published each year since. The maximum number of publications on the technical demands of rugby league training was identified in 2012 (n = 2) and 2016 (n = 2).

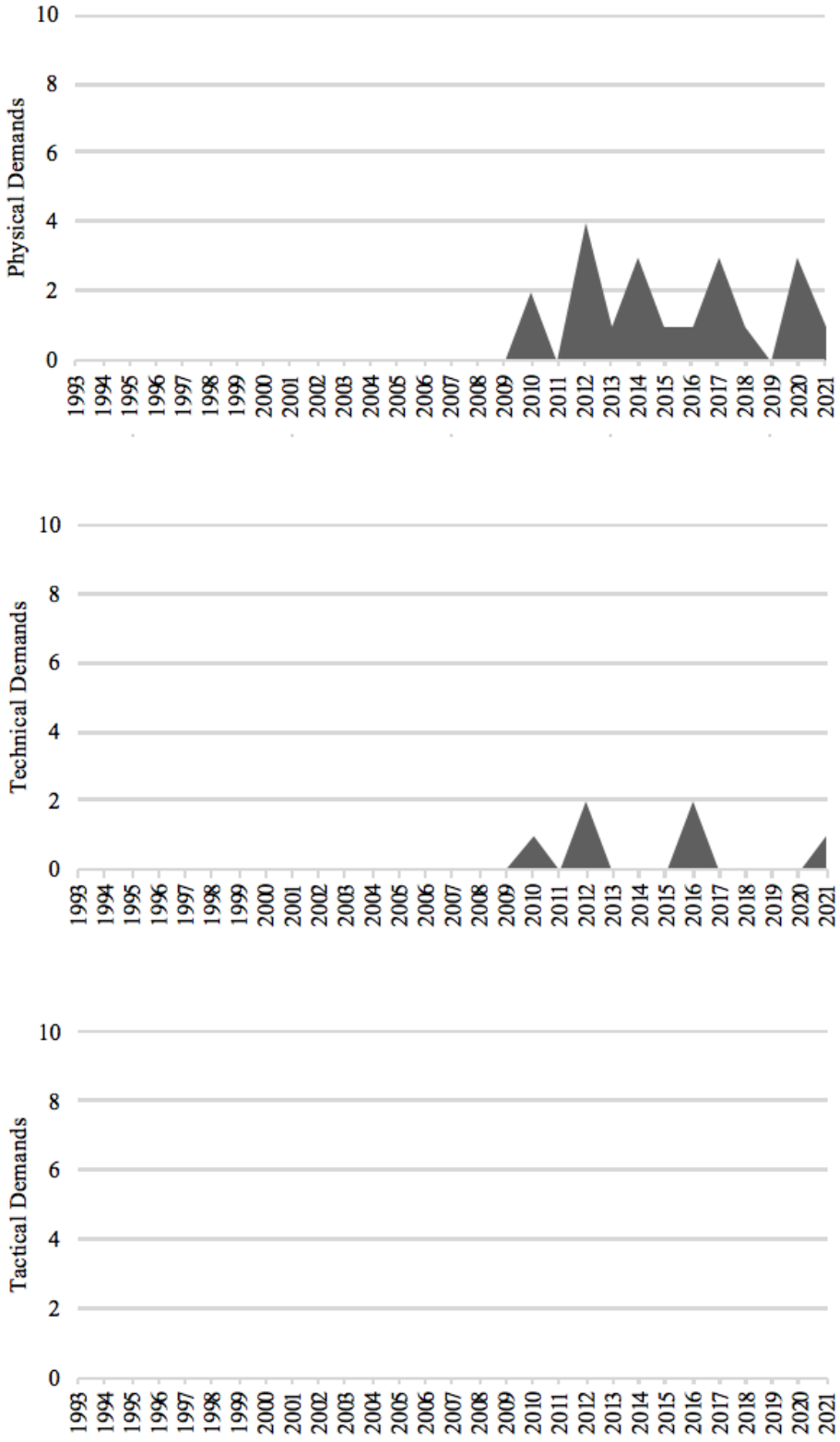


Figure 2.4 Publications of the physical, technical and tactical demands of rugby league training per year (search date 05/10/2021).

Of all studies examining the physical demands of rugby league training (n = 20), 12 studies (60%) were from Australian competitions, 6 studies (30%) were from overseas competitions and 2 studies (10%) did not disclose the geography of competition. The majority of studies investigating the technical demands of rugby league training were from Australian competitions (n = 5, 83%) whiles the remaining study (n = 1, 17%) did not disclose the geography of competition.

The number and proportion of competition levels examined within the included studies is displayed in figure 2.5. The majority of studies examining the physical demands of rugby league training were within the professional level of competition, followed by junior and semi-professional competitions respectively. An equal number of studies examining the technical demands of rugby league training in professional and junior was observed.

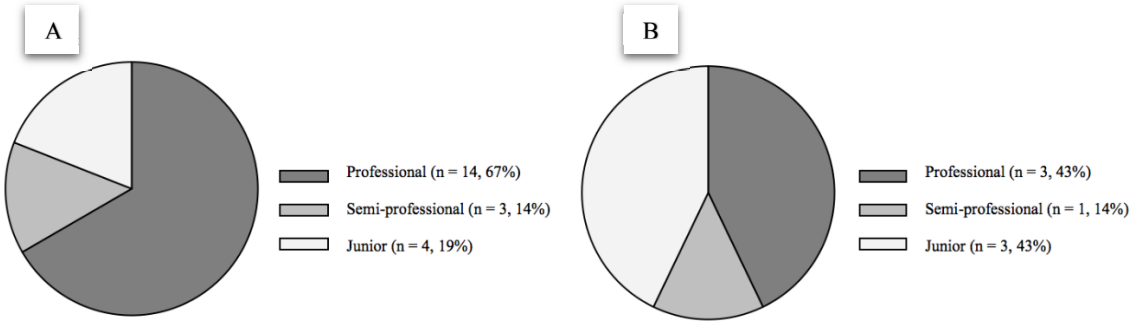


Figure 2.5 Cohort competition levels of studies examining the A. physical and B. technical demands of rugby league training.

2.3.3 Physical Performance

2.3.3a Competition Phase

Twenty studies examined distance, velocity and acceleration parameters to describe the physical demands of rugby league training or training drills within junior [14, 17, 42, 43], semi-professional [12, 19, 40] and professional [10, 11, 14, 15, 18, 38, 44, 45, 47-50, 69, 70] competitions (table 2.2). Characteristics of these studies displayed that 12 out of 20 (60%) exclusively examined the physical demands within pre-season phases (including pre-competition phase) [10-12, 14, 15, 19, 38, 40, 42-45], with 5 studies (25 %) observing the physical demands across the whole season (pre-season and competition phases) [47-50, 69]. Findings have also displayed greater training duration and load measures such as

total distance and high speed running distance within pre-season phases compared to in-season periods (early-, mid-, late-) [69]. Additionally, while the majority of physical parameters remained similar throughout in-season phases, a further reduction of total and relative high-speed running distance was observed during late in-season. Another study examined the number of collisions and associated injury incidences during the whole season, reporting a greater number of collisions and injury rates during training sessions with 10 days recovery between matches compared to shorter turnarounds [47]. Additionally greater collision injury rates occurred during pre-season periods (9.3 per 10,000 collisions) compared to in-season (4.2 per 10,000 collisions) [47].

2.3.3b Training Drills

Fourteen out of the 20 studies (70.0 %) [10, 12, 14, 15, 17-19, 40, 42-45, 48, 50] investigated the physical demands of various training drills. These studies assessed positional differences [10], evaluated the validity of training load and monitoring measures [12, 44, 45, 50] or examined the effect of various constraints of game-based activities [14, 15, 17-19, 40, 42, 43]. Only one study has compared the physical demands of professional rugby league training and match demands to identify training activities useful for physical match preparation [48]. In this previous study, distance, speed and collision-based parameters were analysed within common on-field training drills (traditional conditioning, repeated high-intensity effort, game-based and skills) used to prepare players for the overall match demands of the National Rugby League (NRL) competition. The physical demands of game-based training provided significant comparisons to match performance by exceeding the running demands (137 vs. 96 $m \cdot min^{-1}$), number of repeated high-intensity effort bouts (RHIE) (1 every 4.5 min vs. 1 every 6.9 min) and rate of moderate collisions (0.38 vs. 0.34 $no \cdot min^{-1}$).

Of greater prevalence, eight of the 14 studies (57.1%) exclusively examined physical parameters within various small-sided games (SSG) including constraints in contact [15, 40, 42, 43], on-side and off-side rules [18] field size [14] and task load targets (physical, technical, cognitive, frustration, temporal) [17]. Findings from these studies showed 'non-contact' SSGs allowed greater total distance and high-speed running distances to be achieved when compared to 'contact' SSG. While contact SSGs elicited a greater number of accelerations, RHIE and PlayerLoad variables (2D and Slow) [43]. Additionally,

distances above very high-speed thresholds were reported to be negatively associated with technical and frustration load but increased physical, temporal, effort, performance and total load within elite junior athletes [17].

Table 2.2 Characteristics of studies examining the physical demands of on-field training drills in rugby league.

Study	Study Aims	Comp.	Participants = n	Observation period = n of training sessions	Files = n	GPS Device	GPS Outcome Measures	Physical Demands of Training Results Overview
Black C, et al., 2018 [69]	To compare differences in external training loads during field-based training sessions at different stages of the season (i.e. pre- vs. early, mid and late in-season)	ESL	11 F = 4 B = 5	Whole season 11 week pre-season = 3.5 ± 1.2 per week 11 week early = 2.5 ± 0.7 per week 11 week middle = 2.4 ± 0.7 per week 11 week late = 2.8 ± 0.6 per week	Total = 782 Pre- = 211 Early = 194 Middle = 171 Late = 206	10 Hz *(STATSports Viper Pod, STATSports Technologies LTD)*	Session duration (min), total distance (m, m·min^{-1}), walking ([m] 0.01–1.59 m·s^{1}), jogging ([m] 1.60–2.69 m·s^{1}), cruising ([m] 2.70–3.79 m·s^{1}), striding ([m] 3.80–4.99 m·s^{1}), HSR ([m] 5.00–5.49 m·s^{1}), sprinting ([m] >5.50 m·s^{1}) distance, total-HSR ([m, m·min^{1}] HSR + sprinting)	Training loads (with the exception of distance (m·min^{-1}) and total-HSR (m·min^{-1}), were greater in pre-season compared to in-season periods. A reduction in duration and total-HSR observed in-season compared to pre-season. A further reduction in total-HSR (m, m·min^{1}) observed in late in-season.
Crang Z, et al., 2020 [38]	To investigate the relationship between preseason training load, technical match performance, and physical match activity profiles	NRL	22	12-14 week pre-season = 32.5 ± 8.5 sessions	NR	10 Hz interpolated to 15 Hz with in-built 100 Hz triaxial accelerometer and gyroscope *(EVO; GPSports, Canberra, Australia)*	Distance (m·min^{-1}), HSR ([m, m·min^{-1}], >68% of 30–15 IFT)	Players covered an average distance of 150,130 ± 55,058 m across preseason sessions with 14,502 ± 6,765 m high-speed running. Moderate-large positive association of pre-season HSR load (m) and HSR (m·min^{-1}) match activity in early-, mid- and late-season.
Cummins C, et al., 2017 [10]	To quantify external training loads by position and varying training drills (speed, conditioning, generic, positional) across a preseason	NRL	33 OB = 9 Adj = 9 WRF = 9 HUF= 6	8 week pre-season = NR	NR	10 Hz interpolated to 15 Hz with in-built 100 Hz triaxial accelerometer and gyroscope *(High Performance Unit, GPSports, Canberra, Australia)*	Drill duration (min), distance (m, m·min^{-1}), HSR ([m, m·min^{1}] 15–20 km·h^{-1}), VHSR ([m, m·min^{1}] >20 km·h^{-1}), 2D BodyLoad (AU, AU·min^{1})	The greatest distance was achieved in week 3 of pre-season (17,888 ± 6,591 m). HSR in week 1 (3,296 ± 1,124 m) and week 3 (3,152 ± 1,095 m) were higher than week 2, 7 and 8. VHSR was highest in week 5 (1087 ± 624 m), achieved largely (74%) through during conditioning drills (811 ± 405 m). A reduction in total distance, HSR and VHSR, 2D BodyLoad from weeks 1 to 8 in speed, conditioning, and generic drills was observed. Increases in duration, distance, HSR, VHSR, 2D BodyLoad in positional skills was observed. Minimal differences between positional groups for conditioning, speed and generic drills was observed. HUF reported greater 2D BodyLoad (AU, AU.min^{1}) and OB reported greater HSR + VHSR (m, m.min^{1}) within positional-based drills.

Study	Study Aims	Comp.	Participants = n	Observation period = n of training sessions	Files = n	GPS Device	GPS Outcome Measures	Physical Demands of Training Results Overview
Dobbin N, Atherton A, Hill C, 2021 [17]	To determine if SSGs could be designed to target specific task loads (physical, technical, temporal, cognitive, frustration) and quantify the subjective task loads via NASA-TLX questionnaire. Determine the association between physical and technical demands within each task load.	Elite Junior	26	NR = 1	130	10 Hz with in-built 100-Hz triaxial accelerometer, gyroscope, and magnetometer *(Optimeye S5; Catapult Innovations, Melbourne, Australia)*	Total distance (m), very low (0–1 $m \cdot s^{-1}$), low- ([m] 1–3 $m \cdot s^{-1}$), moderate- (3–5 $m \cdot s^{-1}$), HSR- (5–7 $m \cdot s^{-1}$), and VHSR- (>7 $m \cdot s^{-1}$) distance, accelerations ([$m \cdot min^{-1}$] >3 $m \cdot s^{-1}$), decelerations ([$m \cdot min^{-1}$] >3 $m \cdot s^{-1}$), PlayerLoad (AU), HMP distance ([m] >20 W·kg−1), and peak velocity [$m \cdot s^{-1}$].	Total distance, HSR and VHSR were positively associated with physical load, effort, performance, and total load. HSR negatively associated with technical, frustration, and cognitive load. VHSR negatively associated with technical load and frustration. For every meter covered at VHSR, physical, temporal, effort, performance and total load would increase by 2-4 AU. Very low-speed was positively associated with effort, technical and frustration load. Peak velocity was positively associated with all measures of load except effort. Accelerations positively associated with all but temporal and cognitive load. HMP reported negative associations with physical, cognitive, and performance loads.
Gabbett T, Jenkins D, Abernethy B 2010 [47]	To describe the number and intensity of collisions and relate to recovery periods	NRL	30	Whole season (pre-season + in-season) = 117	NR	5 Hz with in-built 100 Hz triaxial accelerometer and gyroscope *(minimaxX, Catapult Innovations, Melbourne, Australia)*	Total (n, $n \cdot min^{-1}$), mild (n, $n \cdot min^{-1}$), moderate (n, $n \cdot min^{-1}$), and heavy (n, $n \cdot min^{-1}$) collisions	A total of 57,966 collisions were recorded across the season. Average number of training collisions performed by HUF, WRF, Adj and OB were 23, 20, 18, 16 respectively. HUF were involved in more mild (n) collisions than OB, and more moderate (n) and total (n) collisions than OB and Adj. 60% and 9% of training collisions were classified as moderate and heavy collisions respectively.
Gabbett T, Jenkins D, Abernethy B 2010 [18]	To investigate the physical and skill demands of 'on-side' and 'off-side' SSG	NRL	16	Competition phase = 2	NR	5 Hz with in-built 100 Hz triaxial accelerometer and gyroscope *(minimaxX, Catapult Innovations, Melbourne, Australia)*	Distance (m, $m \cdot min^{-1}$), mild ([m] 0.55-1.11 $m \cdot s^{-2}$), moderate ([m] 1.12–2.78 $m \cdot s^{-2}$) and maximal ([m] ≥ 2.79 $m \cdot s^{-2}$), very-low ([m] 0–1 $m \cdot s^{-1}$), low ([m] 1–3 $m \cdot s^{-1}$), moderate ([m] 3–5 $m \cdot s^{-1}$), HSR ([m] 5–7 $m \cdot s^{-1}$), and VHSR ([m] >7 $m \cdot s^{-1}$) distance, short (<30 seconds), moderate (30 – 120 seconds) and long (> 120 seconds) recovery between efforts	'Off-side' SSG resulted in greater total distance (m, $m \cdot min^{-1}$), mild and moderate accelerations and low, moderate and HSR distance and short duration recovery periods.

Study	Study Aims	Comp.	Participants = n	Observation period = n of training sessions	Files = n	GPS Device	GPS Outcome Measures	Physical Demands of Training Results Overview
Gabbett T, Abernethy B, Jenkins D 2012 [14]	To investigate the effect of field size changes on the physiological and skill demands on 'off-side' SSG	Elite Junior and NRL	Elite junior = 16 NRL = 16	Pre-competition phase = 2	NR	5 Hz with in-built 100 Hz triaxial accelerometer and gyroscope *(minimaxX, Catapult Innovations, Melbourne, Australia)*	Distance (m, m·min^{-1}), very-low ([m] 0–1 m·s^{-1}), low ([m] 1–3 m·s^{-1}), moderate ([m] 3–5 m·s^{-1}), HSR ([m] 5–7 m·s^{-1}), and VHSR ([m] >7 m·s^{-1}) distance, short (<30 seconds), moderate (30 – 120 seconds) and long (> 120 seconds) recovery between efforts	Larger field SSG resulted in greater total distance (m, m·min^{-1}), moderate, HSR and VHSR distance compared to smaller fields. NRL players covered more moderate, HSR and VHSR distance and less low and very-low distance compared to junior players. NRL players had less shorter duration recovery periods on a smaller field and less recovery durations on larger sized fields.
Gabbett T, Jenkins D, Abernethy B 2012 [15]	To investigate the influence of wrestling on the physical and skill demands of SSG	NRL	28	Pre-competition phase = 2	NR	5 Hz with in-built 100 Hz triaxial accelerometer and gyroscope *(minimaxX, Catapult Innovations, Melbourne, Australia)*	Distance (m, m·min^{-1}), mild ([m] 0.55-1.11 m·s^{-2}), moderate ([m] 1.12–2.78 m·s^{-2}) and maximal ([m] ≥ 2.79 m·s^{-2}) accelerations, very-low ([m] 0–1 m·s^{-1}), low ([m] 1–3 m·s^{-1}), moderate ([m] 3–5 m·s^{-1}), HSR ([m] 5–7 m·s^{-1}), and VHSR ([m] >7 m·s^{-1}) distance, short (<30 seconds), moderate (30 – 120 seconds) and long (> 120 seconds) recovery between efforts, RHIE bouts (n)	No-wrestling SSG resulted in greater total distance (m, m·min^{-1}), and distance covered at low, moderate, HSR, and VHSR speed. Wrestling SSG reported greater mild, moderate, and maximal acceleration distance, greater RHIE, very-low distance and fewer number of short duration recovery periods.
Gabbett T, Jenkins D, Abernethy B 2012 [48]	To compare the physical demands of match-play to traditional conditioning, RHIE, skills and game-based training drills	NRL	30	Whole season = 124	Total = 786 HUF = 212 WRF = 225 Adj = 29 OB = 29	5 Hz with in-built 100 Hz triaxial accelerometer and gyroscope *(Team 2.5, Catapult Innovations, Melbourne, Australia)*	Distance (m, m·min^{-1}), low ([m] 1–5 m·s^{-1}), HSR ([m] >5 m·s^{-1}), distance, RHIE bouts (n), duration (s) and recovery (s), total (n, n·min^{-1}), mild (n, n·min^{-1}), moderate (n, n·min^{-1}), and heavy (n, n·min^{-1}) collisions	Distance in traditional conditioning exceeded match-play (164 [160-169] m·min^{-1} vs. 96 [93-99] m·min^{-1}). Distance in RHIE drills (91 [84-99] m·min^{-1}) and skills (58 [57-59] m·min^{-1}) were lower than match-play. Collisions and RHIE demands of traditional conditioning and skills were lower than match-play. Distance in game-based training (137 [133-141] m·min^{-1}) exceeded match-play. Moderate collisions (n·min^{-1}) of game-based training was similar to match-play, while heavy collisions was lower than match-play.

Study	Study Aims	Comp.	Participants = n	Observation period = n of training sessions	Files = n	GPS Device	GPS Outcome Measures	Physical Demands of Training Results Overview
Gabbett T, Ullah S, 2012 [49]	To report on the running demands of training and investigate the relative risk of low- and high-intensity activities on lower body soft-tissue injury	NRL	34	Whole season = 117	NR	5 Hz with in-built 100 Hz triaxial accelerometer and gyroscope *(minimaxX, Catapult Innovations, Melbourne, Australia)*	Distance (m, $m \cdot min^{-1}$), mild ([m] 0.55-1.11 $m \cdot s^{-2}$), moderate ([m] 1.12–2.78 $m \cdot s^{-2}$) and maximal ([m] ≥ 2.79 $m \cdot s^{-2}$) accelerations, very-low ([m] 0–1 $m \cdot s^{-1}$), low ([m] 1–3 $m \cdot s^{-1}$), moderate ([m] 3–5 $m \cdot s^{-1}$), HSR ([m] 5–7 $m \cdot s^{-1}$), VHSR ([m] >7 $m \cdot s^{-1}$) distance and total HSR ([m], HSR + VHSR), RHIE bouts (n)	Total distance was higher in pre-season (4003 [971-6750]* m) compared to early- (3923 [609-11058]* m) and late-season (3449 [1219-6592]* m) phases.
Johnston R, et al., 2014 [42]	To assess the influence of physical contact on fatigue and muscle damage following SSG	Elite Junior	23	Pre-season = 2	NR	10 Hz with in-built 100-Hz triaxial accelerometer, gyroscope and magnometre *(Team S4; Catapult Sports, VIC, Australia)*	Distance (m, $m \cdot min^{-1}$), low ([m, $m \cdot min^{-1}$] 0-5 $m \cdot s^{-1}$), and HSR ([m, $m \cdot min^{-1}$] >5.1 $m \cdot s^{-1}$) distance, RHIE (n)	With the exception of RHIE, all variables were greater in non-contact SSG compared to contact SSG.
Johnston R, et al., 2014 [43]	To determine the influence of contact on running performance during SSG	Elite Junior	23	Pre-season = 2	NR	10 Hz with in-built 100-Hz triaxial accelerometer, gyroscope and magnometre *(Team S4; Catapult Sports, VIC, Australia)*	Distance (m, $m \cdot min^{-1}$), low ([m, $m \cdot min^{-1}$] 0-5 $m \cdot s^{-1}$), and HSR ([m, $m \cdot min^{-1}$] >5.1 $m \cdot s^{-1}$) distance, RHIE (n), 2D PlayerLoad (AU)	Greater distance (139 [134-144] $m \cdot min^{-1}$) and low speed distance (120 [116-124] $m \cdot min^{-1}$) was reported in non-contact SSG compared to contact SSG. Only small differences were observed for HSR (m, $m \cdot min^{-1}$) between contact and non-contact SSG. 2D PlayerLoad was greater during contact SSG compared to non-contact SSG (0.20 [0.19-0.21] vs. 0.11 [0.11-0.12] AU).
Johnston R, Gabbett T, Jenkins D, 2015 [40]	To examine the influence of performing single-, double-, or triple contact efforts in a single bout on the physical demands during 'off-sided' SSG	Semi-pro.	18	Pre-season = 1	NR	10 Hz with in-built 100-Hz accelerometers and gyroscopes *(Team S4, Catapult Sports, VIC, Australia)*	Distance ($m \cdot min^{-1}$), % change in low-speed activity (0–3.5 $m \cdot s^{-1}$), moderate-speed running (3.6–5.0 $m \cdot s^{-1}$), and HSR (≥5.1 $m \cdot s^{-1}$), PlayerLoad Slow ([AU], <2 $m \cdot s^{-1}$)	Little difference was observed for distance ($m \cdot min^{-1}$) between the single-, double-, and triple-contact games. Small changes in distance ($m \cdot min^{-1}$) from first to second half were observed in single- and double contact games. Distance ($m \cdot min^{-1}$) in the second half of the double- and triple contact games were lower than the second half of the single-contact game. As the number of contact efforts increased, greater reductions in HSR was observed. PlayerLoad Slow increased with the contact demands of each game.

Study	Study Aims	Comp.	Participants = n	Observation period = n of training sessions	Files = n	GPS Device	GPS Outcome Measures	Physical Demands of Training Results Overview
Johnston R, et al., 2016 [19]	To determine the impact of different RHIE bouts on running intensities, skill involvements, and neuromuscular fatigue during SSG.	QC	22	Pre-season = 4	NR	10 Hz with in-built 100-Hz triaxial accelerometer and gyroscope *(S5; Catapult Sports, VIC, Australia)*	Distance ($m \cdot min^{-1}$), low ([$m \cdot min^{-1}$ 0-3.5 $m \cdot s^{-1}$), moderate ([$m \cdot min^{-1}$] 3.6-5.0 $m \cdot s^{-1}$), and HSR ([$m \cdot min^{-1}$] >5.1 $m \cdot s^{-1}$) distance and Player Load Slow ([AU] <2 $m \cdot s^{-1}$)	Contact-dominant RHIE bouts reduced running intensity during SSG compared to running-dominant RHIE activity.
Lovell T, et al., 2013 [50]	To examine the validity of sRPE for monitoring training intensity in conditioning, skills, skills-conditioning, speed and wrestle training	NRL	32	Whole season = 75.2 ± 25.7 sessions	Total = 2400 Conditioning = 398 Skills = 1097 Skills-conditioning = 365 Speed = 262 Wrestle = 278	5 Hz with in-built 100 Hz triaxial accelerometer *(SPI Pro, GPSports, Canberra, Australia)*	Distance (m, $m \cdot min^{-1}$), HSR ([m, $m \cdot min^{-1}$] >15 $km \cdot h^{-1}$), impacts ([n, $n \cdot min^{-1}$] >5 g), Body Load (AU, $AU \cdot min^{-1}$)	Average training session loads for distance, HSR, impacts and Body Load were 2801 ± 1578 m, 392 ± 316 m, 451 ± 493 and 63,466 ± 70,409 AU respectively. Average training session intensity for distance, HSR, impacts and BodyLoad were 79 ± 38 $m \cdot min^{-1}$, 12 ± 12 $m \cdot min^{-1}$, 13 ± 15 $n \cdot min^{-1}$, 1903 ± 2127 $AU \cdot min^{-1}$ respectively.
Twist C et al., 2017 [70]	To understand any cumulative fatigue responses from training and match loads during a congested-fixture period	ESL	15 F = 8 Adj = 3 B = 4	22-day congested period = 9	NR	10 Hz *(Viper pod 2, STATSports, Belfast, UK)*	Distance (m, $m \cdot min^{-1}$), low ([$m \cdot min^{-1}$] <5.4 $m \cdot s^{-1}$), HSR ([$m \cdot min^{-1}$] ≥5.5 $m \cdot s^{-1}$), accelerometer load (AU)	Average distances covered in training sessions were 57 ± 12 $m \cdot min^{-1}$. Average HSR and low-speed distance in training sessions were 2.8 ± 1.6 and 56 ± 7 $m \cdot min^{-1}$ respectively.
Weaving D, et al., 2014 [45]	To examine the influence of training mode (SSG, conditioning, skills, speed, strongman, wrestle) on the relationship of common training load measures	ESL	17	2 x 12-week preseason = 42 ± 13 sessions	Total = 716 SSG = 88 Skills = 263 Conditioning = 170 Speed = 99 Strongman = 60 Wrestle = 41	5 Hz interpolated to 15 Hz with in-built 100 Hz triaxial accelerometer *(SPI Pro XII, GPSports, Canberra, Australia)*	Duration (min), HSR ([m], 15$km \cdot h^{-1}$), impacts ([n] >5 g), Body Load (AU)	HSR (m) for SSG, skills, conditioning, speed, strongman and wrestle drills were as follows: 479 ± 472, 252 ± 222, 797 ± 512, 232 ± 159, 60 ± 93 and 54 ± 77. BodyLoad (AU) for SSG, skills, conditioning, speed, strongman and wrestle were as follows: 79 ± 85, 36 ± 33, 93 ± 73, 28 ± 18, 9 ± 13 and 11 ± 9. Impacts (n) for SSG, skills, conditioning, speed, strongman and wrestle drills were as follows: 1835 ± 1819, 1069 ± 965, 3202 ± 2490, 603 ± 400, 391 ± 428 and 269 ± 261. A combination of internal and external load measures explain a greater proportion of variation within training drills, rather than internal or external measures independently.

Study	Study Aims	Comp.	Participants = n	Observation period = n of training sessions	Files = n	GPS Device	GPS Outcome Measures	Physical Demands of Training Results Overview
Weaving D, et al., 2017 [12]	To examine the influence of training mode (conditioning and skills) on common measures of training load	KPC	23	12-week preseason = 28 ± 5 sessions	Total = 640 Skills = 448 Conditioning = 192	10 Hz with in-built 100 Hz tri-axial accelerometer *(Optimeye X4, Catapult Innovations, Scoresby, Victoria)*	Duration (min), HSR ([m], >speed achieved in 30-15 IFT [19.6 ± 0.6 km·h^{-1}]), PlayerLoad (AU)	HSR (m) for skills and conditioning were as follows: 202 ± 265 and 559 ± 455. PlayerLoad (AU) for skills and conditioning were as follows: 351 ± 150 and 232 ± 81. A single component explained 56.6 % of the variance within skill drills and two components explained 85.4 % of the variance within conditioning drills.
Weaving D, et al., 2020 [11]	To investigate the relative contribution of duration and intensity to training load	ESL	10	6 week pre-season = 19 ± 4 sessions	197	5 Hz interpolated to 15 Hz with in-built 100 Hz triaxial accelerometer *(SPI Pro XII, GPSports, Canberra, Australia)*	Duration (min), distance (m, m·min^{-1}), BodyLoad (AU, AU·min^{-1})	Average session duration was 44 ± 16 min. Average training load for distance and BodyLoad were 3069 ± 1451 m and 63.3 ± 48 AU respectively. The average training intensity for distance and BodyLoad were 70.1 ± 21.8 m·min^{-1} and 1.5 ± 1.0 AU·min^{-1} respectively. The majority of variability in training load (60-70%) was explained by session duration.
Weaving D, et al., 2020 [44]	To establish the magnitude of difference in training load methods across conditioning, SSG, skills and speed training	ESL	17	2 x 12-week preseason = 42 ± 13 sessions	Total = 716 SSG = 111 Conditioning = 194 Skills = 287 Speed = 124	5 Hz interpolated to 15 Hz with in-built 100 Hz triaxial accelerometer *(SPI Pro XII, GPSports, Canberra, Australia)*	Duration (min), walking ([m·min^{-1}], 0–1.94 m·s^{-1}), jogging ([m·min^{-1}] 1.95–3.87 m·s^{-1}), striding ([m·min^{-1}] 3.88–5.4 m·s^{-1}), sprinting ([m·min^{-1}] ≥5.5 m·s^{-1}) and HSR ([m·min^{-1}] striding + sprinting). Low- ([m·min^{-1}] 0–9.9 W·kg^{-1}), intermediate- ([m·min^{-1}] 10–19.9 W·kg^{-1}), high- ([m·min^{-1}] 20–34.9 W·kg^{-1}), elevated- ([m·min^{-1}] 35–54.9 W·kg^{-1}), max-power ([m·min^{-1}] ≥55 W·kg^{-1}) and HMP distance ([m·min^{-1}] high-, elevated- and max-power)	Players covered greater distance (m.min^{-1}) at moderate velocities (1.95–5.49 m.s^{-1}) and metabolic power (10–34.9 W.kg^{-1}) during conditioning drills compared to SSG. All speed-derived variables were lower in skill drills compared to conditioning and SSG. Players in SSG and skill drills covered greater distances at HMP (≥20 W.kg^{-1}) than high-speed (≥5.5 m.s^{-1}) displaying a greater proportion of 'high intensity' movement through accelerating and decelerating.

*Results expressed as mean ± SD, mean (95% confidence intervals) or *mean (range)*

% percentage 2D 2-dimensional Adj. adjustables (halfback, five-eighth, hooker and fullback positions), AU arbitrary units, AU.min^{-1} arbitrary units per minute, comp. competition, ESL European Super League (professional), F forwards, g g-force, HMP high-metabolic power, HSR high-speed running, HUF hit-up forwards (props and lock positions), Hz hertz, IFT intermittent fitness test, KPC Kingston Press Championship (semi-professional), m metre, m.min^{-1} metres per minute, min minute, n number, n.min^{-1} number per minute, NR not reported, NRL National Rugby League (professional), OB outside back (wing and centre positions), QC Queensland Cup (semi-professional), RHIE repeated high intensity effort, s second, Semi-pro. semi-professional, SSG small-sided games, VHSR very high-speed running, W watts, W.kg^{-1} watts per kilogram, WRF wide-running forwards (second row positions)

2.3.4 Technical Performance

2.3.4a Training Drills

Six studies have examined the frequency of skill involvements (i.e., receives, passes, efficiency and errors) within rugby league training [14-19]. All of these studies (100%) examine these demands within variations of SSG in professional [14, 15, 18], semi-professional [19] and junior rugby league training [14, 16, 17] (table 2.3). Five of these studies are included as part of investigations on the effects of SSG constraints on the physical demands including varying contact demands, manipulations of 'on-side' or 'off-side' rules and varying designs to elicit specific task loads (physical, technical, cognitive, frustration, temporal). Findings from these studies showed more involvements (i.e., touches), total and effective passes in off-side SSG compared to on-side SSG [18], while contact manipulations did not compromise the volume of skill executions and errors [15]. Furthermore, subjective ratings of cognitive load (i.e. mental effort required to complete a task) were reported to be significantly greater during on-side SSG [18] while increasing the quantity of skill involvements can increase physical technical, cognitive and temporal task loads [17].

Table 2.3 Characteristics of studies examining the technical demands of on-field training drills in rugby league.

Study	Study Aims	Comp.	Participants = n	Observation period = n of training sessions	Files = n	Method	Technical Outcome Measures	Technical Demands of Training Results Overview
Bennett K, et al., 2016 [16]	To investigate the relationship between the skill demands of an 'on-side' SSG and match-play	Elite Junior	15	Competition phase = 1	NR	Video-coded *(HDR-JP10E, Digital HD Video Camera Recorder, Sony, Japan)*	Offensive involvements ([n·min^{-1}] ball carry, support run, line break, line break assist), defensive involvements ([n·min^{-1}] body in front), total involvements (n·min^{-1})	Higher frequency of offensive involvements were recorded in the SSG compared to match-play (0.67 [0.17-0.67] n·min^{-1} vs. 0.17 [0.14-0.25] n·min^{-1}). Defensive involvements were higher in SSG compared to match-play (0.67 [0.33-0.84] n·min^{-1} vs. 0.22 [0.05-0.36] n·min^{-1}). Total skill involvements were higher in SSG compared to match-play (1.00 [0.67–1.50] n·min^{-1} vs. 0.41 [0.26-0.52] n·min^{-1}).
Dobbin N, Atherton A, Hill C, 2021 [17]	To determine if SSGs could be designed to target specific task loads (physical, technical, temporal, cognitive, frustration) and quantify the subjective task loads via NASA-TLX task load questionnaire. Determine the association between physical and technical demands within each task load.	Elite Junior	26	NR = 1	130	Skill-notation *(37-mm digital video camera, DCR-TRV 950E; Sony, Nagasaki, Japan)*	Attacking involvement ([n] catches, catching errors, passes, passing errors), defensive involvements ([n] any purposeful contact made to stop any advancement of the ball carrier)	Technical load was emphasized during the technical SSG. Attacking and defensive involvements generally increased the respective task loads (ES: 0.03-0.41, -0.14-0.36 respectively).
Gabbett T, Abernethy B, Jenkins D 2012 [14]	To investigate the effect of field size changes on the physiological and skill demands on 'off-side' SSG	Elite Junior and NRL	Elite junior = 16 NRL = 16	Pre-competition phase = 2	NR	Skill-notation *(37-mm digital video camera, DCR-TRV 950E; Sony, Nagasaki, Japan)*	Total involvements (n), receives (n), catching errors (n), effective passes (n), ineffective passes (n), total passes (n), disposal efficiency (%)	No differences were observed between the SSG on small or large fields for the total involvements, receives, passes, effective passes, ineffective passes, and disposal efficiency. No differences were observed between junior and senior players.
Gabbett T, Jenkins D, Abernethy B 2010 [18]	To investigate the physical and skill demands of 'on-side' and 'off-side' SSG	NRL	16	Competition phase = 2	NR	Skill-notation *(37-mm digital video camera, DCR-TRV 950E; Sony, Nagasaki, Japan)*	Total involvements (n), receives (n), catching errors (n), effective passes (n), ineffective passes (n), total passes (n), disposal efficiency (%)	'Off-side' SSG has a greater number of total involvements (22.4 ± 1.8 vs 14.6 ± 1.4), passes (11.0 ± 0.9 vs. 5.0 ± 0.7) and effective passes (9.6 ± 0.7 vs. 4.5 ± 0.7) compared to 'on-side' SSG.

Study	Study Aims	Comp.	Participants = n	Observation period = n of training sessions	Files = n	Method	Technical Outcome Measures	Technical Demands of Training Results Overview
Gabbett T, Jenkins D, Abernethy B 2012 [15]	To investigate the influence of wrestling on the physical and skill demands of SSG	NRL	28	Pre-competition phase = 2	NR	Skill-notation (*37-mm digital video camera, DCR-TRV 950E; Sony, Nagasaki, Japan)*	Total involvements (n), receives (n), catching errors (n), effective passes (n), ineffective passes (n), total passes (n), disposal efficiency (%)	No differences were observed between wrestle and non-wrestle SSG for the total number of involvements, receives, passes, effective passes, ineffective passes, and disposal efficiency. The number of players experiencing <20 total involvements was higher in intermittent wrestle SSG compared to non-wrestle SSG. The number of players experiencing >40 total involvements was higher in non-wrestle SSG compared to SSG with wrestle.
Johnston R, et al., 2016 [19]	To determine the impact of different RHIE bouts on running intensities, skill involvements, and neuromuscular fatigue during SSG.	QC	22	Pre-season = 4	NR	Video-coded *(Cannon Legria HV40, Japan)*	Total passes (n), effective passes (n, %), disposal efficiency (%), errors (n, %)	With the exception SSG following all-contact RHIE bouts, moderate increases in effective passes (%) was observed from SSG 1 to SSG 2. There was minimal change in total passes (n) between SSG 1 and SSG 2 after any of the RHIE bouts.

Results expressed as mean ± SD or median (interquartile range)

% percentage, comp. competition, ES effect size, ESL European Super League (professional), n number, n.min^{-1} number per minute, NR not reported, NRL National Rugby League (professional), QC Queensland Cup (semi-professional), RHIE repeat high intensity efforts, SSG small-sided games

2.4 Discussion

To the author's knowledge, the present review is the first to scope the available literature on the physical, technical and tactical demands of rugby league training. The literature search identified 21 studies for review with the vast majority describing the physical demands of training. Six studies were found to describe the technical demands, five of which are included as part of investigating the effects of SSG constraints on the physical demands. No studies were found to describe the tactical demands of rugby league training. This highlights a clear gap in research investigating the various elements of rugby league performance in training. To further emphasise, a comparative search in the four online databases using the same terms relevant to the physical, technical and tactical demands in rugby league performance ("rugby league", "rugby league match*", "rugby league performance") returned 3455 papers to review, compared to the 722 papers yielded for this scoping review.

2.4.1 Physical Demands

Physical capacity is important to rugby league performance as it underpins players' ability to tackle [71-73], sprint [74] and endure high-intensity periods [75] during match-play. Preparing for these physical demands is achieved by completing appropriate training, often replicating (or exceeding) the physical demands of match play and providing sufficient recovery before match play. Indeed, planning and monitoring training loads within team sport has become the focal point for athlete management, injury prevention and preparation [52, 53]. As such, the development of practical athlete monitoring tools has allowed sports scientists to quantify physical loads during training and match-play. While there are many approaches that have been used to achieve this [76, 77], the application of wearable microtechnologies have become wide-spread across many team sports such as rugby league, providing spatiotemporal measures derived from GPS sensors (e.g., distance, speed, accelerations etc.) and information about collisions [60] and accumulative accelerometer load (i.e., 'PlayerLoad') [78] via integrated inertial sensors (i.e., triaxial accelerometers, gyroscopes and magnetometers). Although the use of microtechnologies to monitor training is current standard practice within professional rugby league, there is a relatively low number of studies (n = 20) available investigating the physical demands of for on-field training.

In comparison, the physical demands of rugby league match-play has been widely described, with systematic reviews and meta-analyses providing information on the physical demands [3, 6, 33] and collision dose [79]. Additionally, there is available literature examining velocity and accelerometer-based variables between different positional groups [80, 81], levels of competition [82-85] and successful and unsuccessful teams [9, 86, 87] in match-play. While such information can guide performance strategies (e.g., player interchange during match-play [3]), inform training and player preparation strategies (e.g., training load prescription and monitoring), and player development pathways [6], the relationship between physical performance and successful match outcomes remains unclear [86, 87]. Accordingly, it is difficult to objectively evaluate individual physical performances and match outcomes. Moreover, a case study has reported variations of physical parameters between matches, finding large variations of high speed (CV 14.6%) and very high speed running (CV 37.9%) [26], possibly influenced by contextual factors such as opposition, match location, physical capacity and opposition [88, 89]. With the exception of five studies that included technical descriptions of rugby league SSG, studies within this review have not included technical and tactical aspects, (factors which have been suggested to contribute to successful performance [17]) and contextual factors warranting further investigation.

This review identified a small number of studies investigating the physical demands of rugby league training throughout the whole competition season phase (n = 5). These studies be can be utilised as references to inform macro-level (seasonal and weekly) periodisation and recovery strategies (e.g., the gradual introduction of collisions in pre-season training due to the higher rate of collision injuries) and inform game-specific physical conditioning programs for whole teams and positional groups (i.e., SSG and conditioning drills). However, they do not provide a detailed description on the physical demands of numerous team-based training drills also prescribed for tactical preparation within training sessions. This information is important for a holistic approach to training designs and preparation by understanding the preparation of strategies (i.e., game plan), formations and decision-making for upcoming oppositions.

The present review consolidates the descriptions (i.e., means and dispersion) of the physical demands of rugby league training. Within the findings, no studies assessed the

variability of physical activity measures within discrete training drills (e.g., training drill variability). Although speculative, variations between training drills may exist as a result of manipulations within the coaches' prescription, external influences such as upcoming opposition and between match turnarounds, constraints (i.e., field dimensions, duration and number of participants) and level of competition. Collectively, future research investigating the physical, technical and tactical demands and assessing the variability of professional rugby league training drills designed for tactical preparation is warranted.

2.4.2 Technical Demands

It is essential that team sport athletes acquire the technical ability to efficiently perform and execute the planned tactical strategies in high pressure environments [85]. This includes possessing expertise in skills such as passing, kicking, play-the-balls, wrestling and tackling [90] within both attacking and defensive moments of play. Poor execution of these technical skills can lead to errors and penalties resulting in a turnover of possession to the opposition [91]. Indeed, it has been shown that more than 65% of tries were scored following opposition errors and penalties within the professional competition [2]. It has also been demonstrated that successful teams are likely to commit fewer errors, fewer missed tackles, obtain a greater effective tackle percentage and higher frequency of play-the-balls compared to their less successful counterparts [8, 9]. Sports science practitioners and coaches can utilise this information to influence training design so players manage the technical demands required during performance and can modify competition matches to enhance skill involvement and assist in the development pathways [85]. While this highlights the purported importance of technical performance to successful match outcomes, the technical demands within training are not well reported.

Currently, only six studies were found to describe the technical demands of rugby league training, providing information such as skill involvements, passes and errors within one category of drills (i.e., SSG). While SSG can be utilised for preparation by manipulating constraints (e.g., field size) [92], and eliciting physical and technical demands and adaptations in a context closely reflecting match performance [93-95], it does not reflect the majority of drills designed and implemented for team preparation within professional rugby league training. Future investigations assessing the technical demands of various training drills to understand how teams technically prepare through team drills designed

for tactical preparation is needed. This examination would provide coaches with objective evidence to compliment or challenge subjective reviews and may assist in decision making regarding skill development and maintenance.

2.4.3 Tactical Performance

During rugby league performance, 17 individual players must cooperatively interact to execute team strategies (i.e., implemented game plan) [96] and respond to the opposition by showing specific structural, spatial and dynamic properties in an organised manner [31]. Team strategies will often adhere to the principles and style of play preferred by the head coach, or coaching teams [30]. Ultimately, it is the strategic intent of training that will influence the physical and technical requirements of match play and training. Measuring tactical performance within rugby league has also received increased scientific interest, with recent studies explaining match success using team tactical performance indicators [9, 36, 37, 67, 85, 97]. Woods et al., [37] identified five performance indicators; try assists, all run metres, try assists, offloads, line breaks and dummy half runs that explained 66% of losses and 91% of wins within the NRL competition. Additionally, longitudinal analysis has revealed teams that placed an emphasis on attacking play (i.e., all run metres, run metres, hit-ups, passes, post contact metres) and line breaks with relative defensive efficiency (reduced conceded line breaks) had the greatest likelihood of success in the NRL competition [36]. Research also examined technical-tactical performance indicators to explain differences between competition levels within the Australian competition (i.e., NRL vs. National Youth Competition (NYC)) [98] and between professional league profiles (i.e., ESL vs. NRL) [99] to inform talent recruitment and player transitions. Specifically, players in the ESL generated more line breaks, errors, tackles and all metres run compared to their NRL counterparts [99], with all meters run, tackle breaks and tackle indicators differentiating between playing levels within the Australian competition [98].

While research has identified the importance of tactics to successful rugby league performance and can inform game strategies, player capabilities and player development, to date, there has been no investigations on the tactical demands within rugby league training. Accordingly, it is unknown how coaches meet their tactical objectives within training drills and training design to prepare for competition. The lack of studies in this

area identifies a clear gap within sports science research and can be utilised to steer future research questions and designs.

2.5 Conclusion

The present review was the first to scope peer-reviewed literature on the physical, technical and tactical demands of rugby league training. Based on the screening process, a total of 21 manuscripts were included for review. The vast majority of identified research examined the physical demands of various rugby league training drills within pre-season phases. Indeed, this may be due to the proficiency of quantifying these demands via routine athlete and training load monitoring within rugby league. With the exception of five studies that included technical descriptions of rugby league SSG, studies investigating the physical demands of rugby league training do not include other important performance aspects such as technical and tactical demands. Additionally, there is limited descriptions of the team-based training drills often implemented by coaches for tactical preparation. The technical and tactical demands within rugby league training are not well reported, with six studies examining the technical demands within one category of training drill (i.e., SSG), and no studies reporting on the tactical demands. While a systematic search of studies investigating the physical, technical and tactical demands of rugby league training was conducted, it is acknowledged that other studies may exist that were not identified by the search terms. This scoping review summarises the current literature and key findings that can be used guide future research directions and designs. It is apparent the multifaceted demands (physical, technical and tactical) of rugby league training is under-researched.

Part Two

Periodisation Frameworks in Team Sport: A Narrative Review

2.6 Introduction

Periodisation frameworks are widely applied within high performance sport, where training is organised and structured into various phases (i.e., microcycles, mesocycles and macrocycles) to meet specific objectives and optimise training adaptations and performance [56]. These frameworks often consist of planned variations in physical training parameters based on underpinning theories of 'stress-response' and 'fitness-fatigue' paradigms to promote positive adaptations and avoid overtraining [54-56, 100]. Implementing additional skill acquisition frameworks within periodisation design has also been proposed to provide structure for longitudinal monitoring, development and practice of skills (perceptual-cognitive and technical motor skill) [57]. For these reasons, incorporating frameworks that account for the preparation of the multifaceted demands essential to team sport performance has been of significant interest. In particular, 'tactical periodisation' has gained increased attention [20] whereby training is organised to develop the particular 'game-style' and 'logical structure' of the team during all types of practices [23, 24]. As such, this model incorporates all training factors (i.e., tactical, physical, psychological, and technical) adopting a tactical-led approach (figure 2.6). This is based on the principle that the multifaceted components of performance are always integrated within training design rather than the reductionist approach of the traditional periodisation which focusses on 'physical aspects' of performance [25].

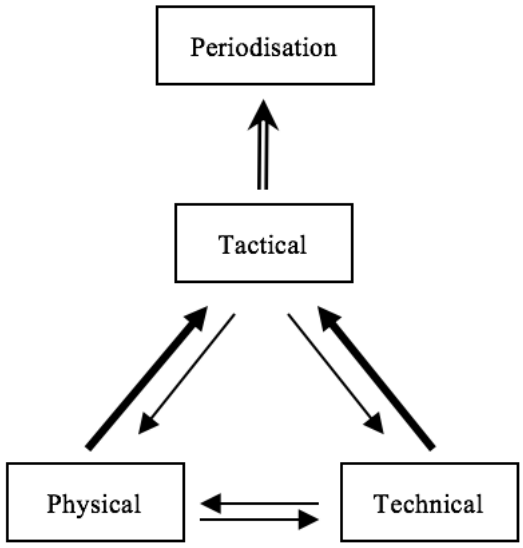


Figure 2.6 Tactical periodisation model displaying the relationship between physical, technical and tactical performance constructs.

This narrative review aims to describe the themes of current training and periodisation frameworks commonly utilised within team sports to understand the training models available in literature that can be implemented to assist planning and preparation for performance. A search to reveal themes of periodisation approaches in team sport was conducted using online searches in Scopus, PubMed, MEDLINE, and SPORTDiscus electronic databases using keyword combinations of: "periodisation", "tactical periodisation", "training planning" AND "team sports". The initial search yielded 689 papers with an additional 32 papers identified through other sources. Articles were reduced to 593 papers after duplicates were removed by the primary researcher (JH). Titles and abstracts were screened against an eligibility, resulting in 70 papers for full-text review. Eligible articles detailed physical, technical and/or tactical planning or periodisation approaches in team or acyclic sports. Articles were excluded if full text articles were not available, not available in English, detailing rehabilitation 'return-to-play' processes or resistance training periodisation designs. Available full-text articles were subsequently evaluated against the eligibility criteria by two members of the research team (JH, AC), deeming 66 articles appropriate. Research has highlighted the complex interplay of the multifaceted – physical, technical and tactical demands present in team sport [62]. Accordingly, the following sections of this review discuss the common models of periodisation according to these categories.

2.7 Training Frameworks

2.7.1 Physical Planning and Periodisation Frameworks

Planning and monitoring the physical aspects of training within team sport has become the focal point for athlete management, primarily as methods to optimise athlete readiness and reduce injury risk [52]. Systematic monitoring of the physical demands provide large data sets ('historical data') that can be used for planning, predicting and periodising training [22]. Traditional periodisation models offer a framework for planned variation in physical training parameters and were designed to optimise individual athlete's performance for one or two major championship events per year [54, 56], however have since been adapted for the preparation of team sports where regular competition seasons last for an extended period of time (i.e., months) [56]. The general adaptation syndrome (GAS) is one of the foundational conceptual models that has been used as to guide physical training periodisation. The GAS is based on an organisms response sequence to an imposed stressor

[54]. This sequence involves an 'alarm' (i.e., shock) and 'resistance' phase which either results in physiological supercompensation (i.e., positive adaptations) or exhaustion (i.e., maladaptation) depending on the magnitude, duration and frequency of stress experienced by the athlete [100]. A subsequent 'fitness-fatigue' model was proposed, whereby the athlete's neuromuscular and metabolic state is the net of these two opposing outcomes [55]. Physical periodisation models have also introduced tactical elements within their design, such as Tactical Metabolic Training (TMT), where tactical practice drills are utilised for physical, technical and tactical preparation specific to the sport [56]. However, the main focus of this approach remains physically-led with time-motion analysis utilised to prescribe and perform sport specific movements (e.g., structured plays) according to the work and rest intervals observed within competition [101].

Several studies have shown that physical match performance (or indicators of physical performance) may not be the major contributing factor to team success [2, 9, 67]. Indeed, like most team sports, rugby league performance relies on the interaction of physical, technical and tactical components [9, 62]. However, detailed planning of training remains largely influenced by past-experience and integrating physical periodisation models from other sports [102]. While it is theoretically acknowledged a unidimensional approach to preparation is limited, researchers and sports science practitioners are yet to find a solution to integrating the multifaceted components to preparation frameworks. Not only is a lack of research present within team sport training, but the current approach may be limited as it applies a unidimensional approach centred around physical condition and neglects to integrate the tactical approaches implemented by high performance coaches. Accordingly, it is important to investigate the technical and tactical approaches to planning and prescription of training to provide a holistic approach to preparation.

2.7.2 Technical Planning and Periodisation Frameworks

A technical approach to planning and periodisation seeks to systematically implement skill acquisition (both perceptual-cognitive and technical motor skill) into short and long term training plans [57]. However, a technically-led approach to planning and periodisation has not been documented in professional rugby league. While coaches routinely grade the quality of players' skill execution, understanding the technical demands during training is not well established. This is potentially due to difficulty in replicating the external pressures

and tactical awareness present during match-play outside the competitive environment to assess skill level. Subjective assessments relating to the quality of skill among professional [91, 103] and junior competitions [104] have been analysed within rugby league. Subjective '0 to 5' ratings of various attack, defence, tackle and evasion skills within game-scenario drills and match performance provide understanding on the effects of accumulated fatigue [91] and comparative assessment between players and competitive levels [103]. Indeed, there is a need to create a systematic monitoring method where sport scientists can assess the representativeness of technical components within training drills [57]. Future investigations are required to assess the technical demands of various training drills as this would provide coaches with objective evidence to compliment or challenge subjective reviews and may assist in decision making regarding position selection and skill maintenance. Additionally, no research has classified the technical complexity of various training drills. More research is needed to describe the planned quantity, quality and difficulty of technical skills within training.

Coaches often utilise an experience-led approach (i.e., drawn from own personal experience or the teachings from others) to incorporate specialised and isolated technical training content into training sessions. Although these sessions are common practice within rugby league, at present, few studies have included these within their investigations. As a consequence, there is presently limited rugby-league specific evidence to assist coaches in the design and/or manipulation the training drills (e.g., random vs. blocked practice, drill constraints, skill density, skill complexity or cognitive effort). To rectify this, the skill acquisition periodisation (SAP) framework was developed for high performance sport to assists in the measurement, monitoring and evaluation of skill training [57], however this is yet to be implemented within sport. It is posited that direct longitudinal monitoring of the players' response to skill training, can help coaches design, prescribe and manipulate specific drills to fit the technical needs of the players. Such a framework provides an important structure for monitoring and developing technical skill by adopting previously reported SPORT (specificity, progressions, overload, reversibility and tedium) principles within a skill acquisition context. Recent frameworks have also been reconsidered to incorporate the 'dynamic' and 'non-linear' environment by using an ecological approach to conceptualising performance [34, 105, 106]. These frameworks consider the interaction of individuals with the task and environment (i.e., complex adaptive system [34]) and the

processing of this information that leads to perceived affordances (i.e., opportunity for action) influencing further actions (i.e., affordance realisation) [106]. Accordingly, when individuals are attuned to these shared affordances in a team environment, coordinated behaviour [34] and team synergy [107] emerge. This approach progressively transitions away from traditional linear methods whereby performance and preparation are dictated by 'linear information' such as key performance outcomes and indicators (i.e., operational outcomes). However, understanding these outcomes within the ecological environment assists the interpretation of contextual information (i.e., how and why a team behaves), eliminating a siloed approach to preparation [34]. Indeed, applying a technical framework independent of any physical or tactical components, would limit the design and monitoring process to a unidimensional approach to optimise preparation. Ideally, future research should integrate a holistic monitoring framework comprising of the physical, technical and tactical elements of performance.

2.7.3 Tactical Planning and Periodisation Frameworks

Similar to most team sports, rugby league performance relies on the interaction of physical, technical and tactical components [9, 62]. Accordingly, to prepare for competition, training plans are constructed to concurrently develop physical, technical and tactical components through a mix of individual and group activities. Tactical periodisation is an approach to training organisation that develops the particular 'game-style' and 'logical structure' of the team during all types of practices and training systems [23, 24]. Following this approach, the fundamental elements of tactical periodisation ensure all training drills are designed to meet the tactics, strategy and game style desired by coaches by utilising tactical principles as the centre or 'superior' element of performance (figure 2.7). Specifically, this model seeks to depart from existing frameworks solely concentrates on physical aspects of performance but also considers all factors present in team sports (i.e., tactical, technical, physical and psychological) [20]. Tactical periodisation frameworks are often composed of two matrices; conceptual matrix (game model) and training model (methodological principles) which are structured into weekly training cycles known as morphocycles [20]. The style of play desired by coaches including particular tactical and strategic behaviours, the quality of players and the principles and sub-principles within moments of the game (attack, defence and transitions) are compiled to form the game model coaches wish to implement [24]. The methodological principles typically consist of three main principles;

complex progressions (of the acquisition and learning of a particular way of playing), horizontal alteration (distribution of principles trained throughout morphocycles) and principle of propensities (experiential learning within specific and natural occurring situations where players solve problems utilising the required game model) [20, 24]. Despite the apparent popularity of tactical periodisation models in team sports [20], there is a poor understanding of how this approach is implemented, or if it is effective. Indeed, few studies have identified the tactical performance indicators underpinning team sport [35] with key principles of tactical periodisation proposed for sports like soccer and tennis [23, 24]. Therefore, despite an increased recognition of this framework as an alternative paradigm to existing periodisation models, there is a lack of empirical evidence investigating this concept in team sports including rugby league [20].

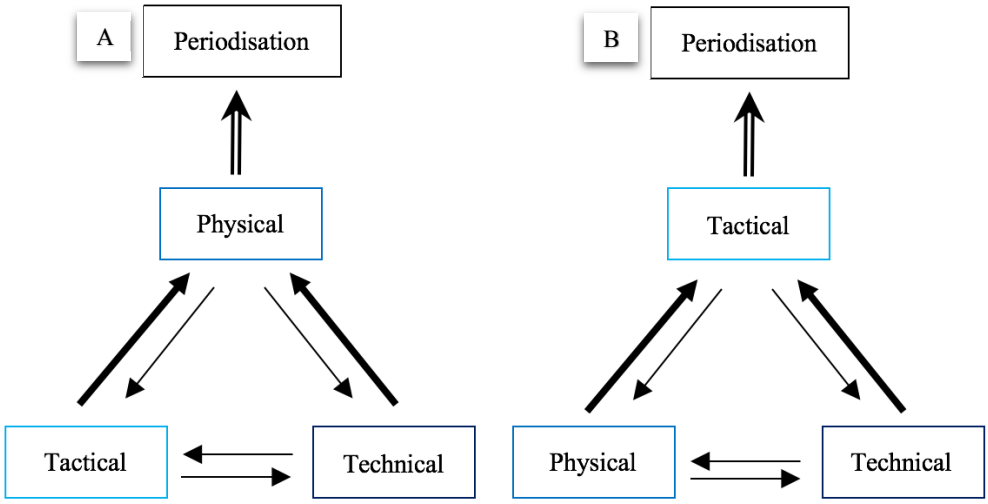


Figure 2.7 A. Traditional periodisation model within team sport, B. Tactical periodisation model.

A method to provide information on the influence of contextual factors to match difficulty (e.g., opposition rank and match location) – known as the Match Difficulty index (MDI) has been proposed within Australian codes such as rugby union and Australian Football (AF) [28, 29] to assist in strategic planning and periodisation. While MDI models do not describe the core factors (i.e., tactical prescriptive indicators) of implemented periodisation frameworks (e.g., tactical periodisation), it could provide supplementary information to inform training designs and logistic decisions against upcoming opponents. Furthermore, this model is yet to be developed and applied in rugby league. Indeed, rugby league coaches may manipulate their tactical prescription within training to ensure appropriate preparation

against varying oppositions, possibly due to perceived strengths, playing personnel and game-style. Given the prevalence of tactical periodisation implementation in professional sport [20], adopting and refining methods to examine how coaches prescribe training may allow the assessment of various game-styles and tactical approaches within rugby league. Furthermore, investigations of how coaches utilise contextual information to manipulate tactical prescription approaches against varying opponents would provide sports scientists an enhanced understanding of rugby league training and encourage a holistic, multi-dimensional approach to periodisation and preparation.

CHAPTER THREE

Study Two: The Development and Evaluation of the Training Drill Questionnaire for Rugby League

3.1 Introduction

Training periodisation is the process whereby training is structured into various training and recovery phases with specific objectives to optimise physical condition [108]. Traditional periodisation models offered a framework for planned variations in physical training parameters to optimise an athlete's performance for one or two major championship events per year, and have been incorporated for team sport preparation where regular competition seasons last for an extended period of time (i.e., months) [109]. These models were theoretically based on the athlete's 'shock' response to an imposed physical stressor resulting in 'supercompensation' and physiological adaptations [54]. Whilst these classic approaches to periodisation have been applied and adapted to individual, cyclic sports (e.g., running, swimming cycling etc.), team sports that compete more regularly have adopted periodisation models whereby training stressors are reduced immediately before and after competition days within the training microcycle, and are greatest in the day's farthest from competition [110]. However, in contrast to most cyclic sports where physical training stimulus is the primary focus of training periodisation approaches, team sports have increased requirements for technical and technical aspects of training to consider in planning [62]. However, at present whilst there have been reports of physical training periodisation strategies applied in team sports [56, 111], there are few reports of the technical and tactical aspects of training. One reason for the lack of information about the periodisation of the technical and tactical aspects of training in team sports is likely due to the difficulty in quantifying these elements of performance.

Team sports are reliant on the collective of physical, technical (individual skill) and tactical (interaction with other individuals) constructs [62]. The preparation, practice and execution of tactical strategies has been particularly emphasised due to the perceived importance to successful match performance [35]. Indeed, coaches spend considerable time developing and implementing the desired tactical elements (e.g., tactical actions, game plan strategies) within training sessions according to their tactical framework. Although all aspects of performance are considered, coaches anecdotally implement a training model or framework to be applied throughout the season to guide session design for tactical preparation of the team. However, to date, there has been no measurement of how coaches plan and design training according to their implemented framework in professional rugby league.

In team sports, technical and tactical aspects are often the focus of training design. Indeed, training drills are often designed to meet the tactics, strategy and game style desired by coaches (tactical periodisation) [20, 24]. While key principles of tactical periodisation and indicators of game style have been noted in sports such as basketball [101, 112], soccer [24, 30, 35, 113] and rugby union [114-116], this is yet to be examined in rugby league. Furthermore, this research is limited as there are no tools available to describe how coaches plan and implement these aspects. Subsequently there is a lack of understanding in how coaches plan, prescribe and assess the tactical elements within rugby league training. Therefore, the aims of this investigation are to identify themes of tactical arrangement and prescription of on-field training drills and develop an assessment tool to measure and quantify the prescription of these factors.

3.2 Methods

Part One: Defining Constructs of Tactical Arrangement

Participants

To identify the tactical prescription of on-field training drills, a purposive sample of four experienced professional National Rugby League (NRL) coaches employed by the same club participated in a 40 to 60-minute interview prior to the 2018 NRL competition season. Coaches were contracted full-time to the NRL club and were aged between 37 and 47 (M = 41.0, SD = 4.2). All coaches had participated as athletes in rugby league, with a combined total of 39 years playing at the professional and semi-professional level. Coaches had a range of 4 – 16 years coaching experience as an assistant or head coach role within the professional and semi-professional grades. Prior to the commencement of this study, two of the participating coaches had five years' experience coaching together at the same club, three coaches had three years' experience and all four coaches had one year of experience coaching together. The primary researcher (JH) also had three years' experience working in semi-professional and professional rugby league, including two years working alongside two of the participating coaches, and one year working alongside all four coaches in a sport science support role (figure 3.1). This pre-existing relationship assisted the interview process, ensuring appropriate depth and quality of responses (i.e., saturation) as a level of trust and rapport between the primary researcher and interviewees had already been established.

All available full-time, contracted NRL coaches employed by the same club were recruited for this study (n = 4). Procedures were approved by the Human Research Ethics Committee of the University of Technology Sydney (ETH16-1074). Informed consent was obtained from all coaches prior to the commencement of this study.

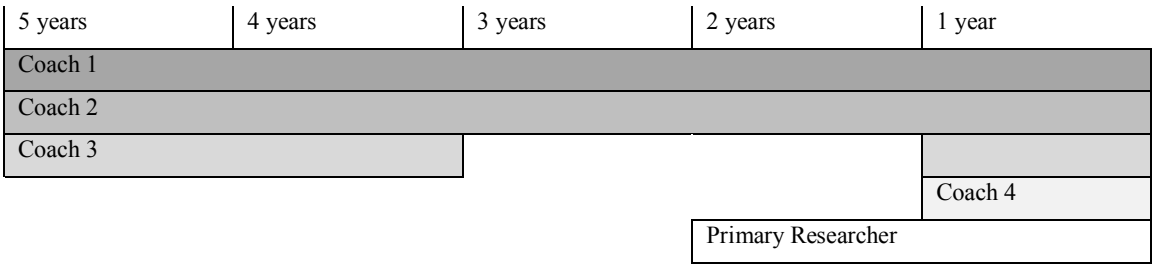


Figure 3.1 Timeline indicating work relationships between coaches and primary researcher at the same club prior to the commencement of this study.

Procedure

A semi-structured interview guide to include similar introductory and follow-up questions for each interview was created by the primary researcher and was crosschecked with the research team. Guidance in developing and conducting the interviews was based upon previous recommendations [117-119] and followed the Consolidated Criteria for Reporting Qualitative research (COREQ) checklist [120]. All participants were informed of the purpose of the interviews, which was to derive information on how coaches design, implement and assess training according to their coaching philosophies, training model and tactical strategies. Although the interviewer had prior working experience with the coaches, general information about their coaching role and years of experience was obtained at the start of the interview to build rapport and encourage a relaxed, conversational environment [121, 122]. As coaches rely, in part, on previous experience to form beliefs that guide training approaches [30], the following section of the interview sought to understand their current coaching philosophies, and understand how this has evolved over time. The subsequent sections of the interview specifically focused on the research question; to identify and understand how coaches tactically design, implement and assess training. Questions and follow-up questions of the interview guide are listed in table 3.1.

Coaches were independently interviewed face-to-face by the primary researcher at their workplace, with no other personnel present. The interviews were conducted in an un-structured format for 40 to 60-minutes to account for the varying depth of responses. Additional subsequent follow up questions and prompts were continuously framed based on individual responses if further information or clarity on responses was required to reach saturation [123]. Due to the high-profile of professional rugby league coaches and competitive nature of the industry, a non-disclosure agreement was arranged to allow the interviewer to take written notes in real-time during the interviews to capture collective responses. As recording devices were not able to be used, the researcher recorded as much verbatim of the key points as possible without summarising responses and asked interviewees to repeat responses if necessary [124]. Within 20-minutes of the conclusion of the interview, the researcher extended the responses into written transcripts. These responses were subsequently cross-checked with the interviewees for accuracy, awareness and data credibility [125]. Interviews were conducted over a 14-day period to allow ample time for the researcher to consolidate and confirm responses from the prior interviewee.

Prior to the commencement of this study, it is noted the primary researcher had exposure to three or four training sessions per week as a member of sports science staff sessions per week over a two-year period. During this time the primary researcher had thorough observations of how training sessions were formed and implemented [126]. Specifically, relevant field notes were composed over a 3-month period prior to the interviews to supplement data collection. These notes were collected to further understand and observe coaching instruction during training, non-verbal cues, terminology and the training planning process [126]. As part of the industry's planning process, coaches spent time together to collaborate and form a training model based on philosophy, player personnel and experience to be implemented for the competition season. Afterwards, coaches gave a separate, short 10-minute presentation on this model with respect to their relevant role (e.g., head coach, attack coach, defence coach, development coach), to which the primary researcher also collected additional free-form, unstructured field-notes in real-time to supplement data collection.

Table 3.1 Semi-structured interview guide.

Questions	Follow-up Questions
Purpose (1) Develop rapport with interviewee	
1. What's your current coaching role in the industry?	- How long have you been a coach? - What level of coaching? - What aspects do you like and dislike about being a coach? Have these changed over time?
Purpose (2) Identify valued coaching philosophies	
2. What are the current coaching philosophies you believe best prepare for successful performance?	- What factors have contributed to shaping your current philosophies? - Have these changed overtime? - Dependent on phase of season or opposition?
Purpose (3) Understand the training model	
3. Do you implement a training model? If so, can you describe how it is developed?	- What are the important aspects of this training model? - Does this change throughout the season? If so, how? - How are training drills assigned within this training model?
Purpose (4) Identify how tactical strategies are implemented within training	
4. Can you describe how training sessions are developed?	- How are tactical components prescribed within training? - How are these tactical components manipulated within or between training sessions? - Dependent on phase of season or opposition?
Purpose (5) Identify current assessment and monitoring processes of implemented tactics and strategies	
5. What methods are utilised to monitor tactical performance within training?	- What methods have been most/least effective? - How do you assess the quality of drills? - Do you assess performance individually or as a group?

Data Analysis

Transcripts were de-identified and stored in associated software (NVivo v10.2.2, QSR International, 2015, Doncaster). A thematic text analysis approach was applied according to previous guidelines and methods [127, 128] to identify categories and subcategories of tactical arrangement for training drills. In the first phase, transcripts and supplementary field notes were read, highlighted and coded by the primary researcher to organise the data. Codes were then compared and clustered by similar or related meanings to create and assign main categories. For example, text tagged as "quarters of the game" and "the first and last 20 minutes" were clustered to form a main category 'period of performance'. All codes were subsequently compiled, listed and ordered within each main category to create sub-categories. The final step of the process involved the naming of categories and

generating definitions of sub-categories. Final categories, sub-categories and definitions were cross-checked with all participating coaches for consultation, approval and adjustment if necessary. To further enhance methodological rigor, robust and open conversations during all phases of the data analysis took place with a second member of the research team (AC). This included the reviewing of codes, categories and sub-categories to ensure consensus on segregation of data, names and definitions.

Results

Development of key categories revealed coaches assign on-field training drills within specific periods of performance, moments of performance and implement a particular design and focus. Definitions of these sub-categories are presented in table 3.2.

Table 3.2 Categories, sub-categories and definitions of how training drills are assigned.

Category	Sub-Categories	Definition
Period of Performance	0 – 20 minutes	First quarter of the match
	20 – 40 minutes	Second quarter of the match
	40 – 60 minutes	Third quarter of the match
	60 – 80 minutes	Fourth or final quarter of the match
	0 – 80 minutes	Whole match
Moment of Performance	Attack	In possession of the ball
	Defence	When the opposition is in possession of the ball
	Transition from Attack to Defence	The period of transferring possession of the ball to the opposition
	Transition from Defence to Attack	The period of receiving possession of the ball from the opposition
Drill Design	Structure	Arrangement of the team
	Execution	Carrying out the skill elements necessary for the tactical action
	Scenario	Preparation for predicted match events or scenes
Drill Focus	Team	All members
	Group	A number of persons classed together e.g., forwards, outside backs
	Individual	Particular persons

Three main categories (*game plan, intensity* and *skill*) and nine sub-categories of manipulated variables within on-field training drills were created. Derived sub-categories included; *familiarity of strategies, attacking predictability, defensive predictability, spine*

combination, attacking pressure, defensive pressure, speed of execution, fatigue of commencement, and *technical complexity.* Descriptions of these sub-themes within each category and relevant quotes are listed in Table 3.3.

Initial review of interview transcripts and field notes disclosed coaches often collaborate post-training to review the overall session, specific training drills and individual players. In particular, codes were clustered to form three main categories: overall satisfaction of the training session or training drill, assessment of drill implementation and player execution. No sub-categories were formed, but three questions were developed to provide a rating of assessment post-training. These were developed with further collaboration with the research team and approved by coaches:

1. Overall, how satisfied are you with the training session / drill?
2. Was the training session / drill implemented as you intended?
3. Did players execute within the training session / drill as you expected?

Table 3.3 Categories, sub-categories and descriptions of the manipulated variables within training drills.

Category	Sub-Category	Descriptor	Quote Examples	Coaching Cues / Field Notes
Game Plan	Familiarity of Strategies	How well-known is the desired plan of action for the team in this drill?	"it is essential for everyone to know and apply their role" (3) "knowing your part creates a uniform team to give flow, momentum and confidence in each other" (1)	"work on line organisation" (2) "play the long game" (1) "we need power running with support" (1)
	Attacking Predictability	As a defender in this drill, how well do you know or pre-empt how the opposition will attack? This can be related to set pieces, strengths and weaknesses, style-of play and common characteristics of the opposition.	"we need to know how to set up our defence to neutralise attacking opportunities from the opposition" (2)	"practice against set pieces" (2) "shift early" (3) "power through the middle" (2)
	Defensive Predictability	As an attacker in this drill, how well do you know or pre-empt how the opposition will defend? This can be related to set pieces, strengths and weaknesses, style-of play and common characteristics of the opposition.	"we need to place emphasis on attacking plays and tactics to expose the defence line of the opposition and score" (3)	"we know they're a physical team" (3) "set up their defence" (1)
	Spine Combination	Is this drill targeted for interaction and coordination between the playmaker positions of the team (hooker, fullback, halfback and five-eight)?	"spine is where it starts, they are mostly responsible for our attacking plays, and that's where the opportunity to score points is" (1) "The fullback needs to control and lead the defence to stop the other team from scoring" (2)	"schedule spine video before the session" (1)
Intensity	Attacking Pressure	When in defence, how difficult does the opposition's attack (i.e., by push, force, player presence) make it to execute the drill?	"we'll modify the drill to mirror the opposition, to get them match ready" (4)	"we modify the intensity of ball carries" (3)
	Defensive Pressure	When in attack, how difficult does the opposition's defence (i.e., by push, force, player presence) make it to execute the drill?	"change the intensity to give the chance and opportunity to coach so players can focus on learning what they're required to do on the weekend" (2)	"3 man tackle with care around the legs" (1) "we might ask for 70 - 80 % contact" (2)
	Speed of Execution	How fast is this drill required to be carried out?	"aim at, or even greater than game pace" (1)	"walk through with joggers" (4) "conduct a video session on-field" (1)
	Fatigue at Commencement	How much physical and/or mental exhaustion do you anticipate players to be at the start of this drill?	"sometimes we'll want players to be fatigued to test decision making and skill execution under fatigue" (1)	"they [the players] should be pretty fresh" (1) "shouldn't be too taxing" (2)
Skill	Technical Complexity	How difficult, or how much risk is associated with the skill actions required in this drill? Technical actions can include, passes, receives, tackles, kicks and play-the-balls	"we need to execute various skills in matches" (4) "high skill level can create winning moments" (1)	"high risk action" (1) "cut out pass" (4) "quick hands" (3) "own the air" (1)

Part Two: Development and Assessment of the Training Measurement Tool

Participants

An exploratory research design was used to develop a Training Drill Questionnaire based on the tactical goals and themes identified in Part One of this study. The four experienced professional rugby league coaches participated in completing paper-based versions of the questionnaire to assess validity and reliability.

Procedure

Based on the results derived in Part One, the questionnaire was segregated into three sections: 1. tactical descriptor, 2. tactical variables and 3. post-training questionnaire (figure 3.2 and figure 3.3). In section 1, coaches were asked to assign the training drill to the relevant tactical descriptors for that drill by placing a '1' under the relevant subsection. Coaches were instructed to place a '1' too all that apply should more than one subsection obtain equal priority. Tactical variables and post-training questions within section 2 and section 3 of the questionnaire contained visual analogue scales (VAS) for coaches to subjectively rate the intended intensity of each variable and self-review question post training. The VAS contained a 100-mm horizontal line, with verbal descriptors at each endpoint to indicate each extremity. End points of each scale was discussed within a focus group and mutually agreed by all coaches. Lower and upper end points of the VAS scales for section 2 and section 3 of the questionnaire as presented in table 3.4 and table 3.5, respectively. Coaches marked a small vertical dash to represent the intensity of each variable. Dashes were manually measured to the nearest 0.5 mm by the primary researcher using the same ruler. Section 1 and section 2 of the questionnaire were completed for every team drill prescribed within the on-field training session during the 2018 competition year (three to four sessions per week). Section 3 was completed within 10-minutes of the concluded session to review the examined training drill and overall training session.

Table 3.4 Lower and Upper VAS End-points for tactical variables included in section 2 of the Training Drill Questionnaire.

Lower VAS End-point	Variable	Upper VAS End-point
Completely new	**Familiarity of required strategies**	Autonomous
Unpredictable	**Attacking predictability**	Predictable
Unpredictable	**Defensive predictability**	Predictable
Unopposed	**Attacking pressure**	Game-like
Unopposed	**Defensive pressure**	Game-like
Static	**Speed of execution**	Greater than game-pace
RPE 0/10	**Fatigue at commencement of drill**	RPE 10/10
No connection between spine positions	**Spine combination**	Combination between all 4 spine positions
Extremely easy	**Technical Complexity**	Extremely difficult

Table 3.5 Lower and Upper VAS End-points for post training drill questions included in section 3 of the Training Drill Questionnaire.

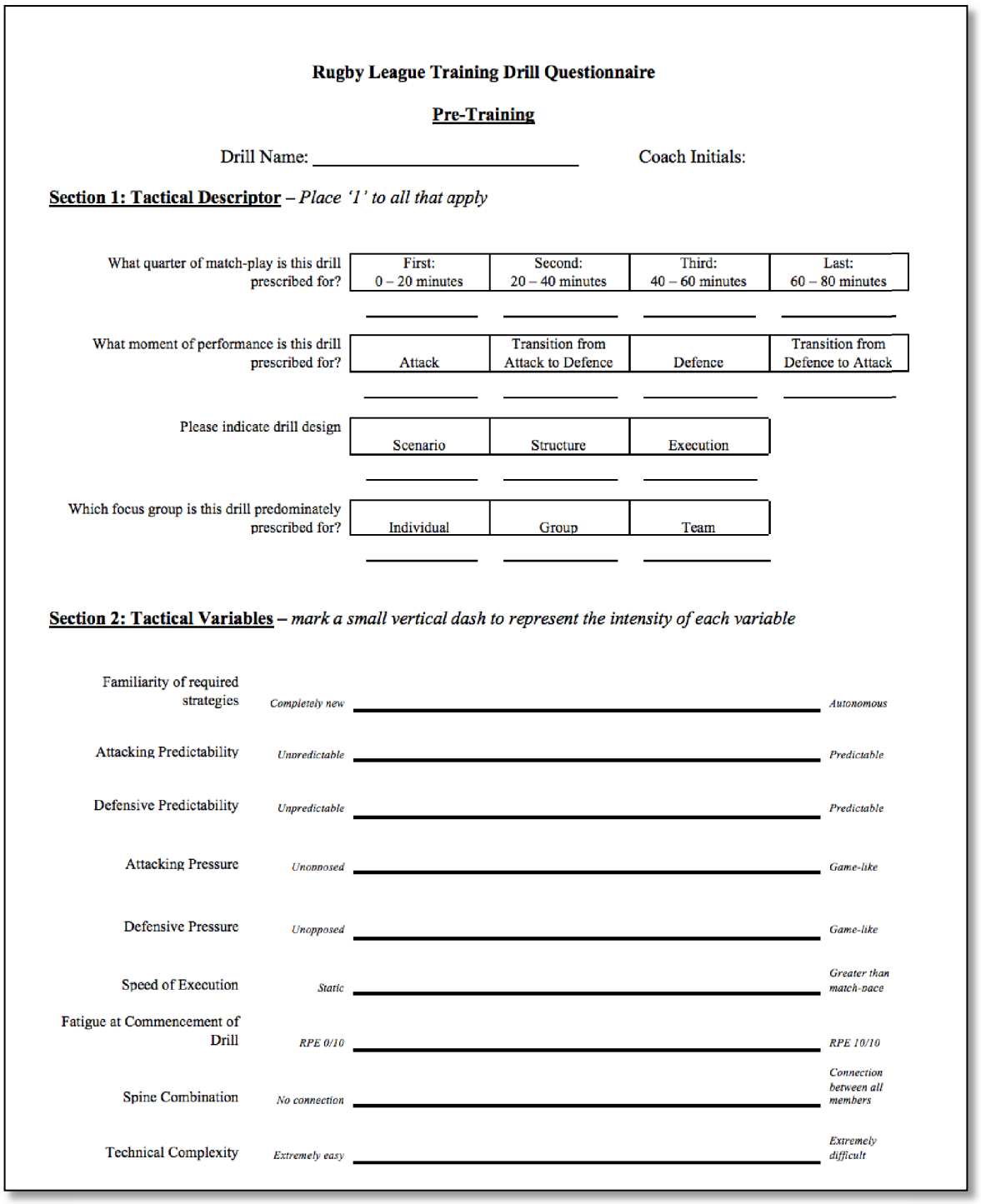
Lower VAS End-point	Variable	Upper VAS End-point
Extremely unsatisfied	**Overall satisfaction of the training drill/session**	Extremely satisfied
Nothing went as planned	**Was the training drill/session implemented as intended?**	Everything went exactly as planned
Did not execute as expected	**Did players execute as expected in this drill/session?**	Execution exceeded expectations

Pilot questionnaires were completed for a week prior to data collection to examine the feasibility of the protocol, to review and assess the validity of the terminology and to confirm VAS end-points. Coaches completed four Likert scale questions ranging from 1 (strongly disagree) to 5 (strongly agree) to assess the face validity of the instrument (table 3.6).

Table 3.6 Four Likert scale questions to assess face validity.

Question 1	Variables included reflect the tactical prescription of training drills
Question 2	The VAS end-points help to decide on a rating
Question 3	Overall, the questionnaire is easy to understand
Question 4	The questionnaire is easy to complete

To assess reliability, 20 test-retests were equally distributed among the four high performance coaches, with one questionnaire completed and a repeat measure completed 20-minutes afterwards. Coaches markings were manually measured to the nearest 0.5 mm by the primary researcher, using the same ruler.



Rugby League Training Drill Questionnaire

Pre-Training

Drill Name: _____ Coach Initials:

Section 1: Tactical Descriptor – *Place '1' to all that apply*

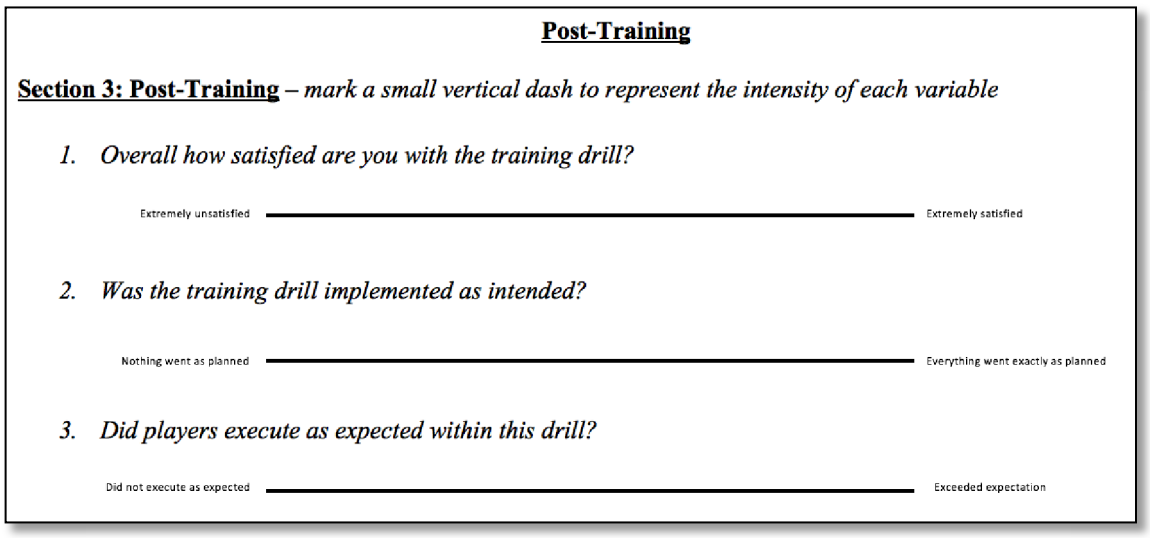
What quarter of match-play is this drill prescribed for?	First: 0 – 20 minutes	Second: 20 – 40 minutes	Third: 40 – 60 minutes	Last: 60 – 80 minutes
What moment of performance is this drill prescribed for?	Attack	Transition from Attack to Defence	Defence	Transition from Defence to Attack
Please indicate drill design	Scenario	Structure	Execution	
Which focus group is this drill predominately prescribed for?	Individual	Group	Team	

Section 2: Tactical Variables – *mark a small vertical dash to represent the intensity of each variable*

Familiarity of required strategies	*Completely new*	*Autonomous*
Attacking Predictability	*Unpredictable*	*Predictable*
Defensive Predictability	*Unpredictable*	*Predictable*
Attacking Pressure	*Unopposed*	*Game-like*
Defensive Pressure	*Unopposed*	*Game-like*
Speed of Execution	*Static*	*Greater than match-pace*
Fatigue at Commencement of Drill	*RPE 0/10*	*RPE 10/10*
Spine Combination	*No connection*	*Connection between all members*
Technical Complexity	*Extremely easy*	*Extremely difficult*

Figure 3.2 Section 1 and section 2 of the Training Drill Questionnaire utilised within this study.

A



B

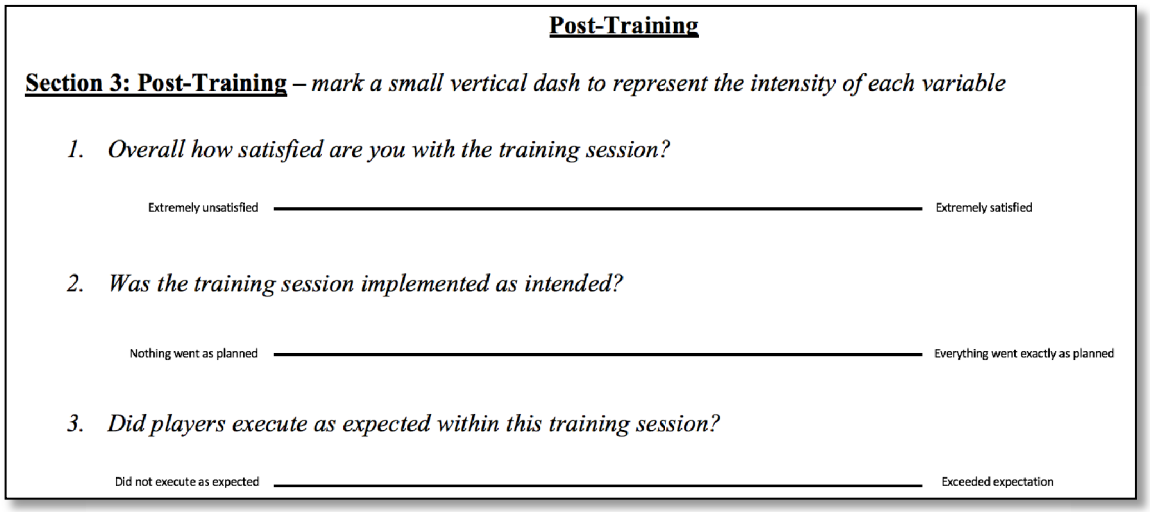


Figure 3.3 Post-training questionnaire for the A. training drill and B. overall session.

Statistical Analysis

Validity and reliability assessments were incorporated according to outlined COSMIN guidelines [129, 130]. Content validity of the Training Drill Questionnaire was determined through face validity, using histogram plot and mode analysis of the four Likert questions via Microsoft Excel spreadsheets (version 16.16.27, Microsoft Office, Australia).

Intra-rater reliability (i.e., variation of data measured by the same rater) of the questionnaire was assessed by a test-retest method. Intra-rater reliability for sections 2 and

3 of the questionnaire was reported as the intraclass coefficient correlation (ICC) and their 95% confident intervals based on a mean-rating (k = 11), absolute agreement, two-way mixed-effects model. Values < 0.5, between 0.5 – 0.75, between 0.75 – 0.9 and > 0.9 were interpreted as 'poor', 'moderate', 'good' and 'excellent' reliability respectively [131]. Intra-rater reliability of section 1 was reported as the Cohen's kappa coefficient, with a value of ≥ 0.6 interpreted as 'adequate agreement' between ratings [132].

Internal consistency (i.e., the degree of interrelatedness between items) of sections 2 and 3 of the questionnaire was examined via Cronbach's alpha ≥ 0.7 as 'acceptable' [133, 134]. All reliability statistics were calculated using SPSS Software (version 21.0. IBM, Australia).

3.3 Results

Mean scores of 4.0 (SD = 0.0) were calculated for both the first and second Likert questions, with mean scores of 3.8 (SD = 1.0) and 3.5 (SD = 0.6) reported for respective questions three and four. Results demonstrate the coaches agreed with the statements, with 50% of the coaches responding 'neutral' to questions three and four, implying the scale adequately measures the tactical prescription of training drills (figure 3.4).

Test-retest results of the VAS component of the questionnaire demonstrated excellent intra-rater reliability [131] (ICC = 0.91 [0.89 – 0.92]) and almost perfect agreement (κ = 0.96) between ratings of categorical variables (i.e., section 1) [132]. Section 2 and section 3 demonstrated a high (α = 0.84) and very high (α = 0.92) degree of internal consistency respectively.

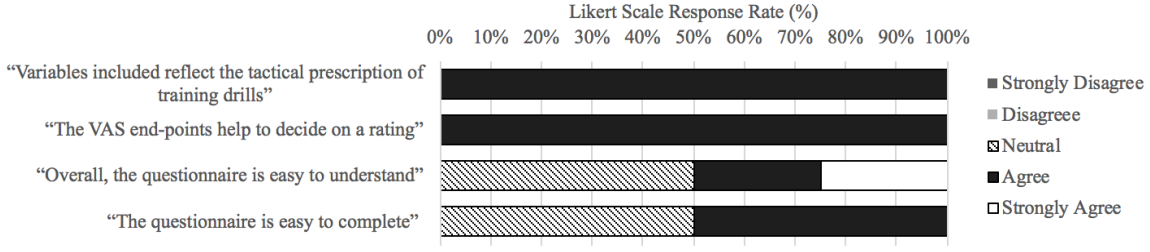


Figure 3.4 Mean face validity Likert outcomes of the Training Drill Questionnaire.

3.4 Discussion

Team sports such as rugby league are reliant on the combination of physical, technical and tactical properties. Recent research has emerged highlighting the significance of team tactics and strategies as a central component for success within team sports [7, 9, 135], however no reports have investigated how tactics are trained, monitored and assessed within rugby league training. The present study is the first to describe how coaches plan and prescribe tactical elements of performance in professional rugby league. Furthermore, a novel approach was applied to explore these elements through interviews with high performance coaches. Coach interviews and presentations revealed common tactical goals and variables which were then used to design a training questionnaire to quantify and describe tactical aspects of rugby league training.

Measuring tactical performance in invasion game team sports such as soccer and rugby union has received increased interest [35, 114-116, 136, 137]. Due the complexity and system of team sports performance (i.e., players interact with each other and with the opposing team in varying contexts) [30], there have been several proxy indicators of tactical performance used. Depending upon the sport, there are various indicators of this construct, including measures of possession, passing patterns, evasion manoeuvres, surface area and transition qualities [31, 115, 136]. Indeed, frameworks that describe and monitor the patterns and movements relating to style-of-play have also been proposed [30, 36]. Whilst these previous investigations have identified potentially useful descriptors of tactical performance, none have identified coaches' intentions with tactical planning and delivery, nor have they identified training descriptors according to these goals.

This study is the first to identify how coaches plan and prescribe tactical elements of performance within training and consequently, direct comparison of derived variables from this study to previous literature proves challenging. Nonetheless, key principles of tactical periodisation have been noted in team sports such as soccer indicating training drills are organised around at least one moment of the game (attack, defence and transitions) and principles of play [24, 30]. In agreement, the present results showed that coaches prescribe training drills for attack, defence and transition moments. Moreover, it was also revealed that other important contextual factors are considered when prescribing and assessing the effectiveness of training drills. In particular, general themes of

familiarity, predictability, complexity, speed, player combination and pressure were revealed to be important tactical aspects of training considered by professional coaches. It is notable that these variables are difficult to quantify objectively, and therefore subjective scales provided in the present questionnaire are a viable solution for quantifying these constructs. Furthermore, the Training Drill Questionnaire displayed excellent levels of reliability and validity suggesting the tool has the potential to be a useful monitoring and measuring tool to quantify the tactical prescription by coaches in the current study. Indeed, this questionnaire can be routinely implemented to measure the prescription of these constructs. Future studies should seek to implement this tool and describe the tactical arrangement of on-field training drills and its distribution within professional rugby league.

This study identified themes of tactical arrangement for on-field training drills in professional rugby league. The competitive and high-profile nature of professional sport prevented the ability to assess the questionnaire's validity and reliability to an out-of-sample data set (i.e., other rugby league clubs). Therefore, it is acknowledged that results from this study are derived from a small sample size of coaches from a single club and prone to selection bias. While the sample is representative of the NRL environment, the generalisability of the tool to the wider rugby league coaching population may be limited. Furthermore, while the primary researcher ensured follow up prompts were explored until saturation was reached [123], research has suggested a data sample of 12 interviews to guarantee data saturation [138]. Accordingly, future research cross-validating this tool with retired coaches or coaches from parallel competitions such as the Super League is warranted as coaches may have distinct game-style philosophies and tactical approaches based on past experiences and personal beliefs. Additionally, a limitation of this study was the absence of audio or video recording the interviews. While methods were implemented to prevent any disadvantages for data collection, it is acknowledged that audio and video recordings would have provided full transcripts and negate the possibility of missing data [139]. It is further acknowledged that structural validity of the tool is difficult to assess as no objective markers have been validated for tactical constructs in rugby league performance. Furthermore, a VAS scale was chosen to allow coaches to specify their judgement of tactical variables and not be limited to a fixed number of potential responses (e.g., Likert scale) however ratings may be prone to greater variability if assessed across a larger number of participants. As such, further validation and reliability assessment in

different sport contexts and within the wider rugby league community using the COSMIN checklist is required [129, 130]. Nevertheless, this is the first study to investigate and offer empirical evidence on how coaches plan and prescribe the tactical elements within rugby league training. Indeed, the unique implementation of interviews to derive this information forms a basis for future work within applied coaching settings. This study is also the first to provide a practical tool that can be easily implemented to identify and measure the tactical prescription. Future studies implementing this tool are encouraged to examine the arrangement of on-field training drills and periodisation cycles based on tactical elements.

3.5 Conclusion

As team sports are reliant on the collective physical, technical and tactical, periodisation frameworks have been refined to develop the multifaceted elements of performance whilst placing tactics as the central focus in its design and implementation. This is the first study to identify markers of tactical arrangement for on-field training drills in professional rugby league, and offers a practical tool to quantify and measure these aspects. As such, coaches plan training according to *moment of performance, period of performance, drill design* and *focus*. Additionally, it was identified that nine tactical variables are intentionally prescribed and manipulated within training. This tool displayed excellent validity and reliability for the purposive cohort, and as such future investigations can implement this tool to describe the tactical arrangement of on-field training drills in professional rugby league. Future research is encouraged to further validate and assess the reliability of the tool across differing sporting environments.

CHAPTER FOUR

Study Three: The Physical, Technical and Tactical Demands of Professional Rugby League Training Drills

4.1 Introduction

Team sports are characterised by a particular organisation and synergy as team members act together towards a shared objective [140]. Teams are required to manage space, time and individual actions within the constraints of the game to present a coherent unit causing disorder within the opponents stability and organisation [35]. Accordingly, team members are required to possess the physical capability, a high level of technical skill and tactical awareness to maintain the competency to deal with the competition demands and effectively execute the required strategies [35]. It is beneficial for sports scientists to understand the interplay of the multifaceted demands of team sports to adopt a holistic approach towards the preparation, prescription and monitoring of training [35].

Rugby league is a collision sport that requires players to intermittently perform high-intensity activity such as running separated by bouts of low intensity exercise (i.e. walking or jogging) or rest (i.e. standing still) [141]. The ability to accelerate, decelerate, change direction and develop speed during all moments of performance (attack, defence and transition periods) are essential as teams try to maintain and protect optimum field position to increase the likelihood of scoring [2]. As the ball-carrier and defending players meet in the field of play, they engage in collision events such as tackling and wrestling [60]. Understanding and monitoring the physical profiles of rugby league performance and training has been of particular focus within sports science practice. This knowledge has assisted the development of valid and reliable athlete monitoring systems; informing training prescription, specificity and dose for match preparation. While the physical demands of rugby league match-play have been thoroughly described within literature [3, 6, 33], there have been relatively fewer studies describing the physical demands of training drills (Chapter Two). Many of these reports have provided observations of distance, velocity and acceleration measures across shorted periods (i.e., pre-season phases) [10-12, 38, 44, 45, 142] and game-based activities such as small-sided games (SSG) [14, 15, 18, 42, 43] to examine the effect of implemented constraints (e.g., contact vs. non-contact [42], on-side vs. off-side [18]).

In addition to physical requirements, a high level of technical skill is required as players tackle, pass, kick and play-the-ball [90]. Teams must also cooperatively interact with each other to develop a structured style-of-play and respond cohesively to the opposition [31].

Players seek scoring opportunities during six consecutive tackles by attempting to cause disorganisation within the defence. Alternatively, defending teams aim to prevent metres gained by the attacking team by tackling and wrestling the ball-carrier. To best achieve this, coaches implement a tactical approach based on the teams' style-of-play and principles within attack, defence and transition moments of performance [20, 30]. Although coaches may modify their tactical model based on player strengths and capabilities, players are required to conform to the desired tactical approach to create an organised system. Research of the technical (individual skill) and tactical (interaction with other individuals) demands of rugby league performance has become increasingly prevalent, highlighting elements of technical performance characteristic of successful and less successful teams [9, 37, 67] and between levels of competition [85, 98]. Despite its purported importance to successful match-play, the technical demands of training are not well reported. A limited number of empirical studies are available and involve only one category of training drill (i.e., SSG) within their investigations [14-19]. Moreover, to-date there have been no studies exploring the tactical description or demands within rugby league training. While much focus has been on the specificity of physiological preparation and performance, these studies do not provide a comprehensive analysis as they neglect to integrate the tactical elements present within team sports. Furthermore, previous analyses have been restricted to a limited variety of training drills and may overlook significant team drills used for strategic preparation.

Ultimately, rugby league performance – or team success – is reliant on the collective physical, technical and tactical abilities of team members, that are developed within deliberate practice prescribed by coaches and support staff [63]. Nevertheless, our current understanding of the complex and dynamic interplay of physical, technical and tactical pillars of performance is limited. The aims of this study are to describe and classify the physical, technical and tactical demands within professional rugby league training drills.

4.2 Methods

Design

This study adopted a prospective cohort design conducted over the 2018 National Rugby League (NRL) Competition. Procedures were approved by the Human Research Ethics Committee of the University of Technology Sydney (ETH16-1074). Written informed

consent and demographic information was obtained from all participants before the commencement of this study.

Participants

Physical, technical and tactical performance data were collected from thirty-six professional rugby league players (age: 24.0 ± 4.0 years; mass: 98.6 ± 8.4 kg; stature: 186.3 ± 6.0 cm) contracted to the same club. Players were from three positional groups; forwards (n = 19, 53%), adjustables (n = 9, 25%) and outside backs (n = 8, 22%) at the start of the season. Forwards consist of hit-up forwards (props) and wide-running forwards (second rowers and lock), adjustables consist of hooker, five-eighth, half-back and fullback positions, and outside backs consist of wing and centre positions. Six players (17%) interchanged positional groups throughout the season.

Data relating to drill design, drill focus and period of performance was collected from four experienced professional NRL coaches. Coaches were contracted full-time to the NRL club, had a combined total of 39 years playing and a range of 4 – 16 years coaching experience as an assistant or head coach role within the professional and semi-professional grade. Distributed roles for the participating coaches included: head coach, defence coach, attack coach and development coach.

Procedures

Data were collected from 29 unique drills obtained across 68 on-field training sessions during the 2018 competition phase. A total of 4,552 individual data files were obtained for physical performance and 67 files were obtained for team technical and tactical performance. Seven training drills were excluded from analysis due to missing technical and tactical data. On-field training frequency was dependent on match turnarounds and ranged from three to four sessions per week.

Measures such as *drill design*, *drill focus* and *period of performance* were identified to provide descriptors for each training drill. These measures were collected according to the recent work developing a Training Drill Questionnaire to identify how coaches' tactically categorise and prescribed on-field training drills in professional rugby league (Chapter Three) (supplementary material figure S1). Twenty-thirty minutes prior to the training

session, coaches marked the tactical description of each drill by placing a '1' under the relevant subsection. Coaches marked a '1' to all that applied should more than one subsection obtain equal priority. Subsections and explanations of tactical descriptors are indicated in table 4.1, with descriptions of drills including name, field position, drill frequency and sample size can be found in table 4.2. Additionally, a breakdown of field position for goodball, midfield and yardage areas in attack and defence is indicated in figure 4.1.

Table 4.1 Tactical descriptors and subsections utilised to describe included training drills in this study.

Tactical Descriptors	Subsections and Descriptions
Period of Performance	First quarter: 0 – 20 minutes
	Second quarter: 20 – 40 minutes
	Third quarter: 40 – 60 minutes
	Last quarter: 60 – 80 minutes
	Whole game: 0 – 80 minutes
Drill Design	Structure: the arrangement of the team
	Execution: carrying out the skill elements necessary for the tactical action
	Scenario: preparing for predicted match events of scenes
Drill Focus	Team: all members
	Group: a number of persons classed together e.g., forwards, outside backs
	Individual: particular persons

Table 4.2 Description, focus, design and field positions of drills utilised.

ID	Drill Name	Drill Focus	Drill Design	Period of Performance	Attack Field Position	Defence Field Position	Frequency	No. Data Points
1	Attack Last Play	Team, group	Structure, scenario, execution	Whole game, first quarter	Goodball	-	19	347
2	Attacking Parts	Team	Structure	Whole game	Goodball	-	4	93
3	Attacking Parts	Group	Structure	Whole game	Goodball	Yardage	3	52
4	Attacking Parts	Group	Structure, scenario	Whole game	Goodball	Yardage	3	62
5	Attacking Parts	Team	Execution	First quarter	Goodball, Midfield	-	1	19
6	Attacking Parts	Team	Structure	Whole game	Goodball, Midfield	-	1	20
7	Attacking Parts	Team	Structure	Whole game	Goodball	-	1	17
8	Attacking Parts	Group	Execution	Whole game	Goodball	-	1	12
9	Attacking Sets	Team	Structure	Whole game	Goodball	-	2	32
10	Attacking Sets	Team, group	Structure, scenario	Whole game	Goodball	Yardage	17	314
11	Attacking Sets	Team	Structure, scenario, execution	Whole game, first quarter	All field	Yardage, GLD	6	118
13	Attacking Sets	Team	Structure, execution	Whole game, first quarter	All field	Yardage	4	79
14	Defence Last Play	Team	Structure	Whole game	Yardage	GLD	22	400
15	Defence Last Play	Team	Structure	Whole game	Yardage	GLD, Midfield	1	16
16	Defence Last Play	Team	Scenario	Whole game	Yardage, Midfield	GLD	1	22
17	Defence Parts	Team	Structure	Whole game	-	GLD	2	30
18	Defence Parts	Team, group	Structure, scenario	Whole game	-	GLD	23	457
19	Defence Parts	Team	Scenario	Whole game	Yardage	GLD, Midfield	4	76
20	Defence Sets	Team	Structure, execution	Whole game, first quarter, last quarter	Yardage	GLD	9	168
21	Defence Sets	Team	Scenario	Whole game	-	GLD	1	20
22	Defence Sets	Team	Structure	Whole game	-	Yardage, Midfield	1	20
24	Multipurpose	Team	Structure, scenario	Whole game, first quarter, last quarter	All field	All field	18	347

GLD: Goal line defence

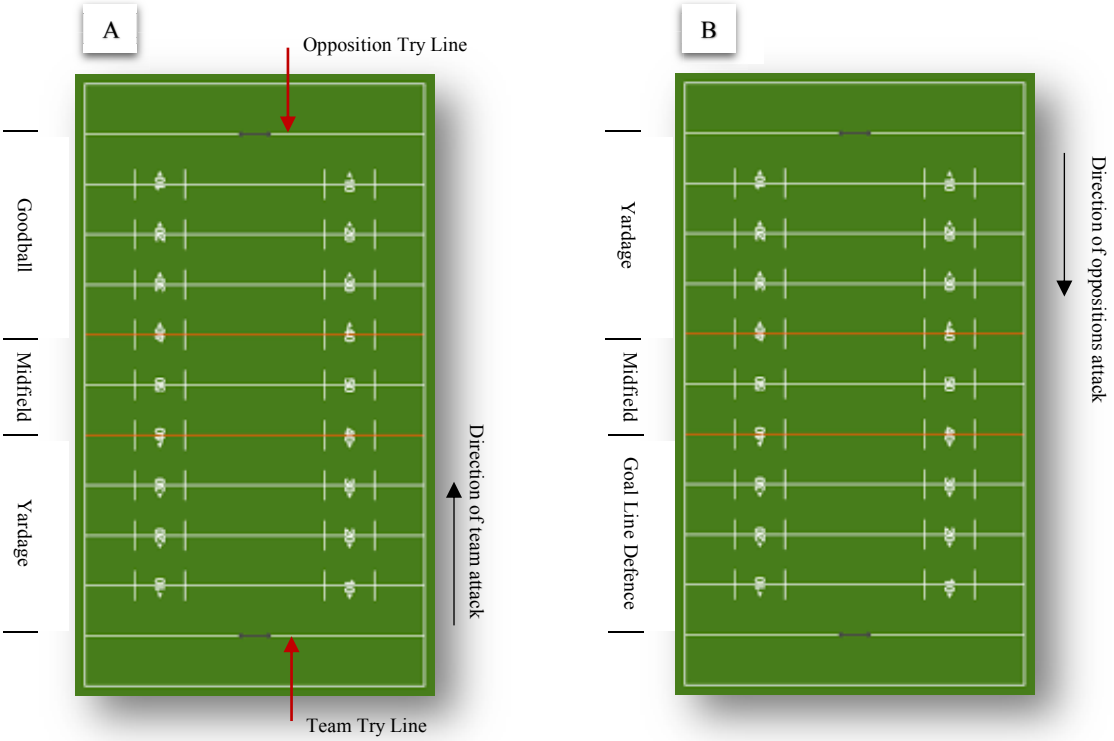


Figure 4.1 Field positions for A. attack and B. defence areas of the field.

To obtain the physical demands of on-field training drills, players wore a GPS device (Optimeye S5, Catapult Sports, Melbourne, Australia) sampling at 10-Hz. These devices obtained a 100-Hz accelerometer, gyroscope and magnetometer and proprietary inertial movement units (IMU)(non-gravity vectors) in-built within the device (firmware version 7.4). All players were assigned the same device to minimise inter-unit variability [143, 144] and were worn in custom-designed vests located in the upper thoracic region to minimise unwanted movement [145]. All players were familiarised with wearing the devices prior to commencement of this study and there were no reports of discomfort. GPS devices sampling at 10-Hz have reported acceptable validity and reliability for velocity movement demands such as total distance, high speed running and maximum velocities [144, 146, 147]. Research has also recommended a minimum sampling GPS rate of 10 Hz to derive threshold-based acceleration measures [148, 149]. Non-gravity resultant vectors of the X, Y and Z planes have been developed and integrated to provide an in-built IMU within GPS devices. This raw accelerometer and gyroscope data filtered with the Kalman technique has allowed the detection of explosive movements such as high intensity accelerations, decelerations and change of directions (COD), known as Inertial Movement Analysis (IMA) [150, 151]. IMA has found to be a valid and reliable method to quantify

explosive actions (expressed as total counts or medium/high threshold counts), with moderate reliability found for IMA categorised into directional bands [151-154].

The mean number of satellites and horizontal dilution of precision (HDOP) during data collection was 12.5 ± 1.0 and 0.75 ± 0.03 respectively, displaying good precision [145]. All GPS devices obtained 'GPS lock' prior to the collection of data each training session. Training drills were 'split' in real-time using Catapult Openfield software (version 2.5.2 build #64421, Catapult Sports, Australia) and a USB connected real-time receiver. All data files were downloaded post session to customised Microsoft Excel databases and abnormal GPS values were manually removed.

The tactical and technical performance demands of on-field training drills were video-coded using SportsCode Elite software (version 11.2.44, Hudl, Sydney, Australia). One coder (> 3 years of experience) was utilised to minimise inter-coding variability. A re-test of 10 samples conducted at least one month apart was conducted to determine intra-observer reliability [5, 155]. Reliability was expressed as the coefficient of variation at <2.4% [7, 8]. All measures were standardised relative to time (e.g., $m \cdot min^{-1}$) or expressed as a percentage to account for the varying duration of training drills.

Measures

Physical Performance

Physical performance measures obtained from GPS included: duration of training drill (min), relative distance covered ($m \cdot min^{-1}$), the number of minutes greater than 100 $m \cdot min^{-1}$ (n), maximum velocity ($m \cdot s^{-1}$), total high speed distance ($m \cdot min^{-1}$), total very high speed distance ($m \cdot min^{-1}$) and sprinting distance ($m \cdot min^{-1}$). Accelerometer-derived data included: the number of accelerations and decelerations ($n \cdot min^{-1}$), change of direction (COD) ($n \cdot min^{-1}$), collisions ($n \cdot min^{-1}$), impacts ($n \cdot min^{-1}$), repeated high intensity efforts (RHIE) ($n \cdot min^{-1}$) and Player Load ($AU \cdot min^{-1}$).

Previous research have reported overall match relative distance of elite players at 90 – 94 $m \cdot min^{-1}$, with adjustable positional groups averaging as high as 99 $m \cdot min^{-1}$ [6]. Accordingly, the number of minutes greater than 100 $m \cdot min^{-1}$ was collected to investigate the volume of time spent above average match intensities. High speed distance, very high

speed distance and sprinting distances were categorised as movement between 5.0 and 6.5 $m \cdot s^{-1}$, 6.5 and 8.0 $m \cdot s^{-1}$ and > 8.0 $m \cdot s^{-1}$ respectively. High speed distance threshold at 5.0 $m \cdot s^{-1}$ has commonly be applied within previous literature [3], with additional very high speed and sprinting thresholds applied as per manufacturer settings.

Accelerations and decelerations were reported as the number of entries above manufacturer set 2.0 $m \cdot s^{2}$ and -2.0 $m \cdot s^{-2}$ thresholds respectively. Player Load (PL) was derived from the instantaneous rate of change of acceleration of the three axes (anterior-posterior, medio-lateral and vertical planes) [6, 78]. The automatic detection of collisions occurs by a change in unit orientation and instantaneous spike in Player Load [156]. Collision exposures above a 2.5 G threshold were included to reduce detection error [157]. RHIE were defined as ≥ 3 maximal accelerations (≥ 2.79 $m \cdot s^{-2}$), high speed (> 5 $m \cdot s^{-1}$) or contact efforts with < 21 second recovery between each effort [158].

Impact profiles detail all forces a player is exposed to such as foot strike, landing, ball kick, dives and change of directions and derived from IMA [159, 160]. Impacts above a manufacturer set threshold of 6.0 g were included for analysis. Change of direction (COD) were detected by the combination count of movement to the left (-135 to -45 degrees) and right (45 – 135 degrees) above a medium / high 2.5 $m \cdot s^{-1}$ predefined threshold [150, 152].

Technical Performance

Outcome measures of technical variables obtained for this study include: tackles made ($n \cdot min^{-1}$), successful tackles (%), tackles received ($n \cdot min^{-1}$), total passes ($n \cdot min^{-1}$), successful passes (%), total receives ($n \cdot min^{-1}$), play-the balls (PTB) ($n \cdot min^{-1}$), territory kicks ($n \cdot min^{-1}$), attacking kicks ($n \cdot min^{-1}$), grubber kicks ($n \cdot min^{-1}$), technical errors ($n \cdot min^{-1}$), tries scored ($n \cdot min^{-1}$), and opposition tries scored ($n \cdot min^{-1}$). Definitions and coding criteria were adopted and modified from previous research [5, 161] by the research team, and confirmed by the high performance coaches. Definitions of these measures are outlined in table 4.3.

Table 4.3 Definitions of collected technical variables.

Technical Variable	Definitions and Criteria
Tackles Made	When a defending player engages in physical contact with the opposing ball-carrier in order to prevent the ball proceeding towards the teams try line. Criteria includes; when contact is made and the ball in play cannot be passed to a teammate, contact is made but results in the ball being transferred to another player (offload) or when contact is made but the defender fails to halt the opponent's progression (missed).
Successful Tackles	When a defending player engages in physical contact with the opposing ball-carrier and the ball in play cannot be / is not passed to a teammate.
Tackles Received	When an attacking ball-carrier engages in physical contact from defending player/s. Criteria includes; when contact is made and the ball in play cannot be passed to a teammate, contact is made but results in the ball being transferred to another player (offload) or when contact is made but the defender fails to halt the opponent's progression (missed).
Total Passes	When an attacking player attempts to transfer the ball to a teammate.
Successful Passes	When the ball is accurately transferred to a teammate and of optimum height: i.e., between chest and head height.
Total Receives	When a player attempts to obtain or maintain possession by catching the ball.
Play-the-balls	When a player successfully rolls the ball backwards, immediately stepping over with one foot after a tackle to transfer the ball to a teammate for the next attacking play.
Kicks (Territory, Attacking, Grubber)	When an attacking player strikes the ball with the foot to gain a territorial (territory kick) or try scoring (attacking kick or grubber kick) advantage. Territory kicks and attacking kicks are characterised by an in-air flight path and often occur from the yardage / midfield area and goodball areas respectively. Grubber kicks are categorised by the ball bouncing along the ground with an attempt to score a try.
Technical Errors	All attacking and defensive events that result in a turnover of possession or tackle restart.
Try Scored	When a player crosses the 'opposition try line' (figure 4.1) and grounds the ball with their fingers, hand, wrist, forearm or torso with control and downward pressure.
Opposition Try Scored	When an opposing player crosses the 'team try line' (figure 4.1) and grounds the ball with their fingers, hand, wrist, forearm or torso with control and downward pressure.

Tactical Performance

Tactical measures of on-field training drills were obtained by coding players in attack (in possession of the ball) (min), defence (opposition is in possession of the ball) (min), transition from attack to defence ((TAD) period of transferring possession of the ball to

the opposition) (min), transition from defence to attack ((TDA) period of receiving possession of the ball from the opposition) (min) or deadball (ball not in play)(min).

These measures were presented as percentages (%) and standardised by minute of drill time for analysis. Whilst all 36 participants are contracted to the same club and partake in training, 18 are selected each week to participate in the upcoming match. Consequently, players are often separated into two teams (selected and non-selected) for training, allowing the selected team to practice against an opposition side. For consistency, tactical measures of the 'selected' team were coded for analysis. The field locations of all PTBs, tries scored and opposition tries scored were included to provide descriptions of the prominent field areas within training drills (table 4.2). The field positions within drills exclusive of PTB (i.e., no consecutive plays and/or unopposed drills) was determined when the ball carrier halts at the end of play. The field was divided into 10 m^2 segments to produce 84 unique areas [2]. A count of all locations per drill was totalled to produce a heat map categorise drills into attacking "goodball" (60–100 m), "midfield" (40–60 m) "yardage" (0 – 40 m) areas and defensive "goal line defence" (0–40 m), "midfield" (40–60 m) and "yardage" (60–100 m) areas (figure 4.1).

Statistical Analysis

To obtain the physical measure of each unique training drill, the individual GPS player files within each drill was first averaged. The physical, technical and tactical measures were next averaged across repeated training drills. These variables were subsequently analysed descriptively with raw means and standard deviations. A Principle Component Analysis (PCA) with varimax rotational method was applied to reduce and refine variables into main components. Pairwise correlations were first conducted to reduce the number of items entered into the PCA in order to satisfy Bartlett's test of sphericity. When two items were highly correlated ($r > \sim 0.9$) only one was retained for analysis. Items were sufficiently loaded together if correlation coefficients were above 0.5. Prior to, correlation outliers (± 3 SD) were removed and variables were log transformed to reduce non-uniformity error, thereby reducing the effect of skewness on the PCA and obtaining a uniform scale across variables. Kaiser-Meyer-Olkin Measure of Sampling Adequacy and Bartlett's test of sphericity were examined.

To classify and group training drills based on similar physical, technical and tactical properties, a hierarchical agglomerative cluster analysis was conducted with the extracted PCA components. A Wards linkage method was applied to group clusters that resulted in the smallest increase of aggregate deviation to the centroid when merged. The number of clusters were subsequently extracted and determined by an associated dendrogram. All analyses were conducted using customised Microsoft Excel spreadsheets (version 16.16.27, Microsoft Office, Australia) and SPSS Software (version 21.0. IBM, Australia).

4.3 Results

The means and standard deviations of the physical, technical and tactical were tabularised to provide the descriptions of training drills explored in this study (supplementary material table S1, S2, S3, S4). Minutes > 100 $m \cdot min^{-1}$ had considerable missing values (31%) and was not included in the subsequent PCA. All other variables had either no missing data or missing values of no more than 5%.

Pairwise correlations identified five variables to be removed due to high correlations with other variables. Table 4.4 shows highly correlated variables between removed and retained variables. Three members of the research team (JH, AC, SS) collaborated to discuss the highly correlated variables and reached a consensus on which to remove and retain. Subsequently PCA with varimax rotation assessed the underlying structure of the 24 items encompassing physical, tactical and technical performance. After rotation, PCA revealed eight factors with eigenvalues greater than 1.0, labelled: *defence technical, speed efforts, attack technical, contact efforts, errors, last play physical, last play technical* and *sprints*. Table 4.5 displays the items and factor loadings for the rotated factors. Labels of PCA components were initially developed by the primary researcher (3 years' experience working in rugby league) and collaboratively agreed upon by the research team.

Table 4.4 Retained highly correlated variables by removed variables.

Retained Variables	**Removed Variables**				
	Distance	**PTB**	**Total Receives**	**Deadball**	**TAD Minutes**
Player Load	**.92**	-.06	.06	-.09	-.03
Total Passes	-.03	**.91**	**.94**	.01	.33
Attacking Kicks	.00	.39	-.31	**1.00**	**.87**

PTB Play-the-balls, TAD Transition from attack to defence

Table 4.5 Principal components factor loadings and correlation coefficient.

Component:	1: Defence Technical	2: Speed Efforts	3: Attack Technical	4:Contact Efforts	5: Errors	6: Last Play Physical	7: Last Play Technical	8: Sprints
Variance Explained:	15.18	13.09	9.73	9.08	6.54	6.02	5.57	5.04
Tackles Made	0.85							
Successful Tackles	0.68							
Total Passes	-0.65		0.59					
Grubber Kicks	-0.54				0.62			
Defence Minutes	0.85							
Try Scored	-0.76							
Opposition Try Scored	0.55				0.50			
Maximum Velocity		0.78						
High Speed Distance		0.83						
Very High Speed Distance		0.65						
Accelerations		0.72						
Decelerations		0.64						
Repeated High Intensity Efforts		0.53		0.60				
Tackles Received			0.84					
Attack Minutes			0.90					
Collisions				0.73				
Change of Direction				0.72				
Impacts				0.71				
Technical Errors					0.83			
TDA Minutes						0.81		
Player Load						0.57		
Successful Passes							-0.76	
Territory Kicks							0.71	
Sprinting Distance								0.87

TDA Transition from defence to attack

Hierarchical agglomerative clustering using Wards linkage with the eight identified components inputted six drill clusters. Cluster names were collaboratively agreed upon by the researchers. Referring to the clustering schedule (table 4.6) and figure 4.2 and, cluster 1 contained three training drills (ID 9, 11, 13) and was termed *Attack Whole*. These drills were designed to practice team attacking sets for the whole game and covered all field areas. The physical characteristics of this cluster displayed a range of relative distance (49.8 – 80.3 $m \cdot min^{-1}$) and high speed distances (3.7 – 8.2 $m \cdot min^{-1}$) and lower means of very high speed and sprinting distances. The technical demands of these drills elicited higher occurrences of tackles received, passes and kicks (territory and attacking). These drills displayed high proportions of time in attack and TDA.

Cluster 2 contained seven training drills (ID 3, 4, 5, 6, 10, 18, 24) and was termed *Part Practice*. These drills were described predominately as attack and defence parts, designed for the team and subset groups contained within goodball and goal line defence areas of the field. The physical characteristics of this cluster displayed a range of relative distance (47.9 – 94.9 $m \cdot min^{-1}$) and collisions (0.08 – 0.29 $n \cdot min^{-1}$) and higher levels of very high speed distance, accelerations and COD. The technical and tactical demands of these drills elicited a range of tackles received (0.9 – 3.9 $m \cdot min^{-1}$) and higher means of passes and grubber kicks and elicited high proportions of time in attack and defence.

Cluster 3 contained two training drills (ID 2, 7) and was termed *Attack Plays*. These drills were designed for the team to practice attacking parts within goodball areas of the field. The physical characteristics of this cluster displayed lower levels of relative distance and collisions and higher means of very high speed distances, sprinting distances and RHIE. The technical demands of these drills elicited higher means of tackles received and passes and a range of all kick types (territory, attacking and crossfield). These drills spent a higher proportions of time in attack and range of TAD.

Cluster 4 also contained two training drills (ID 1, 14) and was termed *Last Plays*. The drills were designed to practice attacking and defence last plays of performance within goodball and goal line defence areas of the field. These drills presented lower means of VHS, decelerations, RHIE and tackles received with high occurrences of all kick types (territory,

attacking and crossfield). These drills spent large proportions of time in TAD and TDA and presented high means of tries scored.

Cluster 5 contained four drills (ID 15, 19, 20, 22) and was defined as *Defence Whole*. This cluster contained a variety of defensive drill designs (defence last plays, defence parts and defence sets) and were contained to midfield and goal line defence areas of the field. The physical characteristics of these drills exhibited higher means of relative distance, collisions and RHIE. These drills elicited higher occurrences of tackles made and spent large proportions of time in defence and TDA.

Cluster 6 labelled *Organisation*, contained four drills (ID 8, 16, 17, 21). This cluster contains a mix of attack and defence drills for the team within the goal line defence area and all attacking areas (goodball, midfield, yardage) of the field. Collectively these drills displayed lower means of physical demands such as relative distance, high speed distances, collisions, COD as well as technical factors such as tackles made and passes. These drills spent large proportions of time in attack and defence.

Table 4.6 Clustering schedule and coefficients.

Stage	Cluster Combined		Coefficients
	Cluster 1	Cluster 2	
1	11	12	0.811
2	14	18	1.758
3	19	21	2.723
4	17	22	3.946
5	3	4	5.182
6	3	6	6.664
7	16	20	8.397
8	8	15	10.373
9	3	10	12.7
10	14	19	15.56
11	1	13	18.692
12	2	7	22.588
13	9	11	26.489
14	3	17	31.842
15	8	16	38.987
16	3	5	47.665
17	3	9	57.116
18	2	3	71.936
19	8	14	92.163
20	1	2	113.221
21	1	8	168

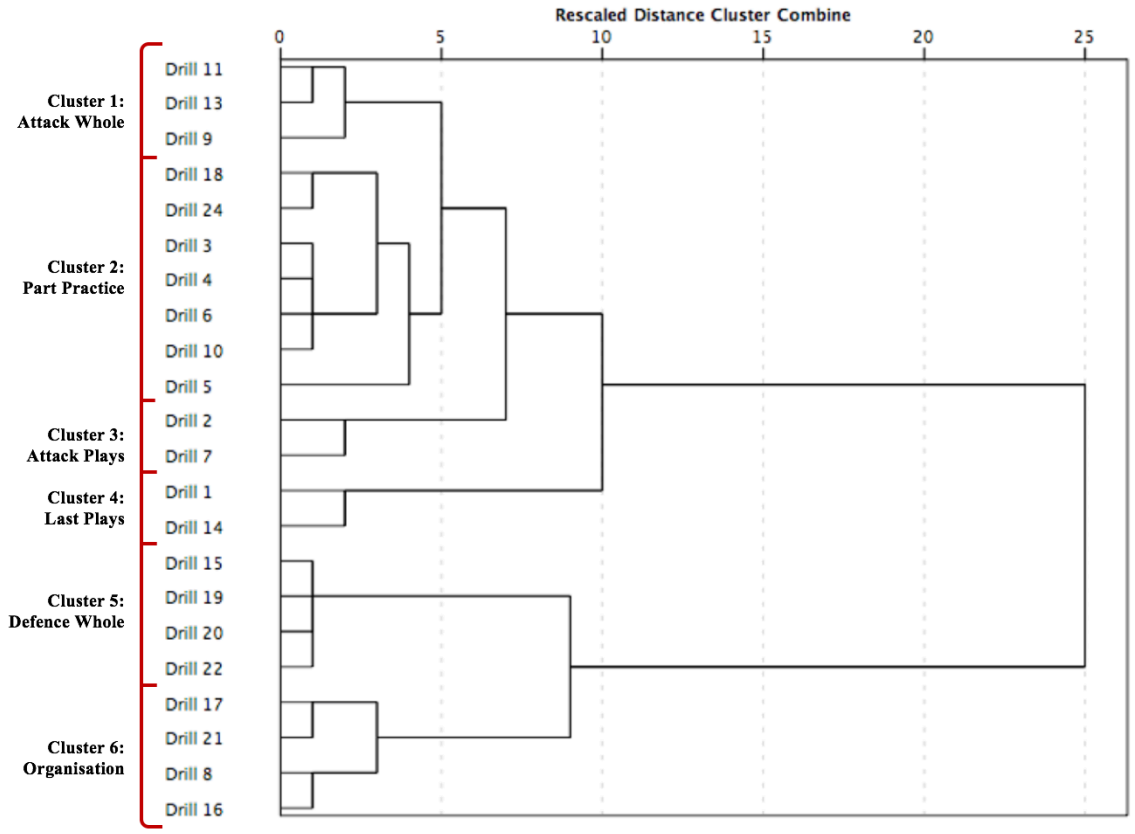


Figure 4.2 Wards agglomerative hierarchical cluster analysis illustrated by dendrogram for the six identified components.

4.4 Discussion

The purpose of this investigation was to describe and classify the physical, technical and tactical demands of professional rugby league on-field training drills. A reduction analysis discerned eight overarching components to broadly describe on-field training drills; *defence technical, speed efforts, attack technical, contact efforts, errors, last play physical, last play technical* and *sprints* (table 4.5). Based on similarities of these components, findings from the cluster analysis identified six central types of drills conducted in training throughout the competition season; *Attack Whole, Part Practice, Attack Plays, Last Plays, Defence Whole* and *Organisation* (figure 4.2). While previous investigations have classified training drills based on the similarities of physical [162, 163] and technical [162] demands in Australian Football, this study is the first to describe the multifaceted physical,

technical and tactical demands and classify team drills in professional rugby league training.

Previous reports within rugby league have described the physical and technical demands of training drills (Chapter Two) designed for physiological preparation such as game-based activities [14-16, 18, 19, 142, 161, 164] and conditioning drills [10, 44, 48, 50]. Previous papers have also investigated the physical training loads conducted throughout the whole season (i.e., pre-season and competition periods) [48, 49, 69] as well as examining the volume and effect of collisions within rugby league training to infer physical periodisation and recovery cycles [165, 166]. The findings from this study provide a novel contribution to this body of knowledge as it is the first to describe the multifaceted demands of rugby league training and includes team drills designed for strategic and tactical preparation within its investigation. Furthermore, this study is the first to implement a classification of training drills within professional rugby league. Although speculative, findings suggest the majority of technical and tactical factors are grouped by moment of performance (attack, defence and transitions). This is possibly explained as technical and tactical actions are specific to the moments of performance in which they occur (e.g., tackles made occurs when in defence, and passes occur when in attack). With the exceptions of PlayerLoad and sprinting distance, the majority of physical variables were segregated into *speed efforts* and *contact efforts*. These findings reflect the physical nature of rugby league performance, whereby players are required to perform frequent bouts of high intensity activities and collision events during all moments of the game [3].

A positive correlation was reported between team 'errors' and 'opposition try' variables (table 4.5). Whilst this relationship has not been reported within rugby league training, this finding is congruent with previous research identifying successful teams commit fewer errors during match performance [9]. A negative correlation between 'passing percentage' and 'territory kicks' was reported and grouped to form the component *last play technical*, suggesting a greater occurrence of territory kicks to gain field position when less successful passing was present in training.

The cluster analysis discerned six central types of drills conducted throughout the competition season: *Attack Whole, Part Practice, Attack Plays, Last Plays, Defence Whole*

and *Organisation* (figure 4.2). Previous research has noted the categorisation of performance moments (attack, defence, transition from attack to defence, transition from defence to attack) in team sport [30]. Indeed, practicing and executing team strategies within these moments during training is important to achieve synergy and align tactical goals [24, 35]. *Attack Whole, Defence Whole, Last Plays* and *Organisation* shared a common observation covering all areas of the field. In contrast, *Part Practice* and *Attack Plays* drills were implemented predominately within attacking goodball and goal line defence areas of the field. The value of possession for all field areas has previously been established [2], identifying possessions in attack commencing close to the opposition's try line increases the likelihood of scoring. As such, coaches and playmakers spend considerable time studying the opposition to create and practicing set attacking plays and maximise their scoring efficiency whilst alternatively developing defensive strategies to prevent scoring opportunities of the opposition [36].

Attack Plays elicited high means of very high speed distances and tackles received and experienced a range of collision intensity. *Attack Whole* similarly displayed a range of collision intensities however displayed low means of very high speed distance. Although both drill types are designed for practice in attack, differences in physical and technical characteristics may reflect variances in execution (e.g., speed of movement) and opposition pressure. *Organisation* drills were characterised by low means of speed, contact and technical variables such as high speed distance, collisions, tackles made and received and total passes. Explanations may be two-fold whereby physical demands are prescribed at reduced intensities as per physical periodisation models allowing for recovery and optimal preparation for performance [55, 56, 108]. For example, previous research has suggested physical contact should be performed in training well in advance of scheduled games [166]. However, the additional occurrence of low technical demands suggested the drills may have been planned and implemented by coaches for tactical and strategic reasons such as; applying new strategies, making team or positional adjustments and providing feedback [167]. Future research examining the coaches' prescription of training drills would provide a comprehensive understanding of the intent of the multifaceted demands of training drills in preparation for performance. Furthermore, examining the variability and distribution of these drills over weekly and competitive periodisation models is encouraged to provide

sports scientists a holistic understanding to assist in preparation strategies for rugby league performance.

The consideration of team tactics and strategy is becoming increasingly prevalent, with many reports highlighting the contribution of technical and tactical behaviour to success within rugby league match-play [7, 9]. Despite the current study being the first to describe and classify the multifaceted demands of rugby league training drills, it is not without its limitations. This study applies an analytical method to data obtained from one team during one season and acknowledges that coaches from different clubs will obtain distinctive philosophies, strategies and training approaches. As such, results may only be applicable to the studied population. Furthermore, varying turnarounds between matches throughout the season can lead to unequal frequency of training drills. Nonetheless, findings from this study allows coaches and high performance staff to discern the similarities and differences of the multifaceted demands between training drills, which may be useful for planning, drill selection and distribution. For example, coaches may distribute *Organisation* drills earlier in the training week to implement the team strategies required for the upcoming match, or provide learning opportunities from the previous match performance. Although this is a novel approach and extends on previous investigations informing physiological preparation in rugby league, the PCA reduction technique applied may pose challenges for practical interpretation and warrants further examination. Additionally, due to the methods of PCA to reduce the dimensions within a dataset (i.e., explore constructs to produce a smaller set of variables while maintaining most of the variability in the original dataset [168]) it is acknowledged the name of extracted components and measure of underlying construct for each component are subject to speculation. As such, discerning whether the use of original variables or other reduction techniques may be beneficial to inform meaningful changes and assessments (e.g., comparisons of drill outputs to established benchmarks) in practical settings.

This study expands on previous research describing the physical and technical demands of rugby league training by including tactical features and incorporating an integrated analysis approach in its design. Indeed, findings derived from this study are important for preparation of performance as it provides high performance coaches and support staff a holistic understanding of the multifaceted demands for rugby league training [162]. Further understanding of the variance of these demands and the interaction between players or

positional groups within training drills would be useful in assessing training design and interpreting training outcomes and is encouraged for future investigations. This study also expands on previous research by describing team-based drills implemented for tactical preparation. However, as the design and implementation of these drills is coach driven, often according to their desired style of play and principles [30, 36], future research should examine how coaches plan, prescribe and distribute training drills.

4.5 Conclusion

The aims of this investigation were to describe and classify the physical, technical and tactical demands within professional rugby league on-field training drills. The present study identified eight broad components that encapsulate the physical, technical and tactical aspects of performance providing a multifaceted approach to describing training drills. These components were segregated by their relation to moment of performance (attack, defence and transition) and physical requirements (high intensity efforts and collision events). In addition, this study is the first to classify rugby league training drills. Six central types of drills were identified to strategically prepare the team for match performance throughout the season. These drills were centred on practicing attack and defence sets, attack and defence parts, transitions and team organisation. These findings have implications for sports scientists to develop and integrate a holistic approach to understanding the preparation for rugby league performance.

CHAPTER FIVE

Study Four: Between Drill Variation in Professional Rugby League Training

5.1 Introduction

Rugby league is a team sport comprised of the complex interplay of physical, technical and tactical components. Players are required to obtain the necessary physical capacities to perform and withstand the demands of competition which include collision events and high intensity movements [79]. Players must also be able to perform sport-specific technical skills such as tackling, grappling, kicking, passing and wrestling events both as individuals but also work together as a collective to execute tactical and strategic actions [67, 91, 135]. Players are also required to understand their individual role within the team and how it contributes to the team's strategy of obtaining optimum field position and scoring more points than the opposition. Rugby league training programs are designed and implemented to concurrently develop these elements of performance (e.g., build physical capacity, develop requisite skills, practice the strategies according to style-of-play). As such, understanding these multifaceted elements of performance has been of significant interest within sports science to assist the development and holistic preparation of players for performance.

In Chapter Four, eight overarching components that describe the physical, technical and tactical demands of on-field training drills within professional rugby league were identified in recent research (i.e., *defence technical, speed efforts, attack technical, contact efforts, errors, last play physical, last play technical* and *sprints*). Based on the similarities of these components, 6 central types of drills (i.e., *Attack Whole, Part Practice, Attack Plays, Last Plays, Defence Whole* and *Organisation*) were observed to be conducted throughout the season. While this study is novel in its contribution to understanding the multifaceted demands of rugby league training, a poor understanding of the typical variability of these measures remain. Variations in team sport performance have been investigated, possibly attributed to factors such as match outcome, physical fitness and environmental conditions within team sports [26, 88, 89]. Indeed, variations between training drills may be influenced by these factors as well as other considerations such as phase of season, upcoming opponent, match turnaround or learning the required tactical strategies. Understanding the variability of training drills and how the physical, technical and tactical demands vary will be useful in assessing training design and interpreting training outcomes.

A large degree of variation in high speed activities have been reported between matches in professional rugby league [26] and Australian Football [27]. Specifically, between match variability for high speed and very-high speed variables in rugby league was 14.6% and 37.0% respectively [26]. Furthermore, higher variability (%CV 28.3 – 55.3) for technical performance measures such as possessions, kicks and handballs have also been reported between matches in Australian Football [27]. Whilst these studies assist with interpreting physical and technical performance changes in team sport, to-date, there have been no studies investigating the variability of training drills in professional rugby league. Furthermore, no studies have incorporated the multifaceted physical, technical and tactical demands in their investigations. Accordingly, the aim of this study was to determine between-drill variability of physical, technical and tactical measures within professional rugby league training.

5.2 Methods

Design

This study utilised a prospective cohort design conducted over the 2018 National Rugby League (NRL) Competition. Procedures were approved by the Human Research Ethics Committee of the University of Technology Sydney (ETH16-1074). Written informed consent and demographic information was obtained from all players before the commencement of this study.

Participants

Physical, technical and tactical performance data were collected from 36 professional rugby league players (age: 24.0 ± 4.0 years; mass: 98.6 ± 8.4 kg; stature: 186.3 ± 6.0 cm) and four high performance coaches from the same team in the NRL competition. Players were from three positional groups; forwards (n = 19, 53%), adjustables (n = 9, 25%) and outside backs (n = 8, 22%) at the start of the season. Forwards consist of hit-up forwards (props) and wide-running forwards (second rowers and lock), adjustables consist of hooker, five-eighth, half-back and fullback, and outside backs consist of wing and centre positions. Six players (17%) interchanged positional groups throughout the season.

Measures and Procedures

Data were collected from 29 unique drills obtained across 68 training sessions spanning one competition season. A total of 4,552 individual data files were obtained for physical performance and 67 files were obtained for technical and tactical performance. Seven training drills were excluded from analysis due to missing technical and tactical data. All physical, technical and tactical measures were collected according to methods reported previously (Chapter Three).

To obtain the physical demands of on-field training drills, players wore a GPS device (Optimeye S5, Catapult Sports, Melbourne, Australia) sampling at 10-Hz. Physical performance measures included: duration of training drill (min), relative distance covered ($m \cdot min^{-1}$), the number of minutes greater than 100 $m \cdot min^{-1}$ (n), maximum velocity ($m \cdot s^{-1}$), total high speed distance ($m \cdot min^{-1}$), total very high speed distance ($m \cdot min^{-1}$) and sprinting distance ($m \cdot min^{-1}$), the number of accelerations and decelerations ($n \cdot min^{-1}$), change of direction (COD) ($n \cdot min^{-1}$), collisions ($n \cdot min^{-1}$), impacts ($n \cdot min^{-1}$), repeated high intensity efforts (RHIE) ($n \cdot min^{-1}$) and Player Load ($AU \cdot min^{-1}$).

The technical and technical performance demands of on-field training drills were video-coded using SportsCode Elite software (version 11.2.44, Hudl, Sydney, Australia). Outcome measures of technical variables included: tackles made ($n \cdot min^{-1}$), successful tackles (%), tackles received ($n \cdot min^{-1}$), total passes ($n \cdot min^{-1}$), successful passes (%), total receives ($n \cdot min^{-1}$), play-the balls (PTB) ($n \cdot min^{-1}$), territory kicks ($n \cdot min^{-1}$), attacking kicks ($n \cdot min^{-1}$), grubber kicks ($n \cdot min^{-1}$), technical errors ($n \cdot min^{-1}$), tries scored ($n \cdot min^{-1}$), and opposition tries scored ($n \cdot min^{-1}$). Tactical measures of on-field training drills were obtained by coding players in attack (min), defence (min), transition from attack to defence (TAD) (min), or transition from defence to attack (TDA) (min).

A Principal Component Analysis (PCA) was utilised to reduce the data set and identified 8 overarching components to describe the physical, technical and tactical demands of training drills (supplementary material table S5). Based on the similarities of these properties, a cluster analysis was conducted to classify and group training drills. Six clusters; *Attack Whole, Part Practice, Attack Plays, 'Last Plays, Defence Whole* and *Organisation* were derived and utilised in this study (supplementary material figure S2).

Statistical Analysis

All data were checked for normality prior to analysis. Physical, technical and tactical performance measures were analysed using customised Microsoft Excel spreadsheets and SPSS Software (version 21.0. IBM, Australia). The physical, technical and tactical description of training drills were retrieved from previous research (Chapter Three). Data was log-transformed and typical error of performance measures was presented as the coefficient of variation (%CV), calculated by dividing the standard deviation (SD) over the mean score. The smallest worthwhile change (SWC) for each performance variable was obtained by multiplying the between subject standard deviation by 0.2 [26].

5.3 Results

The %CV and SWC of physical, technical and tactical components of training drills and drill clusters are reported in table 5.1. The data show that the majority clusters elicited lower variability of *defence technical*, higher variability of *contact efforts* and even higher variability for *sprints*. A large spread of variability for *attack technical* and *errors* components between clusters was observed, with *Defence Whole* and *Organisation* reporting large %CV. The %CV of *speed efforts, last play physical* and *last play technical* variables were relatively uniform across all clusters.

Table 5.1 Between drill variation of physical, technical and tactical components for drill clusters (%CV, %SWC).

	Drill ID	Drill N	Player N	Defence Technical		Speed Efforts		Attack Technical		Contact Efforts		Errors		Last Play Physical		Last Play Technical		Sprints	
				CV	SWC	CV	SWC	CV	SWC	CV	SWC	CV	SWC	CV	SWC	CV	SWC	CV	SWC
Attack Whole	9	2	32	0.0	0.0	30.3	1.8	0.0	0.0	77.0	0.6	0.0	0.0	44.6	4.8	0.0	0.0	556.8	0.6
	11	6	118	3.4	0.6	28.2	2.1	37.2	3.3	76.1	1.0	84.0	0.4	13.3	1.2	24.0	0.8	990.6	0.7
	13	4	79	5.3	1.0	24.8	1.7	32.7	2.9	59.3	1.1	45.6	0.2	12.9	1.1	32.3	0.9	883.2	0.3
Total		**12**	**229**	**4.2**	**0.5**	**28.1**	**2.0**	**33.9**	**3.0**	**74.2**	**1.1**	**66.4**	**0.3**	**24.2**	**2.2**	**26.6**	**0.8**	**931.4**	**0.6**
Part Practice	3	3	52	5.2	1.0	24.8	1.9	7.6	0.7	48.0	0.8	35.0	0.2	12.2	1.0	10.8	0.2	519.9	1.2
	4	3	62	3.3	0.6	39.0	2.5	19.9	1.7	74.8	0.9	3.1	0.0	14.6	1.0	11.9	0.3	488.7	1.3
	5	1	19	0.0	0.0	24.9	1.9	0.0	0.0	59.5	1.6	0.0	0.0	9.5	0.9	0.0	0.0	0.0	0.0
	6	1	20	0.0	0.0	41.4	3.0	0.0	0.0	68.3	0.8	0.0	0.0	12.9	1.1	0.0	0.0	435.9	1.0
	10	17	314	4.0	0.7	35.0	2.3	15.2	1.5	73.1	1.0	62.5	0.4	17.2	1.4	41.7	0.7	622.2	1.1
	18	23	457	4.0	0.8	27.4	1.9	51.5	3.4	42.5	0.9	61.1	0.7	11.1	0.9	16.8	0.4	507.4	0.7
	24	16	347	3.9	0.8	29.3	2.0	19.3	1.4	49.1	1.0	75.7	0.4	27.7	2.5	17.7	0.4	439.7	1.3
Total		**64**	**1271**	**8.8**	**0.6**	**30.7**	**2.1**	**34.6**	**2.7**	**55.6**	**1.0**	**76.6**	**0.6**	**20.3**	**1.7**	**25.9**	**0.5**	**520.6**	**1.1**
Attack Plays	2	3	93	2.9	0.5	35.3	2.3	27.4	2.8	64.9	0.7	62.4	0.5	16.0	1.2	32.0	1.1	372.1	1.4
	7	1	17	0.0	0.0	35.3	2.5	0.0	0.0	56.3	0.6	0.0	0.0	19.0	1.3	0.0	0.0	400.0	3.1
Total		**4**	**110**	**3.2**	**0.2**	**35.5**	**2.3**	**26.0**	**2.6**	**63.6**	**0.7**	**71.7**	**0.5**	**16.6**	**1.2**	**31.9**	**1.0**	**402.7**	**1.8**
Last Plays	1	19	347	6.6	1.0	35.9	2.3	17.0	1.0	82.2	0.8	42.1	0.9	32.9	2.7	42.8	1.0	718.9	0.3
	14	22	400	5.4	1.0	39.1	2.0	34.0	1.8	72.3	0.9	51.2	1.3	25.4	2.6	14.6	0.3	0.0	0.0
Total		**41**	**747**	**11.4**	**1.0**	**38.8**	**2.2**	**27.2**	**1.5**	**77.2**	**0.9**	**48.3**	**1.2**	**30.3**	**2.8**	**31.5**	**0.7**	**1060.3**	**0.2**
Defence	15	1	16	0.0	0.0	33.3	2.1	0.0	0.0	63.1	0.9	0.0	0.0	4.5	0.5	0.0	0.0	0.0	0.0
Whole	19	4	76	2.1	0.5	27.0	1.6	51.3	0.7	38.3	0.7	108.3	0.2	9.3	0.8	64.2	1.1	866.0	0.5
	20	9	168	3.3	0.7	41.6	2.2	107.9	1.7	69.3	1.3	110.4	0.4	35.7	3.9	47.7	0.7	1292.3	0.3
	22	1	20	0.0	0.0	20.9	1.1	0.0	0.0	63.9	1.5	0.0	0.0	10.2	1.0	0.0	0.0	0.0	0.0
Total		**15**	**280**	**3.6**	**0.3**	**36.4**	**2.0**	**98.7**	**1.3**	**63.7**	**1.2**	**114.8**	**0.4**	**31.0**	**3.2**	**51.6**	**0.8**	**1179.6**	**0.3**
Organisation	8	1	12	0.0	0.0	24.7	1.1	0.0	0.0	55.5	0.3	0.0	0.0	5.0	0.3	0.0	0.0	0.0	0.0
	16	1	22	0.0	0.0	35.3	1.2	0.0	0.0	143.0	0.4	0.0	0.0	9.2	0.7	0.0	0.0	0.0	0.0
	17	2	30	0.1	0.0	30.3	1.0	87.4	0.2	79.2	0.6	87.4	0.2	19.3	1.5	29.8	0.6	0.0	0.0
	21	1	20	0.0	0.0	30.0	1.3	0.0	0.0	57.0	0.9	0.0	0.0	16.2	1.3	0.0	0.0	0.0	0.0
Total		**5**	**84**	**8.3**	**0.0**	**34.1**	**1.3**	**111.1**	**2.8**	**97.9**	**0.8**	**113.2**	**0.2**	**15.5**	**1.2**	**20.1**	**0.4**	**0.0**	**0.0**

N number, CV coefficient of variation, SWC smallest worthwhile change, CV and SWC values reported as percentages (%).

5.4 Discussion

The present study is the first to examine between drill variations of physical, technical and tactical parameters within professional rugby league training. Main findings revealed lower variability in *defence technical*, higher levels in *contact efforts* and even higher variability in *sprints* across the majority of clusters. In addition, *Defence Whole* and *Organisation* clusters specifically displayed large variations of *attack technical* and *errors*. This study extends on previous research describing the multifaceted nature of training drills (Chapter Four) and provides further understanding on the characteristics of team-based training drills which may be useful for assessing and interpreting meaningful changes and inform drill design.

While lower variability values of *defence technical* was observed across all clusters, contact efforts conversely demonstrated higher variations between training drills, indicating little variation in defence-related technical and tactical factors but larger variances in physical aspects (i.e., *contact efforts*). While previous reports have suggested collision events to be periodised well in advance of upcoming matches for physical recovery [42], another explanation may be, in part, related to how coaches plan and periodise training drills. For example, coaches may vary the intensity and opposition pressure by modifying contact and speed of execution to either allow players the opportunity to learn the required strategies or practice these strategies at game like intensities to mimic the decision-making and technical execution required for match performance [162]. However, the prescription of these factors and other tactical measures by coaches are not yet able to be quantified.

Large variations of *sprints* component were observed across five of the six clusters, likely related to the inconsistent exposure within training drills. This observation aligns with previous research displaying large variability in higher speed activities in professional rugby league matches [26]. Indeed, the capability to perform high speed movement is essential during attack, defence and transition moments of performance. For example, players may be required to execute important events such as executing or chasing conceded line-breaks, or chasing territory field kicks to prevent the opposition from gaining field territory [36]. However, this factor may be largely variable in training due to the consistent

focus on practicing the strategies and team structures responsible for exposing these opportunities rather than the *sprint* outcome.

Large variations of *attack technical* were present across clusters, with *Organisation* and *Defence Whole* drills eliciting %CV as high as 111.1% and 98.7%, respectively. These findings are likely influenced by the representativeness of drill design as coaches plan and prescribe training to prepare for the different moments of match performance. For instance, the large variations of *attack technical* demands are likely due to few occurrences of attacking play characteristics (e.g., time in attack, passes) present within these drills. Indeed, coaches often design and plan training drills to develop and practice strategies and tactical execution during all moments of performance (attack, defence, transitions) [24, 116]. These findings can be utilised by coaches to inform training drill design and selection to ensure appropriate preparation.

This is the first study to investigate the variability of physical, technical and tactical components of on-field training drills and as a consequence, direct comparisons to previous research remains challenging. Furthermore, it is acknowledged that these findings are derived from a case-study from one team and may not be generalisable to the wider rugby league population. However, this study provides new information and a greater understanding of the physical technical and tactical description and characteristics of professional rugby league training drills, which may be used to inform drill design and outcomes. As such, findings may assist in establishing typical values or benchmarks for different training drills, albeit only for the club investigated. While the observed variations may be partially attributed to factors beyond the scope of this investigation such as environmental conditions and task constraints, factors such as the training design, prescription and manipulation of drills by coaches may contribute. However, information of how coaches prescribe the tactical elements of on-field training drills in professional rugby league remains anecdotal. Given the purported importance of tactical performance to successful match outcomes in rugby league [7, 9], it is vital for sports scientists to understand the coaches approach to tactical preparation within training. Future research investigating how coaches plan, prescribe and manipulate training drills to tactically prepare players for performance is warranted.

5.5 Conclusion

This study examined the physical, technical and tactical variability of on-field training drills in professional rugby league. The results demonstrate the majority clusters elicited lower variability in *defence technical,* higher variability in *contact efforts* and even higher variability of *sprints* respectively. *Defence Whole* and *Organisation* clusters reported large variations of *attack technical* and *errors* components compared to the remaining clusters. While these findings have implications in to inform training changes and design, explanations of findings remain limited without understanding how coaches plan, implement and manipulate training drills. Future research should aim to investigate how coaches prescribe the tactical elements of on-field training drills in professional rugby league.

CHAPTER SIX

Study Five: How do Coaches Prescribe the Tactical Elements of Training in Professional Rugby League? A Case Study

6.1 Introduction

Rugby league is intermittent collision team sport that requires players to have well developed physical, technical and tactical abilities [7]. Players must cooperate with their teammates to create synergy and organisation as a collective team but also in sub units (e.g., positional groups and playmakers). Both individual and collective actions (i.e., strategies) are implemented during attack, defence and transition moments of the game to trigger disorganisation and disruption of the opposition thereby increasing the likelihood of creating scoring opportunities. When in attack, players are required to perform high intermittent intensity actions (e.g., collisions, accelerations and high-speed running) [3] in an attempt to gain field metres and establish optimum field position for try scoring opportunities [2]. Whilst in defence, intense actions such as repeated accelerations / decelerations, wrestling, tackling and collisions [78] are frequently required to prevent the opposition from gaining field territory towards the team's try line. Players are frequently required to perform technical actions such as passing and kicking the ball, execute play-the-balls and tackling the opposition[91] that are essential for effective performance [9, 67, 91].

Anecdotally, when preparing players for competition, coaches apply a tactical approach based on the style and principles of play developed by their philosophies, beliefs and past experience. Indeed, coaching panels spend considerable time planning and implementing training to ensure the team are prepared for all moments (i.e., attack, defence and transition between attack and defence and vice versa) and specific time periods of the game [30]. When training to prepare for these game moments and periods, coaches implement a tactical focus within training, manipulating constraints to achieve the desired tactical outcome. Specifically, implementing tactical periodisation models have become popular by high performance coaches as it focuses on the system, game model and desired style-of-play [25]. This is usually achieved by implementing drills to encourage the team to learn a particular way of playing and distribute the desired principles throughout training [20] and manipulating tactical variables such as familiarity of strategies, opposition pressure and speed of execution (Chapter Three). While there is anecdotal evidence of its application in professional sport settings [23, 24], no studies have described tactical periodisation and prescription approaches in rugby league [20].

A major role of sports science practitioners has been to implement athlete monitoring systems each that are used to assess how athletes are coping with training and to provide heuristic indicators of their readiness to train and identify risks of injury [58]. These systems often quantifying the external load undertaken and internal response to those loads during training which provides information that can be used to improve training periodisation and to describe the stimulus provided by different training drills [44]. An important responsibility of the sport scientist within professional sporting clubs has been the improved integration with coaching through monitoring and reporting on technical and tactical aspects of training [162]. In particular, implementing tactical periodisation models to prepare players has been of significant interest as it includes all training factors (i.e., tactical, physical, psychological, and technical) in training design rather than the reductionist approach of the traditional 'training load' periodisation which focusses on 'physical aspects' of performance [20, 169]. Accordingly, understanding the coaches' goals, intention and prescription of training is critical for effective prescription using a tactical-led approach. A recent training drill questionnaire has been developed to assist in quantifying the tactical prescription of on-field training drills in professional rugby league (Chapter Three). While this tool provides sports scientists the opportunity to identify the coaches' training goals and describe the tactical elements of training, it is yet to be implemented within rugby league research. Therefore, the purpose of this investigation was to describe the tactical arrangement of on-field training and its distribution in professional rugby league. Specifically, we examined changes in tactical aspects of training within each week and also variations during a competition season.

6.2 Methods

Design

A case-study approach was used to describe the tactical prescription of on-field training by comparing the tactical prescription of training drills across weekly training and early, mid and late phases of the competition. This study was conducted over the 2018 National Rugby League (NRL) competition. Procedures were approved by the Human Research Ethics Committee of the University of Technology Sydney (ETH16-1074). Written informed consent and demographic information was obtained from all coaches before the commencement of this study.

Participants

Data was collected from four professional NRL coaches during the 2018 competition season. Coaches were full-time contracted to the NRL club and had a combined total of 39 years of playing and a range of 4 – 16 years coaching experience as an assistant or head coach role within the professional and semi-professional level in rugby league. Individual roles for the participating coaches include: head coach, defence coach, attack coach and development coach.

Procedures

Previous research developed a Training Drill Questionnaire to quantify the tactical arrangement and prescription of on-field training drills (Chapter Three). Within on-field training sessions, coaches are responsible to design, coach and assess specific drills relevant to their role (e.g., defence coach responsible for coaching defensive drills). Prior to the commencement of each training session during the 2018 competition year, all coaches completed the Training Drill Questionnaire (figure 6.1) for only the team drills they designed and coached. The pre-training component of the questionnaire required coaches to assign tactical descriptors to drills by placing a '1' under the relevant subsection. Should more than one subsection obtain equal priority, coaches marked a '1' to all that applied. Coaches were then required to identify and rate the tactical variables of training drills on a visual analogue scale (VAS) and was completed 20-30 minutes prior to the training session. The post-training component of the questionnaire was completed up to 10 minutes after the completion of the training session and required coaches to rate three self-review questions on a VAS. VAS scales contained a 100-mm horizontal line, with verbal descriptors at each endpoint to indicate each extremity. Coaches marked a small vertical dash to represent the intensity of each variable and were manually measured with the same ruler to the nearest 0.5 mm by the primary researcher (JH). Pilot questionnaires were completed for a week prior to data collection for familiarity. The number of sessions ranged from three to four sessions per week dependent on match turnarounds. Training days were categorised as 'Day 1', 'Day 2', 'Day 4', indicating the number of days prior to the upcoming match and '2 Days Post', indicating the first training session after the previous match as shown in figure 6.2. Training days 4-days prior and 5-days prior during short (< 7 days) and normal to long (≥ 7 day) turnarounds respectively were both categorised as '2 Days Post' due to the similar recovery period after the previous match. The competition

season was separated into rounds 1 – 8, 9 – 18, 19 – 25 to create early-, mid- and late-season thirds. Previous test-retest assessment (Chapter Three) displayed excellent reliability for both categorical ($\kappa = 0.96$) [132] and VAS components of the questionnaire (ICC = 0.91 [0.89 – 0.92]) [131].

Measures

Measures obtained from the Training Drill Questionnaires were recently developed and described in previous research (Chapter Three). The tactical descriptors of training drills were categorised into: *period of performance* (0 – 20 minutes, 20 – 40 minutes, 40 – 60 minutes, 60 – 80 minutes), *moment of performance* (attack, defence, transition from attack to defence, transition from defence to attack), *drill design* (structure, execution, scenario), *drill focus* (team, group, individual). When more than one variable obtained equal priority, the tactical descriptors were categorised as *combination. Whole match* was used to describe when all *periods of performance* obtained equal priority. Nine tactical prescriptive variables obtained include; *familiarity of strategies, attacking predictability, defensive predictability, attacking pressure, defensive pressure, speed of execution, fatigue of commencement, spine combination* and *technical complexity.* Descriptions of these variables are provided in supplementary material (table S6, S7). Measures obtained from the post-training section of the questionnaire were subjective ratings pertaining to *overall satisfaction, drill implementation* and *player execution.* Descriptions and upper and lower VAS endpoints of variables are provided in table 6.1 and 6.2.

Table 6.1 Lower and Upper VAS End-points for tactical variables included in section 2 of the Training Drill Questionnaire.

Lower VAS End-point	Variable	Upper VAS End-point
Completely new	**Familiarity of required strategies**	Autonomous
Unpredictable	**Attacking predictability**	Predictable
Unpredictable	**Defensive predictability**	Predictable
Unopposed	**Attacking pressure**	Game-like
Unopposed	**Defensive pressure**	Game-like
Static	**Speed of execution**	Greater than game-pace
RPE 0/10	**Fatigue at commencement of drill**	RPE 10/10
No connection between spine positions	**Spine combination**	Combination between all 4 spine positions
Extremely easy	**Technical Complexity**	Extremely difficult

Table 6.2 Lower and Upper VAS End-points for tactical variables included in section 3 of the Training Drill Questionnaire.

Lower VAS End-point	Variable	Upper VAS End-point
Extremely unsatisfied	**Overall satisfaction of the training drill**	Extremely satisfied
Nothing went as planned	**Was the training drill implemented as intended?**	Everything went exactly as planned
Did not execute as expected	**Did players execute as expected in this training drill?**	Execution exceeded expectations

Rugby League Training Drill Questionnaire

Pre-Training

Drill Name: _____ Coach Initials:

Section 1: Tactical Descriptor – *Place '1' to all that apply*

What quarter of match-play is this drill prescribed for?	First: 0 – 20 minutes	Second: 20 – 40 minutes	Third: 40 – 60 minutes	Last: 60 – 80 minutes
What moment of performance is this drill prescribed for?	Attack	Transition from Attack to Defence	Defence	Transition from Defence to Attack
Please indicate drill design	Scenario	Structure	Execution	
Which focus group is this drill predominately prescribed for?	Individual	Group	Team	

Section 2: Tactical Variables – *mark a small vertical dash to represent the intensity of each variable*

Familiarity of required strategies	*Completely new*	*Autonomous*
Attacking Predictability	*Unpredictable*	*Predictable*
Defensive Predictability	*Unpredictable*	*Predictable*
Attacking Pressure	*Unopposed*	*Game-like*
Defensive Pressure	*Unopposed*	*Game-like*
Speed of Execution	*Static*	*Greater than match-pace*
Fatigue at Commencement of Drill	*RPE 0/10*	*RPE 10/10*
Spine Combination	*No connection*	*Connection between all members*
Technical Complexity	*Extremely easy*	*Extremely difficult*

Post-Training

Section 3: Post-Training – *mark a small vertical dash to represent the intensity of each variable*

1. *Overall how satisfied are you with the training drill?*

Extremely unsatisfied _____ Extremely satisfied

2. *Was the training drill implemented as intended?*

Nothing went as planned _____ Everything went exactly as planned

3. *Did players execute as expected within this drill?*

Did not execute as expected _____ Exceeded expectation

Figure 6.1 Training Drill Questionnaire utilised within this study.

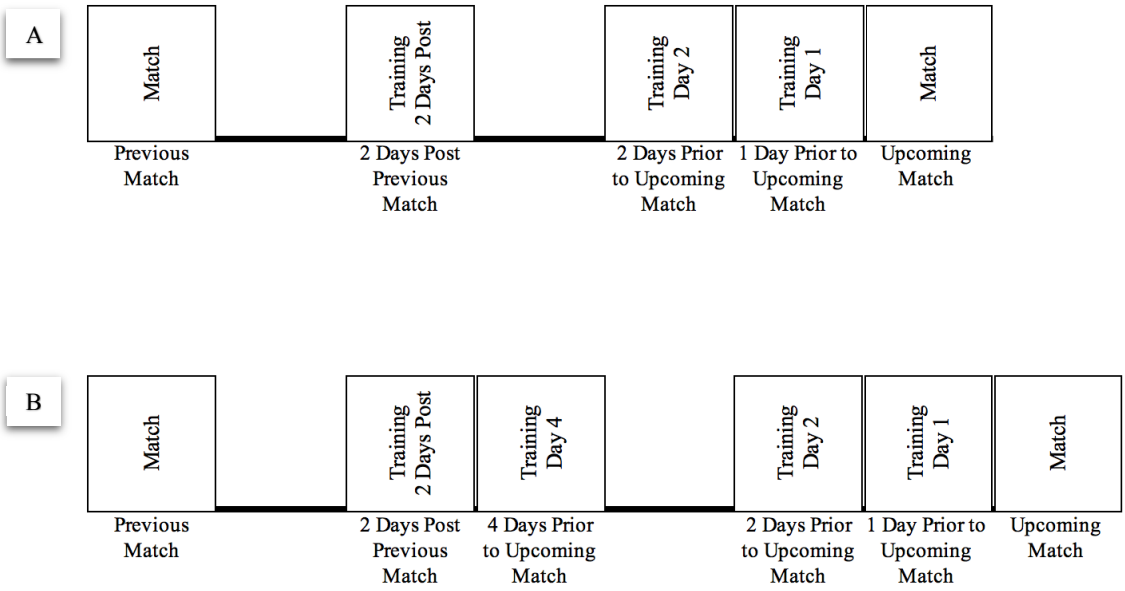


Figure 6.2 Categorisation of on-field training days for A. short (< 7 day) turnarounds and B. normal to long (≥ 7 day) turnarounds.

Statistical Analysis

Dependent variables were described descriptively and checked for outliers (mean ± 3 SDs). One-way ANOVAS to detect differences between days on coaching ratings were conducted, as well as one-way ANOVAS to detect differences between season thirds on coaching ratings. Where dependent variables violated assumptions of homogeneity according to Levene's statistic, non-parametric Kruskal-Wallis tests with post-hoc Mann-Whitney U tests and Bonferonni correction ($p < 0.008$) were used.

6.3 Results

Twenty rounds of the 2018 NRL season were included for analysis providing 142 pre-training and 141 post-training questionnaire responses for 23 unique drills. Frequency of Day 1, Day 2, Day 4 and 2 Days Post training days were 20, 20, 10 and 18, respectively. Frequency statistics of the coaches' tactical descriptors for each training day is presented in table 6.3. Frequency of competition rounds included in early-, mid- and late- season thirds were 7, 6 and 7, respectively.

Table 6.3 Frequency of tactical descriptors by training day.

		2 Days Post	Day 4	Day 2	Day 1	Total
Moment of Performance	Attack	14	21	8	18	61
	Transitions	4	1	7	22	34
	Defence	4	7	33	2	47
	Combination	1	1	1	0	3
Period of Performance	0-20 min	1	7	6	2	16
	20-40 min	0	0	0	0	0
	40-60 min	0	0	0	0	0
	60-80 min	0	2	6	0	8
	Whole Match	22	21	37	40	120
Drill Design	Execution	1	2	2	4	9
	Scenario	3	14	30	26	73
	Structure	19	14	16	12	61
Drill Focus	Group	3	10	17	8	38
	Team	20	20	32	34	106
	Individual	0	0	0	0	0
	Combination	0	0	1	0	1

Summary of Daily Changes

After removal of outliers, the tactical prescriptive factor *spine combination* was the only dependent variable that did not violate assumptions of homogeneity. One-way ANOVA showed no significant differences between days on coaches' ratings of spine combination ($p = 0.359$).

Kruskal-Wallis tests showed significant differences between days on all remaining dependent variables (figure 6.3 and figure 6.4): *familiarity of strategies* ($\chi^2(3,137) = 32.18$, $p < 0.001$, $\text{eta}^2 = 0.21$), *attacking predictability* ($\chi^2(3,137) = 29.78$, $p < 0.001$, $\text{eta}^2 = 0.19$), *defensive predictability* ($\chi^2(3,110) = 14.69$, $p = 0.002$, $\text{eta}^2 = 0.11$) *attacking pressure* ($\chi^2(3,110) = 75.45$, $p < 0.001$, $\text{eta}^2 = 0.66$), *defensive pressure* ($\chi^2(3,137) = 73.07$, $p < 0.001$, $\text{eta}^2 = 0.51$), *speed of execution* ($\chi^2(3,138) = 102.05$, $p < 0.001$, $\text{eta}^2 = 0.72$), *predicted fatigue* ($\chi^2(3,138) = 27.37$, $p < 0.001$, $\text{eta}^2 = 0.17$), *overall satisfaction* ($\chi^2(3,137) = 14.03$, $p = 0.003$, $\text{eta}^2 = 0.08$), *implementation as intended* ($\chi^2(3,137) = 11.84$, $p = 0.008$, $\text{eta}^2 = 0.06$) and *player execution* ($\chi^2(3,138) = 8.55$, $p = 0.036$, $\text{eta}^2 = 0.04$). Post-hoc Mann-Whitney results are presented in table 6.4.

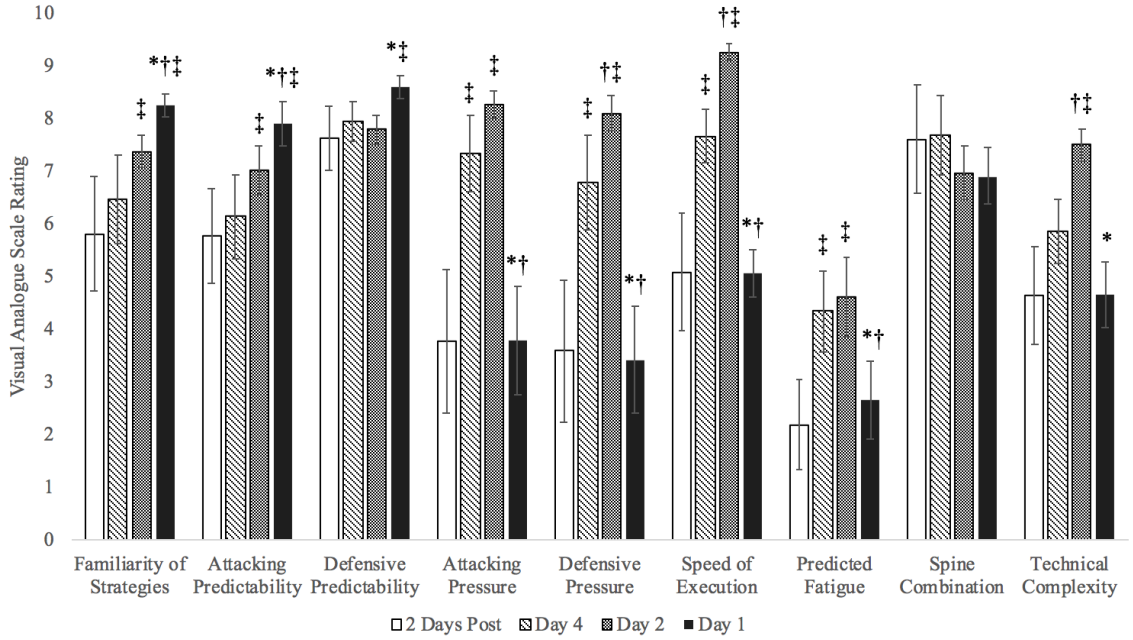


Figure 6.3 Coaches' ratings of tactical variables by day.

**significantly different from Day 2, †significantly different from Day 4, ‡significantly different from 2 Days Post.*

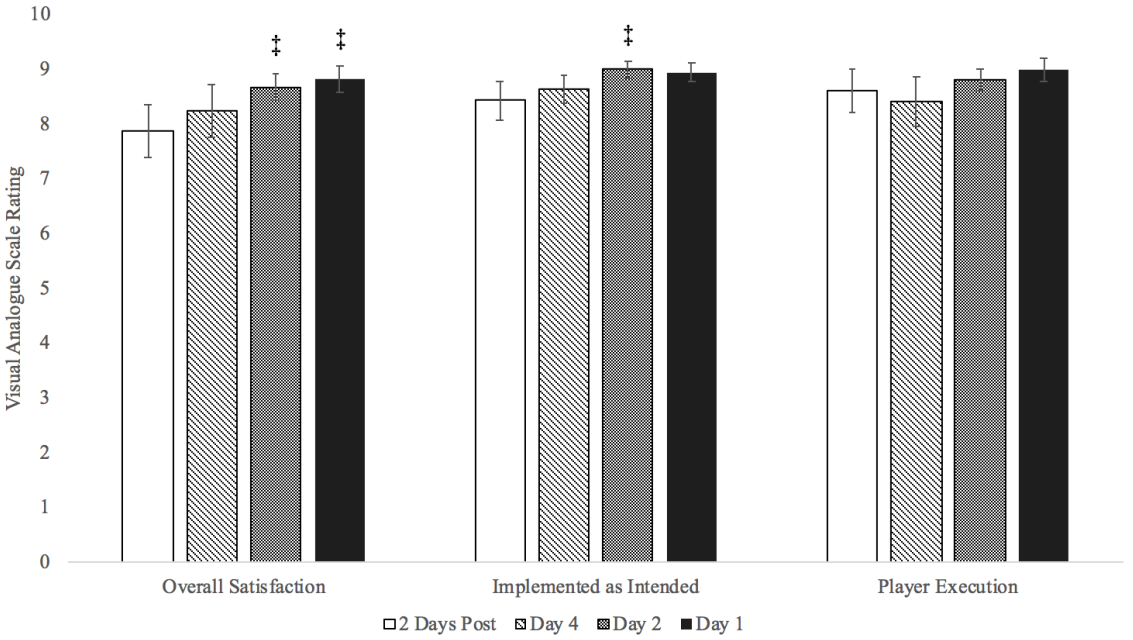


Figure 6.4 Coaches' ratings of post training questions by day.

**significantly different from Day 2, †significantly different from Day 4, ‡significantly different from 2 Days Post.*

Table 6.4 Post-hoc Mann-Whitney results of coaches' ratings of tactical variables and post training questions.

	Day 1 vs Day 2			*Day 1 vs Day 4*			*Day 1 vs 2 Days Post*		
	U	*p*	*r*	*U*	*p*	*r*	*U*	*p*	*r*
Familiarity of Strategies	**490.0**	**< .001**	**0.45**	**253.5**	**< .001**	**0.46**	**159.5**	**< .001**	**0.53**
Attacking Predictability	**619.0**	**0.001**	**0.34**	**227.5**	**< .001**	**0.50**	**161.5**	**< .001**	**0.53**
Defensive Predictability	**270.5**	**0.001**	**0.40**	177.5	0.015	0.35	**77.0**	**0.001**	**0.51**
Attacking Pressure	**97.5**	**< .001**	**0.78**	**153.0**	**< .001**	**0.61**	439.0	0.546	0.07
Defensive Pressure	**110.5**	**< .001**	**0.77**	**179.0**	**< .001**	**0.57**	451.0	-0.66	0.05
Speed of Execution	**1.0**	**< .001**	**0.86**	**94.0**	**< .001**	**0.70**	452.5	0.676	0.05
Predicted Fatigue	**524.5**	**< .001**	**0.42**	**337.0**	**0.005**	**0.34**	469.5	0.853	0.02
Technical Complexity	**177.0**	**< .001**	**0.71**	378.0	0.020	0.28	478.5	0.951	0.01
Overall Satisfaction	914.0	0.463	0.08	432.0	0.097	0.23	**240.5**	**0.001**	**0.44**
Was the Drill Implemented as Intended?	969.5	0.635	0.05	414.0	0.060	0.23	302.5	0.013	0.31
Did Players Execute as Expected?	833.5	0.119	0.16	374.0	0.018	0.29	301.5	0.013	0.31

	Day 2 vs Day 4			*Day 2 vs 2 Days Post*			*Day 4 vs 2 Days Post*		
	U	*p*	*r*	*U*	*p*	*r*	*U*	*p*	*r*
Familiarity of Strategies	551.0	0.230	0.14	**316.5**	**0.003**	**0.33**	244	0.195	0.15
Attacking Predictability	495.5	0.072	0.21	**313.5**	**0.003**	**0.33**	250	0.239	0.14
Defensive Predictability	551.5	0.411	0.08	29.0	0.442	0.11	178	0.285	0.16
Attacking Pressure	382.5	0.003	0.34	**74.5**	**< 0.001**	**0.70**	**100**	**< 0.001**	**0.58**
Defensive Pressure	**339.5**	**< 0.001**	**0.40**	**90.0**	**< 0.001**	**0.67**	**123.5**	**< 0.001**	**0.52**
Speed of Execution	**110.0**	**< 0.001**	**0.69**	**21.5**	**< 0.001**	**0.77**	**111.5**	**< 0.001**	**0.55**
Predicted Fatigue	660.5	0.991	0.00	**223.0**	**< 0.001**	**0.48**	**125.5**	**< 0.001**	**0.51**
Technical Complexity	**226.5**	**< 0.001**	**0.54**	**107.5**	**< 0.001**	**0.65**	212	0.055	0.27
Overall Satisfaction	539.0	0.183	0.15	**319.0**	**0.003**	**0.35**	240	0.170	0.19
Was the Drill Implemented as Intended?	453.0	0.024	0.26	**330.5**	**0.005**	**0.33**	267.5	0.402	0.12
Did Players Execute as Expected?	550.0	0.226	0.14	480.5	0.316	0.12	285	0.619	0.07

Summary of Seasonal Changes

Levene's statistic showed variables *familiarity of strategies* and *implemented as intended* violated assumptions of homogeneity. Kruskal-Wallis tests showed no significant differences between season thirds (i.e., early-, mid- and late-) on *familiarity of strategies* (p = 0.140) and significant differences between thirds on *implemented as intended* ($\chi^2(2,139) = 25.25$, $p < 0.001$, $eta^2 = 0.17$). Post hoc Mann-Whitney tests showed significant differences between early- and mid-third ($U = 895$, $p = 0.01$, $r = 0.25$), the mid- and late-third ($U = 503$, $p < 0.001$, $r = 0.41$) and early- and late- third ($U = 313$, $p < 0.001$, $r = 0.6$) (figure 6.6).

One-way ANOVA showed significant differences between *attacking predictability* ($F(2,139) = 3.83$, $p = 0.024$, $eta^2 = 0.05$), *overall satisfaction* ($F(2, 137) = 12.25$, $p < 0.001$, $eta^2 = 0.15$) and *player execution* ($F(2,138) = 9.53$, $p < 0.001$, $eta^2 = 0.12$). Post-hoc Tukey HSD tests showed that coaches' rating of *attacking predictability* was significantly higher in the late-third compared to the early-third (p = 0.018, d = 0.23) (figure 6.5). Post hoc Tukey HSD tests showed that *overall satisfaction* was significantly different between early- and mid-third ($p < 0.001$, d = 0.49), mid- and late-third (p = 0.041, d = 0.52) and early- and late-third (p = 0.03, d = 0.45) (figure 6.6). Post hoc Tukey HSD test showed significant differences between *player execution* between the mid- and late-third (p = 0.04, d = 0.50) and early- and late-third ($p < 0.001$, d = 0.38).

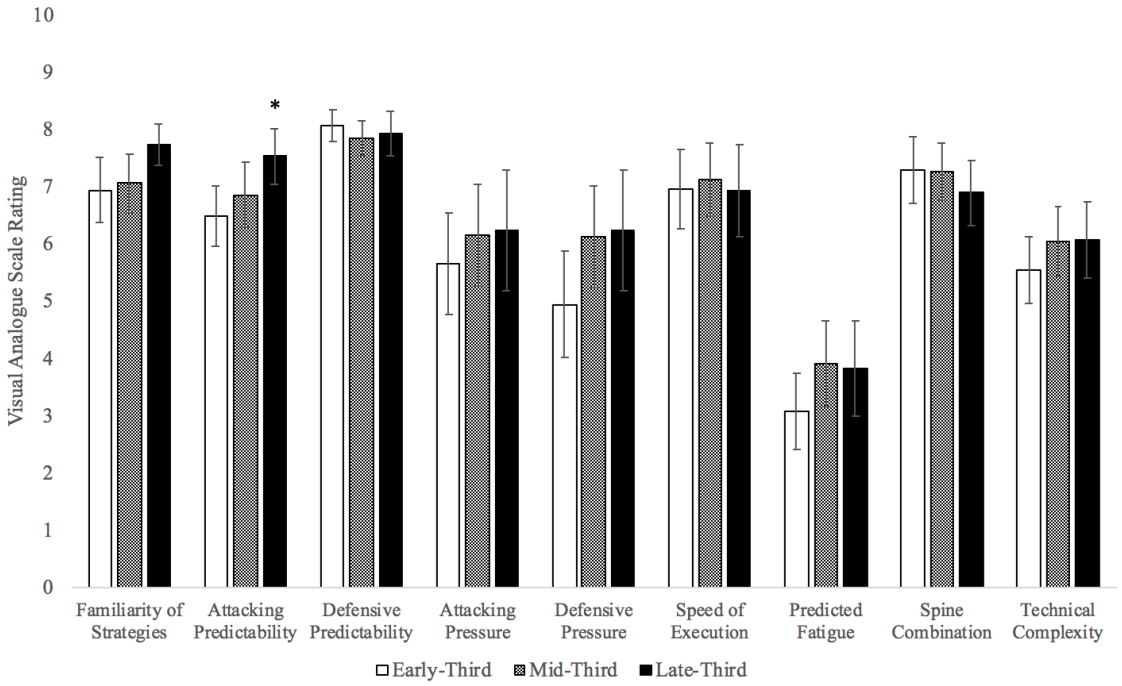


Figure 6.5 Coaches' ratings of tactical variables by season thirds.

[*]significantly different from early-third.

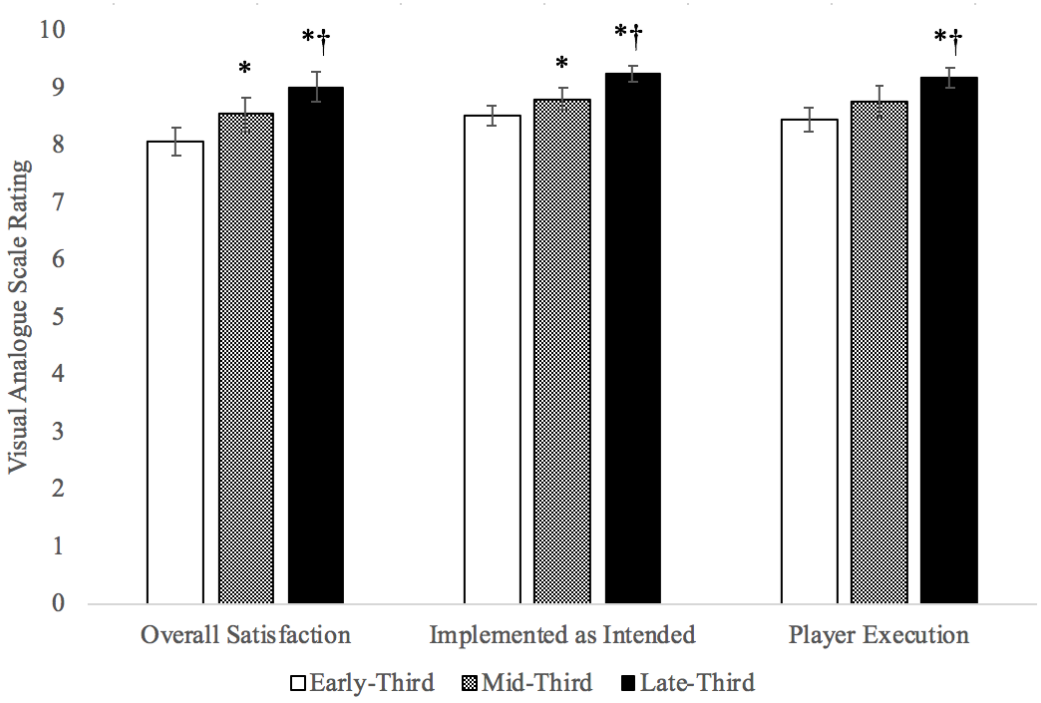


Figure 6.6 Coaches' ratings of post-training questions by season thirds.

[*]significantly different from early-third, [†]significantly different from mid-third.

6.4 Discussion

An important role for sport scientists in professional team sports is to provide information – and understanding – of how teams tactically prepare for competition [137]. It is common that a game model approach is used by coaches to guide training design in manner that training is developed to prepare players to prepare for how the coach wants the game to be played [30]. Whilst principles and approaches to tactical periodisation have been described previously [23, 24], this study is the first to identify and describe the tactical arrangement and distribution of on-field training within professional rugby league.

Frequency statistics revealed the distribution of attack, defence and transition prescribed drills throughout the training week, whereby a high occurrence of attack drills were prescribed earlier in the training week, followed by defence and transition drills on subsequent training days leading into match-day. Furthermore, it was identified the majority of training drills were intended for whole match preparation. Whilst it has been reported that coaches arrange training according to the moments of performance [24, 30], the present findings provide novel insight how these drills are distributed within a tactical periodisation model. Findings also showed structure-based drills (i.e., arrangement of the team) were evenly distributed throughout the training week, while more scenario-based drills (i.e., preparation for predicted match events or scenes) were completed within training days closer to match-day, suggesting an attempt to provide greater familiarity with the required game-plan in response to specific, anticipated conditions (i.e., according to the upcoming opposition).

The present results revealed general weekly trends of tactical arrangement with the coaches rating of both *familiarity of strategies* and *predictability of attack and defence* progressively increasing in the days leading into the match (figure 6.1). The observed increases in *familiarity strategies* ratings is likely a result of players learning what is required by coaches and provided with continual exposure and practice of strategies and game plans in training drills (e.g., within structure based drills). Similarly, increases in coaches' rating of *predictability of attack and defence* reflects the increase in knowledge and expectation of how the opposition will likely behave and perform during performance. Indeed, coaches and players examine the upcoming opposition to identify playing patterns, player strengths and weaknesses to modify or implement tactical actions and strategic

plans within training drills for preparation [170]. Additionally, as teams participate in an irregular competition schedule (i.e., may verse an opponent more than once), players and coaches can rely on previous playing experience and learnings to assist preparation.

It was also observed the ratings of *attacking and defensive pressure, speed of execution, predicted fatigue* and *technical complexity* synonymously increased to peak two days prior to match performance. This shows that the coaches planned for the team to execute and apply tactical strategies at game-like intensities within training drills two days prior to match performance. For example, coaches may prescribe training drills at these intensities to mimic the reactions, decision-making processes and high level of concentration required in competition [162]. Indeed, rugby league players are required to utilise 'problem-solving techniques' and convey 'high-consequence decisions' under physiologically demanding (i.e., under fatigue) and highly pressured situations [171]. For example, players may be required to digest varying cues (e.g., body positioning, eye gaze) to assess the opponents current state in performance to capitalise on any opportunity to contribute to winning opportunities. Such aspects can include assessing the organisation and speed of the defensive line, observing the speed and manoeuvre patterns of attacking players and observing physical cues to identify fatigue (e.g., slow retreat into the defensive line, breathing heavily) [171]. Accordingly, coaches expose the team to these situations for tactical preparation to successfully transfer the interaction of technical skill and tactical learning, with the aim to improve the quality of decision making by players during performance [96, 135, 172].

The present study provides the first description of tactical intent and prescription used in professional rugby league training that could be utilised to guide future tactical periodisation models and implementation within training. While previous research has offered key principles of implemented tactical periodisation frameworks [20], the present provides empirical evidence on the tactical arrangement and manipulation of training. As such, this information can be utilised by sport scientists to inform holistic player and team preparation through influencing training drill and session design and used to guide player expectations (e.g., the number of team errors when learning new strategies). Indeed, future research understanding the interplay of these factors between players and positional groups

with reference to the tactical prescription by coaches may provide important contextual information to team behaviour and performance.

A second purpose of the present study was to describe the seasonal variability in tactical design approaches adopted in professional rugby league. The present results showed that *attacking predictability* was the only variable to significantly increase throughout the competition season. Increases in this prescription of this variable is likely related to, in part, the expectation that defenders will have an increased anticipation of opposition attacking strategies and game plan during training drills. For example, as coaches instruct the attacking team to execute and mimic set-plays of the upcoming opposition, the defence team has an increased understanding of this behaviour as the season evolves (e.g., attacking structure, directional and evasion manoeuvres [115]). Indeed, teams will reveal tactical characteristics throughout the competition which can be reviewed and studied by coaches and players via video footage and statistics. The lack of variability in other measures indicates that coaches predominately manipulate the tactical variables within a weekly model of training, indicating a precedence of preparing for the upcoming opposition each round (i.e., every 5 – 9 days).

A further novel finding is that all coaches' ratings of training (*overall satisfaction*, *drill implementation* and *player execution*) increased throughout each third of the competition season. Although speculative, possible explanations of these ratings could be attributed to the formation of player combinations and team synergy, successful display of desired game-style and tactical strategies and successful match performance and outcomes. Indeed, factors contributing to coach satisfaction such as consistency in performance, commitment and coachability (i.e., players adhering to the coaches' game plan and system) have been noted [173, 174]. Furthermore, motivating factors behind sports coaches have identified external influences such as winning to be a contributing factor [175]. As data retrieved for this study was from a very successful club (i.e., NRL champions) during the observation period, this in combination with the pressure experienced by high performance coaches to deliver winning results [176] may attribute to the increased ratings observed. Nevertheless, further research is encouraged and required to investigate and identify the influential, key performance indicators of these ratings and their association with training outputs.

As this is the first study to describe the tactical elements of training prescribed by professional rugby league coaches, comparisons to previous research proves challenging. Others have described evasion strategies in attack and defence within rugby union performance [114, 115] and game-style frameworks in professional soccer [30], however the present findings provide new information on how coaches prescribe and manipulate training drills for tactical preparation within professional rugby league. While these findings provide new information on the prescription and arrangement of training drills within a tactical periodisation model, it doesn't account for the contextual factors experienced (e.g., opposition rank, match location). Indeed, previous research has developed Match Difficulty Index (MDI) models based on external influences to evaluate the difficulty of the opposition [28, 29]. Future research could expand on our current findings by examining how rugby league coaches plan and manipulate the tactical elements of training in accordance with the perceived difficulty of upcoming oppositions.

Whilst the present study provides new information, it is not without its limitations. A main limitation of this study includes the low number of participants involved. This study is a case study, and although provides a realistic sample within the NRL environment, retrieving and analysing data from four coaches involved in one club of the professional rugby league competition may not be representative of other coaching philosophies and training approaches from other clubs and team sports. Additionally, the club was very successful during the observation period (i.e. i.e., obtained a win percentage of 66.7% for the regular competition season [top 8 teams vs. bottom 8 teams: 64.6% vs. 35.4%] and were NRL competition champions). Although this provides examples of a successful club, it also provides a limited description and therefore the findings may not be generalisable. Future research recruiting a variety of coaches from differing clubs and levels would provide a robust understanding of the tactical prescription and periodisation process. Moreover, this may yield diverse results as coaches are exposed to an array of experiences dependent on team ranking and ratio of wins and losses. Whilst this study has revealed the detailed nature of how a select group of coaches plan and prescribe training for upcoming matches, collecting data from pre-season phases is warranted as its main focus is to develop the foundations of the desired game-style.

6.5 Conclusion

The present study is the first to examine and describe the tactical arrangement of training drills and its distribution within professional rugby league. The results revealed two overarching trends of tactical prescription in the weekly lead up to match performance. Secondly, attacking predictability was the only tactical variable that increased throughout the competition season. Coaches' subjective ratings of training also increased throughout the season however causal factors that explain these observation remain unclear. The present findings highlight how coaches deliberately plan, manipulate and assess training drills to ensure the tactical preparation of players. Sports scientists can apply similar frameworks to expand on the multifaceted preparation of players in professional rugby league.

CHAPTER SEVEN

Study Six: Developing a Match Difficulty Index (MDI) for Professional Rugby League

7.1 Introduction

Similar to other professional team sports, rugby league coaches and support staff carefully prescribe training to prepare players for the specific physical, technical and tactical demands of competition. Detailed training plans are developed to organise team structures, establish tactical game-plans and to obtain an optimal level of physical preparedness (referred to as 'peaking') to perform against upcoming oppositions [177]. To assist, information gathered provided from training plans and collected during athlete monitoring is used to assess the effectiveness of training and also to provide feedback on the planning-training process to coaches. For example, information relating to the planned and actual training loads (i.e., external and internal), skill requirements and tactical focus are routinely collected and analysed as part of the training preparation and feedback cycle. Additionally, collecting such data over long periods (e.g., months) of time can be used to quantify the training completed and guide future periodisation design choices in rugby league.

The National Rugby League (NRL) is the premier professional rugby league competition of the Australasian region and consists of 16 teams across four different states / territories (New South Wales, Queensland, Victoria and Australian Capital Territory) and two countries (Australian and New Zealand). Accordingly, NRL teams are subject to various amounts of interstate and international travel for competition matches and are susceptible to travel fatigue [178]. There are other contextual factors that can affect the preparation for matches. For example, teams play on an irregular competitions cycle with the number of days between matches varying between 5 – 11 days during the 7 months season. Additionally, due to the length of the season and the number of teams competing in the NRL, each team may play another once or twice during a season, resulting in an unequal draw. Collectively, these factors may affect preparation for performance by influencing the amount and nature of the physical, technical and tactical content prescribed within each between match microcycle.

Previous research has investigated the effects of travel on rugby league performance, showing a reduction in winning probability by -2.7% for every 1,000 km travelled from a team's home stadium [179]. While this can be useful to inform strategies to negate the negative effects of travel (e.g., travel logistics and sleeping environments) [179], it failed to account for other important contextual factors, such as opposition strength, time between

matches, travel distance and match location. Indeed, there are numerous factors which may influence decisions about training content and scheduling, and many of these have been reported to influence the likelihood of success in future matches [28, 29]. These factors, either independently or combined may influence the difficulty of an upcoming match and therefore should be considered when planning training and player expectations (e.g., performance of developing players).

The Match Difficulty Index (MDI) has been developed and implemented within other football codes such as rugby union [29] and Australian Football [28] in an attempt to objectively account for the contributing influence of contextual factors to successful match outcomes. These models have examined and quantified the influence of external factors such as; opposition rank, match turnarounds, travel distance and match location to match outcome to develop predictive models of match difficulty. One of the aims for developing these models has been to inform future training plans, by providing information that can be used to make decisions about tactical periodisation and planned loads in an attempt to optimise physical capabilities throughout a competitive season [28, 29]. Despite the NRL competition being exposed to similar external factors to those described in these earlier studies, understanding their influence to match outcome and contribution to match difficulty is yet to be determined.

In practice, coaches and players study the opposition to identify supposed strengths, weaknesses and current form to anecdotally assess the difficulty of upcoming matches. It is anticipated that with the development of a MDI specific to rugby league, coaches and support staff can strategically manipulate physical and technical loads and tactical approaches to training. Accordingly, this paper sought to replicate previous work [28, 29], and develop a MDI model to predict the difficulty of regular competition season matches in professional rugby league by examining the influence of external factors to match outcome.

7.2 Methods

Design

Information from 582 regular season games played over the 2016 - 2018 National Rugby League (NRL) seasons were collected from publicly available online sources; https://www.nrl.com/draw/, https://www.nrl.com/ladder/ and https://www.gps-coordinates.net/distance. Since information for this study was obtained from publicly available sources, no ethics was required for this investigation.

Measures

Methods and measures included in this study were replicated from previous work developing an MDI model in Super Rugby [29]. Five predictors derived from this work and included for analysis in this study were:

- Opponent rank previous year (the rank of the opposing team based on their final ladder position from the previous year). A rank of 1 was assigned to the team who won the competition and a rank of 16 was assigned to the team who finished at the bottom of the ladder.
- Opponent rank current year (the ladder position of the opposition at the time of relevant round). A rank of 1 was assigned to the opposition team leading the competition during the round in which the game was played and a rank of 16 was the team at the bottom of the ladder during that round.
- Between match break (the number of days between matches). Categorised into 'short' (≤ 6 days), 'normal' (7 - 9 days) and 'long' (> 9 days) turnarounds.
- Match location (home / away). Away games were categorised into intrastate (travelled to a match within the same state as home location), interstate (travelled to another state) and international (travelled to another country).
- Distance travelled (calculated as between city distance - 'as the bird flies'). Distance travelled is 0 when competing at home location. In instances of competing at an away location within the same city, distances between suburbs was calculated ('as the bird flies').

External predictors; *opposition rank previous year, opposition rank current year*, *between match break*, *match location* and *distance travelled*, were replicated within this study and similarly deemed uncontrollable measurable influences on match outcome [29]. *Time-zone difference* was the only predictor not replicated in this study, as the majority of

travel within the NRL competition remains within the same time zone (and at most, crosses a two-hour time zone) and did not reflect the regular travel across 4 hour time zones in other team sports such as rugby union and soccer [29, 180]. The authors of this study deemed remaining measures appropriate for the NRL competition. Match outcome (win / loss) was included as the dependent variable.

Statistical Analysis

All data were assessed for assumptions of normality prior to analysis. As *opponent rank* and *between match break* is unavailable for the first-round competition, this round was removed from analysis (n = 40). Match data from the 2016 and 2017 were used as the training data set for testing on the 2018 data. As such descriptive statistics (mean (SD)) of predictor variables; *opponent rank previous year, opponent rank current year, distance travelled, between match break* and score margin (team score minus opposition team's score) were analysed for each team across the 2016 and 2017 competition seasons. Differences between 2016 and 2017 seasons for *distanced travelled*, and *between match break* predictors were assessed with one-way ANOVA and chi-square analysis, respectively. Spearman correlations between predictor variables were used to check for assumptions of multicollinearity.

Binary logistic regression was used to assess if the five predictor variables; *opponent rank previous year*, *opponent rank current year*, *between match break*, *match location* and *distance travelled* significantly predicted successful match outcome (i.e., win). Outputted predicted probabilities obtained from the logistic regression models were utilised to determine the MDI for each match. The logit probability of 'win' for each game was subtracted from 1 and then multiplied by 10, resulting in a MDI output reported in arbitrary units and scaled between 0 and 10. Developed MDI models were cross validated with data collected from the 2018 competition season.

The predicted probabilities of *win* were utilised to compute receiving operating character (ROC) curves, with the area under the curve (AUC) values reported as the summary statistic in each case. All analysis was conducted using SPSS software (version 21.0. IBM, Australia) with an alpha level of .05.

7.3 Results

Results from the one-way ANOVA showed no notable differences between 2016 and 2017 for *distance travelled* (p = 0.96). Pearson chi-square also showed no notable differences between 2016 and 2017 for *between match break* (p = 0.67) therefore all matches were included for logistic analysis. Descriptive data of each predictor and score margin outcomes for all participating teams of the 2016 and 2017 NRL competition seasons are reported in table 7.1. Spearman correlations discerned no notable concerns of multicollinearity between predictors (r = 0.028 - 0.294), with the exception of *match location* and *distance travelled* (r = 0.83). Match location was retained for inclusion in the analysis.

Data from 2016 and 2017 (368 unique games equating 736 cases of game/opponent data) competition seasons were used to develop MDI models. Results from binary logistic regression analyses are presented in table 7.2. Results from Model 1 showed that between match break did not significantly contribute to the model and was removed for Model 2. Model 2 showed a slight improvement in prediction performance (64.1 vs. 63.7%) whilst maintaining similar log-likelihood statistics (944.8 vs. 943.3). Knowing *match location* greatly improved the odds of predicting a win, followed by *opponent rank current year* and *opponent rank previous year*. Results indicate that matches played at home significantly improved the odds of winning compared to matches played internationally (Exp(B) [95% CI]) = 2.77 [1.44 - 5.36]) followed by interstate matches (1.86 [0.92 - 3.75]) and intrastate matches (1.67 [0.83 - 3.36]). Furthermore, results suggest teams competing against an opposition of lower ladder position (and therefore higher numerical value) had increased odds of winning (1.13 [1.09 - 1.17]).

Data from 2018 (184 unique games (equating to 368 cases of data) was utilised to cross validate MDI models. Results presented in table 7.2 show slight decreases in predictive performance for both Model 1 (63.7 vs. 61.1 %) and Model 2 (64.1 vs. 60.6 %). Results from MDI calculations ranged from 2.5 - 8.1. Table 7.3 showcases Model 2 MDI calculations for 10 samples extracted from the 2018 competition season. The area under ROC curves (AUC) was computed for Model 1 and Model 2, and delivered similar results (0.641[0.581 – 0.697] vs. (0.638 [0.581 – 0.694]).

Table 7.1 Combined 2016 and 2017 descriptive (mean (SD)) predictors and score margin data for each team within the National Rugby League competition.

	Opponent Rank Previous Year	Opponent Rank	Distance Travelled*	Between Match Break	Score Margin
Brisbane Broncos	8.5 (4.8)	9.1 (4.6)	439 (600)	7.9 (3.1)	5.9 (19.0)
Canberra Raiders	8.7 (4.9)	8.7 (4.3)	347 (607)	7.9 (2.6)	2.8 (16.1)
Canterbury Bulldogs	10.0 (4.4)	8.8 (4.0)	175 (479)	7.9 (2.0)	-3.9 (15.5)
Cronulla Sharks	8.8 (4.7)	8.5 (5.2)	287 (571)	8.0 (2.2)	4.8 (14.0)
Gold Coast Titans	8.6 (4.9)	8.0 (4.8)	442 (572)	8.0 (2.7)	-7.7 (18.1)
Manly Sea Eagles	8.0 (4.4)	8.0 (5.1)	253 (567)	7.9 (3.0)	1.9 (19.2)
Melbourne Storm	9.0 (5.0)	8.1 (4.6)	497 (700)	7.9 (2.5)	12.7 (16.6)
New Zealand Warriors	8.3 (4.6)	8.3 (4.4)	1214 (1215)	7.9 (2.4)	-5.9 (11.7)
Newcastle Knights	7.5 (4.5)	8.4 (4.4)	216 (433)	7.9 (2.7)	-9.4 (15.8)
North Queensland Cowboys	8.2 (4.7)	8.4 (5.2)	851 (855)	7.8 (2.8)	0.9 (12.9)
Parramatta Eels	7.7 (4.1)	9.5 (4.9)	276 (575)	7.8 (2.8)	1.3 (16.1)
Penrith Panthers	8.9 (4.6)	8.7 (4.1)	257 (568)	7.9 (3.0)	3.3 (18.1)
Saint George Dragons	8.8 (4.8)	9.3 (5.3)	202 (482)	8.0 (2.6)	2.2 (14.1)
South Sydney Rabbitohs	8.3 (4.8)	7.6 (4.0)	152 (389)	7.9 (3.0)	-3.7 (19.4)
Sydney Roosters	8.1 (4.7)	8.3 (4.8)	181 (478)	7.9 (2.7)	2.5 (15.2)
West Tigers	8.7 (4.9)	7.9 (4.9)	161 (387)	8.0 (2.6)	-8.1 (16.3)

**Where at home games = 0 km*

Table 7.2 Logistic regression results using 2016-2017 data for testing with dependent variable set as 'win' ('win'= 1).

	Model 1				**Model 2**			
	Beta (SE)	***p***	**Exp(B)**	**95% CI**	**Beta (SE)**	***p***	**Exp(B)**	**95% CI**
Constant	-1.49 (0.23)	<.001	0.22		-1.53 (0.22)	<.001	0.21	
Opponent Rank Previous Year	0.03 (0.02)	0.09	1.03	1.00 - 1.07	0.03 (0.02)	0.10	1.03	1.00 - 1.07
Opponent Rank Current Year	0.13 (0.02)	<.001	1.13	1.09 - 1.17	0.12 (0.02)	<.001	1.13	1.09 - 1.17
Away International		0.01				0.03		
Home	1.00 (0.34)	0.01	2.71	1.40 - 5.24	1.02 (0.34)	0.02	2.77	1.44 - 5.36
Away Intrastate	0.49 (0.36)	0.17	1.63	0.81 - 3.29	0.51 (0.36)	0.15	1.67	0.83 - 3.36
Away Interstate	0.59 (0.36)	0.10	1.81	0.89 - 3.66	0.62 (0.36)	0.08	1.86	0.92 - 3.75
Between Match Break: Long		0.46						
Between Match Break: Normal	-0.27 (0.23)	0.23	0.76	0.49 - 1.19				
Between Match Break: Short	-0.15 (0.24)	0.54	0.86	0.54 - 1.39				
	2016-2017		**2018**		**2016-2017**		**2018**	
log liklihood	943.30		489.35		944.88		490.37	
χ^2 (df)	77.00 (7)		20.78 (7)		75.43 (5)		19.78 (5)	
Cases correctly predicted	63.7%		61.1%		64.1%		60.6%	

Beta: Beta coefficient, SE: standard error, Exp(B): odds ratio, CI: confidence interval, χ^2 (df): Walds chi-square (degrees of freedom), statistical significance set at $p \leq 0.05$

Table 7.3 Example Match Difficulty Index output for 2018.

Team	Opponent	Match Location	Match Break	Opponent Rank Previous Year	Opponent Rank Current	Pred. Prob. of 'Win'	MDI	Result	Score Margin
Newcastle Knights	Parramatta Eels	Intrastate	Short	5	16	0.55	4.46	Win	26
Parramatta Eels	Newcastle Knights	Home	Normal	16	11	0.66	3.36	Loss	-26
Cronulla Sharks	South Sydney Rabbitohs	Intrastate	Short	12	3	0.35	6.55	Loss	-8
West Tigers	Sydney Roosters	Intrastate	Normal	3	7	0.35	6.47	Loss	-2
Manly Sea Eagles	North Queensland Cowboys	Home	Short	2	15	0.63	3.66	Loss	-14
New Zealand Warriors	Manly Sea Eagles	International	Long	8	13	0.63	3.68	Win	20
Brisbane Broncos	Melbourne Storm	Interstate	Long	1	5	0.30	7.01	Loss	-16
South Sydney Rabbitohs	Gold Coast Titans	Interstate	Normal	15	12	0.55	4.49	Win	2
North Queensland Cowboys	Parramatta Eels	Interstate	Normal	5	16	0.55	4.49	Loss	-6
Penrith Panthers	Canberra Raiders	Interstate	Long	10	10	0.47	5.33	Win	1

Pred. predicted, Prob. probability

7.4 Discussion

The aim of this study was to develop a model to predict the difficulty of regular competition season matches in the NRL by examining the influence of external factors on match outcome. Understanding the proposed difficulty of upcoming matches can assist physical, technical and tactical coaches by contributing a strategic element to the planning and periodisation approach for preparation. Both models developed in this study demonstrated an ability to predict match outcome, with slight differences in log-likelihood statistics (943.3 vs. 944.8) and percentages of correct predictions (63.7 vs. 64.1%) observed. This work has extended on previous research developing MDI models within professional rugby union (Super Rugby) [29] and Australian Football [28] in applying it to the leading Australian rugby league competition. The percentages of correct predictions from both Model 1 and Model 2 displayed similar ranges to Super Rugby (63.7 – 66.2%) and Australian Football (65.5 – 69.7%) models. As confirmed by match outcome, *match location* was the greatest contributing external factor to match difficulty, followed by *opponent rank current year* and *opponent rank previous year.*

Previous Super Rugby and Australian Football models showed *match location* to be an influential factor on match difficulty. For example, match difficulty found to increase for Super Rugby matches played interstate, and further increased for matches played internationally compared to home matches [29]. Similarly, the present results also identified *match location* as a substantial contributor to determining match difficulty. Specifically, there are greater odds of winning NRL matches played at home (Exp(B): 2.77), when compared to matches played internationally, followed by interstate (1.86) and intrastate (1.67) matches. Home advantages and the effects of travel on performance have been explored within various team sports [179-182], with a reduction in winning probability by -2.7% and -1.1 points for every 1,000 km travelled observed within the NRL competition [179]. Explanations for home advantages within the NRL have been derived from player surveys, perceiving home crowds, family and friends' support, normal travel and familiarity of weather conditions to be positively contributing factors [183].

Whilst the present findings are similar to those reported in Super Rugby [29], the differences in travel requirements between codes should be noted. Fifteen of 16 participating teams in the NRL are located within Australia, with one team based in New

Zealand. Additionally, the vast majority of teams are located within New South Wales, with five of 16 teams located in additional states / territories, resulting in uneven travel requirements for teams within this study. Further development of the MDI model including additional competition seasons to obtain a larger sample size of interstate and international travel is encouraged.

To prepare for competition, both coaches and players spend large portions of time studying the upcoming opposition, identifying opposition strengths and weaknesses to develop a strategic plan for performance whilst aligning to their style-of-play [30]. Similar to reports within Super Rugby [29] and Australian Football [28] the current results showed that *opponent rank current year* is an important consideration when determining match difficulty. Of particular note, was the present observation that the odds of winning was 13% more likely for every unit decrease in ladder position of the opposition. Understanding the contribution of this factor to match difficulty through its influence on match outcome can inform strategic manipulations of training activities. For example, coaches and physical performance staff can utilise this information to plan training and match exposure through altering player rotation plans (e.g., for those with 'niggling' injuries or playing opportunities for developing athletes), managing training loads (e.g., for those participating in representative matches adjacent to the competition season). Despite this application, understanding how coaches utilise this information to prescribe the tactical elements of training drills to prepare against oppositions of varying difficulty is not understood. Therefore, future work examining the tactical arrangements of training drills in accordance with perceived difficulty of upcoming matches is warranted.

The present findings showed non-meaningful contributions of *between match break* within the MDI model, with a slight improvement in model predictability observed subsequent to its removal (63.7 vs. 64.1%). Similarly, time periods between matches also did not significantly contribute to the MDI models developed in Super League [29] and Australian Football [28]. As players participate in collision and impact events within rugby league match performance [60], it may be perceived a scheduled short turnaround between matches may leave players vulnerable to an acute accumulation of fatigue and negatively influence subsequent matches [166]. However, possible reasons for these findings may be attributed to careful periodisation and recovery strategies. For example, research has

revealed that with appropriate training, it is possible for neuromuscular and perceptual recovery markers to return to baseline four days following rugby league match performance [110]. This information is useful for coaches and performance staff to distinguish the importance of other contextual factors, which should take precedence when planning and periodising for a competition schedule.

While both Model 1 and Model 2 displayed an ability to predict match outcome, Model 2 may be considered parsimonious due to its slightly higher predictive capabilities and goodness-of-fit achieved with lower degrees of freedom. Additionally, only a difference of -0.5% cases correctly predicted was observed during cross-validation. Furthermore, it is acknowledged there may be other contextual factors (e.g., current form of individuals and the team) that may improve the predictive capabilities of these models and should be considered in future investigations. Applying this model within rugby league may be useful to inform physical, technical and tactical periodisation strategies. However, further research is encouraged to specifically understand how coaches plan and prepare their team against oppositions of varying difficulty. For example, it has been suggested that coaches and high performance support staff can utilise MDI models to inform plans to sacrifice physical 'freshness' [28] for particular games to sustain physical fitness throughout the competition. However, coaches alter their approach to have greater focus on technical or tactical aspects of training at the expense of less physical stimulus. At present, it is not known if match difficulty influences how coaches alter programming to account for these factors. These moments may be required to provide more training activities targeted towards tactical learning against particular oppositions, where individuals apply and practice their role and the decision making necessary in game-like environments. Future research examining how coaches prescribe tactical training activities with reference to the difficulty of upcoming opponents would enhance our understanding of current tactical periodisation and preparation processes.

7.5 Conclusion

The present study extends on previous work quantifying match difficulty in Australian codes by developing an MDI model for the professional rugby league competition. Developed models demonstrated an ability to predict match outcome, with Model 2 displaying a slight improvement in prediction compared to Model 1 and only slight decreases in predictive performance observed during cross-validation. The external factors; *match location, opponent rank current year and opponent rank previous year* were deemed most influential to match outcome and accordingly contributed to match difficulty. With a greater knowledge of the external factors influencing match difficulty, coaches and support staff can strategically manipulate physical, technical and tactical approaches to training. However, studies understanding how coaches plan and manipulate the tactical approaches to training and prescription to prepare against oppositions of varying difficulty is required and warranted for future research.

CHAPTER EIGHT

Study Seven: How do Coaches Design Training to Prepare for Upcoming Oppositions?

8.1 Introduction

An important role of sport scientists working in professional team settings is to establish evidence-based practices that assist their preparation and performance [1, 21]. One of the most common approaches, is through athlete monitoring, where data regarding individual athletes training and their response to that training is collected used to guide future training prescription. These activities are usually undertaken with the intent to maximise an athlete's readiness to train [58] and reduce their injury risks [184]. This approach has been based on the concept of periodisation, and is supported by Bannister's 'fitness' and 'fatigue' model [54-56, 185]. However, as the roles of sports scientists have developed and become better integrated with coaching departments, there is a shift for monitoring systems to account for the physical (i.e., work), technical (individual skill) and tactical (interaction with teammates and opposing individuals) components of performance [58]. Indeed, it has been reported that tactical behaviour is a significant contributor to successful match outcomes [9, 86]. However despite its importance, relatively little has been published on how coaches plan and periodise the tactical elements of training (tactical periodisation) relative to their coaching beliefs, philosophies and game-style [30].

Understanding the implementation of a tactical-led approaches to periodisation has been of significant interest as this integrated approach accounts for the myriad of factors considered essential to team sport performance (i.e., tactical, physical, psychological, and technical) [20]. While performance frameworks recognise the symbiotic relationship between these factors, tactical performance (i.e., 'how' the game is played by individuals and the team) is treated as the central component from which the remaining factors emerge [20]. In Chapter Six, the tactical prescription and distribution of on-field training drills in professional rugby league was quantified, revealing increases in ratings of *familiarity of strategies* and *predictability of attack and defence* throughout weekly training for upcoming matches. Variations in *attack and defensive pressure* were also observed, whereby ratings increased to peak two days prior to performance. Suggested reasons for these differences have been attributed to focussing on tactical activities in game-like situations within training to fortify the strategies needed to control match-play and respond to expected opposition behaviours [96]. Whilst this previous study described how coaches manipulate the training drills for tactical preparation, it did not examine if training was manipulated to account for the expected opposition. Although coaches manipulate training

drills relevant to upcoming oppositions to instil efficacy, motivation, ensure the necessary level of tactical preparation is achieved and influence positive match outcomes [186-189], evidence of this remains anecdotal. Accordingly, examining how coaches prescribe training to prepare their players for oppositions of varying difficulty is critical to understand the tactical-led approach to training prescription and holistic preparation in rugby league.

In Chapter Seven, a Match Difficulty Index (MDI) model was developed within professional rugby league to quantify the difficulty of upcoming oppositions based on the influence and contribution of external factors to successful match outcome. In particular, match location and opposition rank from the current and previous year were found to be the most influential predictors in determining match difficulty. While this information has been useful to inform physical periodisation approaches and sustain physical fitness for competition seasons [28, 29], it is not yet known how coaches prescribe the tactical elements of training in relation to the difficulty of upcoming opponents. Such information could be utilised to inform decision making and training design in team sports such as rugby league and provide further evidence of applied tactical periodisation frameworks. For example, coaches may prescribe greater attacking and defensive pressure from the opposition within training, to mimic game-like environments and encourage practice of high-level tactical decision making required against high difficulty opponents [96]. Accordingly, to further develop and understand the utility of this MDI, as well as provide further evidence of tactical perioidsation frameworks, the aim of this study is to examine how coaches prepare and manipulate training drills for upcoming oppositions by comparing the differences in tactical prescription with training day and difficulty of upcoming opponents.

8.2 Methods

Design

This study utilised a prospective cohort design conducted over the 2018 National Rugby League (NRL) Competition. Comparative analysis was implemented to detect differences in coaches prescription of tactical variables with training day and match difficulty of upcoming opponents. Procedures were approved by the Human Research Ethics Committee of the University of Technology Sydney (ETH16-1074). Written informed

consent and demographic information was obtained from all participants before the commencement of this study.

Participants

Data was collected from four professional NRL coaches during the 2018 competition season. Coaches were full-time contracted to the NRL club and had a combined total of 39 years of playing and a range of 4 – 16 years coaching experience as an assistant or head coach role within the professional and semi-professional level in rugby league. Distribution of coaching roles were head coach, attack coach, defence coach and development coach.

Measures and Procedures

A Training Drill Questionnaire previously developed within research to quantify the tactical prescription of rugby league training drills was completed for every team drill during the 2018 competition season (Chapter Three)(supplementary material figure S3). The questionnaire contained two components: 1. pre-training questionnaire and 2. post-training questionnaire. The pre-training component of the questionnaire required coaches to rate the tactical variables for only the team drills they designed and coached on a visual analogue scale (VAS) and was completed 20 – 30 minutes prior to the training session. The post-training component of the questionnaire was completed up to 10 minutes after the completion of the training session and required coaches to rate 3 self-review questions on a VAS. All procedures, ratings and descriptions of tactical variables and post-training questions were collected according to methods previously reported (Chapter Six). Variables including tactical descriptors and VAS end-points are supplied in supplementary material (table S6, S7, S8).

The number of training sessions was dependent on match turnaround and ranged from three to four sessions per week. As shown in figure 8.1, these training days were categorised as ‘Day 1’, ‘Day 2’, ‘Day 4’, and ‘2 Days Post’. The training day scheduled 4-days and 5-days prior to the upcoming match were both categorised as ‘2 Days Post’ for short (< 7 days) and normal to long (≥ 7 day) between match periods due to the similar recovery period after the previous match.

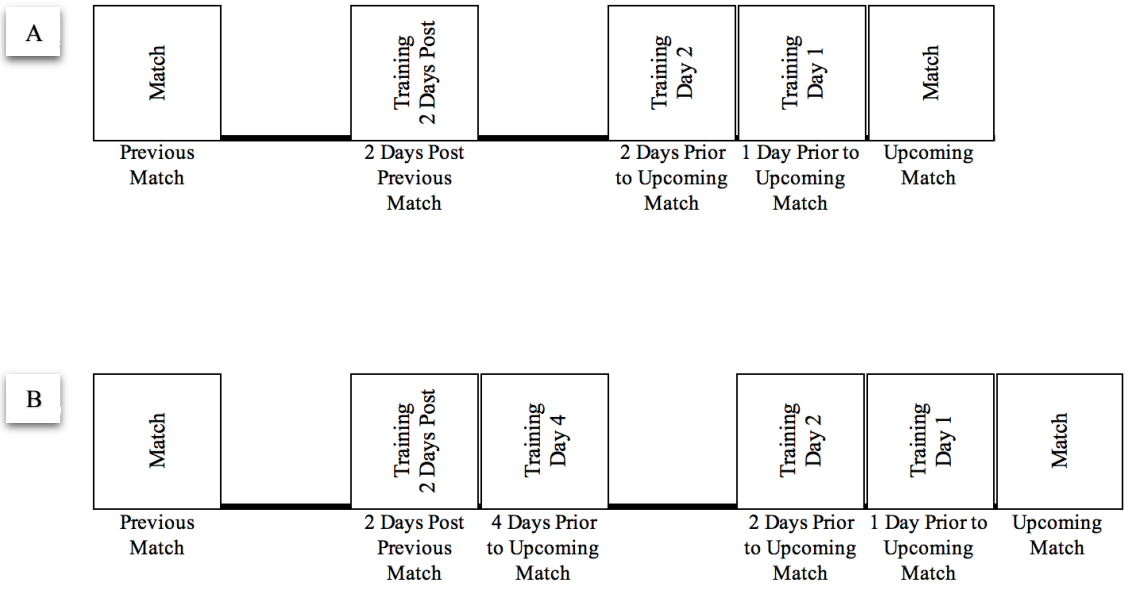


Figure 8.1 Categorisation of on-field training days for A. short (<7 day) turnarounds and B. normal to long (≥7 day) turnarounds (Chapter Six).

The difficulty of regular competition matches was calculated using scores from the recently developed MDI model in professional rugby league (Chapter Seven). MDI scores were reported in arbitrary units, scaling between 0 and 10, and was calculated as the logit probability of 'win' for each game subtracted from 1 and then multiplied by 10. Calculated MDI scores of the oppositions ranged between 3.0 – 7.13, which were segregated into equal thirds were created to form predicted low (<4.38), mid (4.39 – 5.14) and high (>5.14) difficulty categories of upcoming opponents.

Statistical Analysis

Dependent variables (i.e., coaches' ratings) were first descriptively described. Two-way ANOVAs were conducted to detect differences of coaches' ratings with training day and match difficulty. Where dependent variables violated assumptions of homogeneity according to Levene's statistic, four subsequent one-way ANOVAs or non-parametric Kruskal-Wallis tests, one for each day, were conducted with match difficulty as the independent variable to detect interactions. Relevant Tukey or Mann-Whitney U tests (Bonferonni correction ($p < 0.008$) post-hoc tests were used. As the MDI can only be calculated after the first round of competition, this round was eliminated from two-way ANOVA analyses.

8.3 Results

Twenty rounds of the 2018 NRL season were included for analysis providing 142 pre-training responses for 23 unique drills and 209 post-training questionnaire responses. Frequency of training days included 20 Day 1 training days, 20 Day 2 training days, 10 Day 4 training days and 18 Day 5 training days. Overall descriptive statistics (means (SD)) of tactical variables and post-training questions are presented in table 8.1. Table 8.2 reports the frequency of coach ratings by low, mid and high MDI categories of upcoming opponents. Descriptive statistics of coaches' ratings for tactical variables and post-training questions by training day and difficulty of upcoming opponent is presented in table 8.3.

Table 8.1 Means and standard deviations of tactical variables and post-training questions.

Dependent Variables	**n**	**m (SD)**
Familiarity of Strategies	142	7.2 (1.8)
Attacking Predictability	142	6.9 (1.9)
Defensive Predictability	114	7.9 (1.0)
Attacking Pressure	142	6.0 (3.2)
Defensive Pressure	142	5.7 (3.3)
Speed of Execution	142	7.0 (2.4)
Predicted Fatigue	142	3.6 (2.5)
Spine Combination	129	7.1 (1.9)
Technical Complexity	142	5.9 (2.1)
Overall Satisfaction	209	8.2 (1.1)
Was the Session Implemented as Intended?	209	8.6 (0.9)
Did the Players Execute as Expected?	209	8.5 (1.0)

Table 8.2 Frequency of coach ratings by upcoming opponent.

MDI of Upcoming Opponent	**Frequency**	**Percent**
Low	67	31.9
Mid	72	34.3
High	48	22.9

Table 8.3 Descriptive statistics (Means (SD), 95% confidence intervals) of coaches' ratings of tactical variables and post-training questions for training day and difficulty of upcoming opponent.

	MDI	2 Days post		Day 4		Day 2		Day 1	
		M (SD)	95% CI	M (SD)	95% CI	M (SD)	95% CI	M (SD)	95% CI
Familiarity of Strategies	Low	4.9 (2.9)	2.7 - 7.2	5.4 (1.5)	4.2 - 6.6	7.6 (0.8)	7.2 - 8.1	8.1 (0.5)	7.8 - 8.5
	Mid	6.8 (1.9)	5.1 - 8.5	7.1 (2.2)	5.6 - 8.6	7.5 (0.9)	7.0 - 8.0	8.2 (0.8)	7.8 - 8.7
	High	5.9 (2.8)	2.9 - 8.8	8.2 (0.3)	7.4 - 9.0	7.1 (1.4)	6.2 - 7.9	8.6 (0.6)	8.2 - 9.0
	Total	5.8 (2.6)	4.6 - 6.9	6.6 (2.0)	5.7 - 7.5	7.4 (1.0)	7.1 - 7.7	8.3 (0.7)	8.1 - 8.5
Attacking Predictability	Low	4.9 (2.6)	2.9 - 6.9	5.5 (1.9)	4.0 - 7.0	7.7 (0.9)	7.2 - 8.1	7.7 (1.4)	6.9 - 8.5
	Mid	5.7 (1.8)	4.0 - 7.4	6.3 (1.7)	5.1 - 7.5	7.1 (1.6)	6.2 - 8.0	8.2 (0.9)	7.7 - 8.6
	High	6.4 (2.1)	4.2 - 8.5	**8.2 (0.4)***	7.1 - 9.3	6.4 (2.0)	5.2 - 7.6	8.4 (0.7)	7.9 - 8.9
	Total	5.5 (2.2)	4.6 - 6.5	6.2 (1.9)	5.4 - 7.0	7.1 (1.6)	6.6 - 7.6	8.1 (1.0)	7.7 - 8.4
Defensive Predictability	Low	7.7 (1.1)	6.7 - 8.7	7.5 (1.0)	6.7 - 8.3	8.0 (0.7)	7.6 - 8.4	8.8 (0.6)	8.3 - 9.3
	Mid	7.5 (1.4)	5.3 - 9.7	8.1 (1.0)	7.5 - 8.8	7.6 (1.2)	6.9 - 8.2	8.4 (0.1)	8.3 - 8.6
	High	8.0 (1.2)	6.0 - 10.0	8.5 (0.6)	7.0 - 9.9	7.8 (0.8)	7.3 - 8.3	8.5 (0.4)	7.9 - 9.0
	Total	7.8 (1.1)	7.1 - 8.4	7.9 (1.0)	7.5 - 8.4	7.8 (0.9)	7.5 - 8.1	8.6 (0.5)	8.4 - 8.8
Attacking Pressure	Low	4.5 (3.5)	1.8 - 7.2	7.0 (2.6)	5.0 - 9.0	8.3 (0.6)	7.9 - 8.7	4.0 (3.3)	2.0 - 6.0
	Mid	2.9 (2.9)	0.2 - 5.5	7.3 (1.6)	6.2 - 8.3	8.6 (0.5)	8.3 - 8.9	3.9 (3.4)	2.0 - 5.8
	High	2.5 (2.9)	-0.6 - 5.6	8.3 (0.8)	6.2 - 10.3	8.4 (0.9)	7.9 - 9.0	3.8 (3.7)	1.2 - 6.4
	Total	3.4 (3.2)	2.0 - 4.8	7.3 (1.9)	6.5 - 8.1	8.4 (0.7)	8.2 - 8.6	3.9 (3.3)	2.8 - 5.0
Defensive Pressure	Low	4.8 (3.3)	2.3 - 7.4	6.6 (2.6)	4.6 - 8.6	8.2 (0.7)	7.8 - 8.6	3.5 (3.3)	1.4 - 5.5
	Mid	2.7 (2.8)	0.2 - 5.3	7.0 (1.8)	5.8 - 8.2	8.3 (1.4)	7.5 - 9.1	3.4 (3.4)	1.5 - 5.3
	High	2.7 (3.2)	-0.7 - 6.1	8.1 (0.8)	6.3 - 10.0	8.3 (0.9)	7.8 - 8.8	3.8 (3.7)	1.1 - 6.4
	Total	3.6 (3.2)	2.2 – 5.0	7.0 (2.1)	6.1 - 7.9	8.3 (1.0)	8.0 - 8.6	3.5 (3.3)	2.4 - 4.6
Speed of Execution	Low	5.7 (3.1)	3.3 - 8.1	7.7 (0.7)	7.2 - 8.3	9.1 (0.7)	8.7 - 9.5	5.2 (1.5)	4.3 - 6.1
	Mid	4.8 (2.0)	2.9 - 6.7	7.3 (1.7)	6.2 - 8.5	9.4 (0.4)	9.2 - 9.6	4.8 (1.4)	4.1 - 5.6
	High	4.2 (2.6)	1.5 - 6.9	8.4 (0.9)	6.0 - 10.7	9.3 (0.5)	9.0 - 9.6	5.9 (1.2)	5.0 - 6.7
	Total	5.0 (2.6)	3.8 - 6.2	7.6 (1.3)	7.1 - 8.2	9.3 (0.6)	9.1 - 9.4	5.2 (1.4)	4.8 - 5.7

	MDI	2 Days post		Day 4		Day 2		Day 1	
		M (SD)	95% CI	M (SD)	95% CI	M (SD)	95% CI	M (SD)	95% CI
Predicted Fatigue	Low	2.5 (2.1)	0.8 - 4.1	4.2 (2.3)	2.5 - 6.0	5.5 (2.4)	4.2 - 6.8	2.6 (2.5)	1.1 - 4.1
	Mid	2.2 (2.0)	0.3 - 4.1	4.5 (1.8)	3.3 - 5.8	4.6 (2.8)	3.0 - 6.1	2.8 (2.4)	1.4 - 4.2
	High	1.9 (2.1)	-0.3 - 4.2	5.2 (2.6)	-1.3 - 11.6	4.5 (2.7)	2.8 - 6.1	2.8 (2.6)	1.0 - 4.7
	Total	2.2 (2.0)	1.3 - 3.1	4.5 (2.0)	3.6 - 5.4	4.9 (2.6)	4.1 - 5.7	2.7 (2.4)	1.9 - 3.5
Spine Combination	Low	8.4 (1.2)	7.3 - 9.5	6.5 (2.5)	4.4 - 8.5	7.0 (1.5)	6.1 - 7.8	6.8 (1.7)	5.8 - 7.8
	Mid	7.8 (1.9)	6.1 - 9.5	7.8 (2.2)	6.2 - 9.4	6.2 (2.2)	5.0 - 7.4	7.0 (1.6)	6.1 - 7.9
	High	7.7 (1.8)	4.8 - 10.5	7.9 (2.1)	2.6 - 13.1	7.2 (1.9)	5.9 - 8.6	7.0 (2.0)	5.5 - 8.4
	Total	8.0 (1.6)	7.2 - 8.8	7.3 (2.3)	6.3 - 8.4	6.8 (1.9)	6.1 - 7.4	6.9 (1.7)	6.3 - 7.5
Technical Complexity	Low	4.3 (2.3)	2.5 - 6.1	6.6 (1.7)	5.3 - 7.9	7.8 (1.1)	7.2 - 8.4	4.4 (2.0)	3.2 - 5.6
	Mid	4.8 (1.7)	3.2 - 6.4	5.9 (1.0)	5.2 - 6.6	7.9 (0.8)	7.5 - 8.4	4.8 (1.9)	3.8 - 5.9
	High	4.3 (2.4)	1.8 - 6.8	5.9 (0.9)	3.7 - 8.1	**7.0 (1.2)**[*†]	6.3 - 7.7	4.6 (2.4)	2.9 - 6.3
	Total	4.5 (2.1)	3.5 - 5.4	6.2 (1.3)	5.6 - 6.7	7.6 (1.1)	7.3 - 7.9	4.6 (2.0)	3.9 - 5.3
Overall Satisfaction	**Low**[‡]	**7.6 (1.1)**	**6.9 - 8.2**	**7.6 (1.6)**	**6.6 - 8.6**	**8.5 (0.9)**	**8.0 - 8.9**	**8.1 (1.1)**	**7.6 - 8.6**
	Mid	7.6 (1.1)	7.0 - 8.3	8.8 (0.8)	8.4 - 9.3	8.7 (0.7)	8.4 - 9.0	8.9 (0.9)	8.4 - 9.3
	High	8.5 (1.0)	7.8 - 9.1	8.6 (0.7)	7.5 - 9.7	8.5 (0.8)	8.1 - 8.9	8.3 (1.2)	7.7 - 9.0
	Total	7.8 (1.1)	7.5 - 8.2	8.3 (1.3)	7.8 - 8.8	8.6 (0.8)	8.4 - 8.8	8.5 (1.1)	8.2 - 8.8
Was the Session Implemented	Low	8.0 (1.2)	7.3 - 8.6	8.6 (0.6)	8.2 - 9.0	8.7 (0.7)	8.4 - 9.0	8.4 (0.9)	8.0 - 8.9
as the Coach Intended?	Mid	8.1 (0.9)	7.6 - 8.7	8.9 (0.8)	8.4 - 9.3	**9.2 (0.5)**[*]	9.0 - 9.4	9.0 (0.7)	8.7 - 9.3
	High	8.6 (0.9)	7.9 - 9.2	8.6 (0.6)	7.7 - 9.6	8.8 (0.6)	8.5 - 9.0	8.6 (1.0)	8.0 - 9.1
	Total	8.2 (1.0)	7.9 - 8.5	8.7 (0.7)	8.5 - 9.0	8.9 (0.6)	8.7 - 9.0	8.7 (0.9)	8.4 - 8.9
Did the Players Execute	**Low**^	**8.0 (1.4)**	**7.2 - 8.8**	**7.9 (1.4)**	**7.1 - 8.8**	**8.7 (0.9)**	**8.3 - 9.1**	**8.6 (1.0)**	**8.1 - 9.1**
as Expected?	Mid	8.3 (0.9)	7.7 - 8.9	8.8 (0.9)	8.3 - 9.2	8.9 (0.6)	8.6 - 9.2	8.9 (0.9)	8.5 - 9.3
	High	8.7 (1.0)	8.0 - 9.4	8.8 (1.1)	7.1 - 10.4	8.7 (0.7)	8.4 - 9.1	8.5 (1.2)	7.8 - 9.1
	Total	8.3 (1.2)	7.9 - 8.7	8.4 (1.2)	8.0 - 8.9	8.8 (0.7)	8.6 - 9.0	8.7 (1.0)	8.4 - 8.9

[*]significantly different ($p < 0.05$) from low match difficulty, [†]significantly different ($p < 0.05$) from mid match difficulty, [‡]denotes interaction of ratings between training days and match difficulty (ratings for low match difficulty < than mid and high match difficulty), ^denotes interaction of coaches' ratings and match difficulty (ratings for low match difficulty < mid match difficulty

Coaches' Ratings of Tactical Variables

Familiarity of strategies, attacking pressure, defensive pressure, speed of execution and *predicted fatigue* all violated assumptions of equal variances and subsequent match difficulty tests on each day showed no notable differences on these measures (p = 0.159 - 0.986). Further one-way ANOVAs showed no significant differences between match difficulty across all days on these dependent variables (p = 0.340 - 0.972).

Kruskal-Wallis tests showed significant differences between days on *familiarity of strategies, attacking predictability, attacking pressure, defensive pressure, speed of execution, predicted fatigue, technical complexity,* coaches' *satisfaction and* coaches' rating of *implementation* (p <0.001). Kruskal-Wallis tests showed no significant differences on coaches' rating of *player execution* between days (p = 0.125).

Two-way ANOVA showed significant differences between days on *defensive predictability* (F(3,97) = 3.39, p = 0.021, eta^2 = 0.10), no notable differences between match difficulty (F(2,98) = 0.52, p = 0.60, eta^2 = 0.009) and no notable interaction (p = 0.47). Tukey post-hoc showed that Day 1 had significantly higher *defensive predictability* ratings than Day 2, and 2 Days Post-Match (p = 0.013, d = 0.65, CI: 0.12, 1.42; p = 0.044, d = 0.66, CI: 0.016, 1.65).

Attacking predictability violated assumptions of equal variances and subsequent interaction tests on each day showed notable differences on Day 4 (X2(2, 23) = 6.73, p = 0.03, eta^2 = 0.24) and no notable differences on the remaining days (p = 0.230 - 0.471). Post-hoc Mann-Whitney tests showed that on Day 4, high match difficulty had significantly higher *attacking predictability* vs low match difficulty (Z = -2.5, p 0.009, r = 0.65). No notable differences were found between match difficulties (p = 0.475).

Two-way ANOVA on *spine combination* showed no notable differences between days (F(3,113)= 1.69, p = 0.17), match difficulty (F(2,114)=0.15, p = 0.85) or the interaction between the two (F(6,110) = 0.826, p = 0.55).

Technical complexity violated assumptions of equal variances and subsequent interaction tests on each day showed notable differences on Day 2 (F(2, 40) = 3.41, p = 0.04, eta^2 =

0.14) and no notable differences on the remaining days (p = 0.473 - 0.855). Post-hoc Tukey tests showed that on Day 2, high match difficulty had notably lower *technical complexity* than mid match difficulty (p 0.057, r = 0.65, CI: -1.78, 0.09) and low match difficulty (p = 0.08, r = 0.55, CI: -1.86, 0.02). No notable differences were found between match difficulties (p = 0.695).

Coaches' Ratings of Post-Training Questions

Two-way ANOVA showed significant differences on coaches' *satisfaction* between days (F(3, 182) = 3.63, p = 0.01, eta^2 = 0.05), match difficulty (F(2,183) = 6.30, p = 0.002, eta^2 = 0.06) and the interaction neared significance (F(6,179) = 1.97, p = 0.07, eta^2 = 0.06). Post-hoc Tukey tests showed low match difficulty had notable lower coach satisfaction than mid (p = 0.004, d = 0.39, CI: -1.0, -0.15) and high (p = 0.068, d = 0.31, CI: -0.91, 0.02).

Coaches' rating *of implementation* violated assumptions of equal variances and subsequent interaction tests on each day showed notable differences on Day 2 (F(2, 58) = 3.9, p = 0.02, eta^2 = 0.12) and no notable differences on the remaining days (p = 0.149 - 0.573). Significant differences between match difficulty were found (F(2, 183) = 4.21, p = 0.016, eta^2 = 0.04). Post-hoc Tukey tests showed lower coaches' ratings of *implementation* on low match difficulty than mid (p = 0.012, d = 0.12, CI: -0.74, -0.76).

Coaches' rating of *player execution* violated assumptions of equal variances and subsequent interaction tests on each day showed no notable differences (p = 0.159 - 0.529). Coaches' ratings of *player execution* between match difficulty showed notable differences (F(2, 183) = 2.90, p = 0.058, eta2 = 0.03). Post-hoc Tukey tests showed coaches' rating of *player execution* on low match difficulty was lower than mid match difficulty (p = 0.05, d = 0.28, CI: -0.79, -0.0003).

8.4 Discussion

It is important for the sports science practitioner to understand how teams tactically prepare for competition, particularly due to its significance to successful performance [7, 9] and the symbiotic relationship with the other performance elements (physical, technical and psychological) [20]. While recent work has expanded on traditional physical periodisation models by examining the tactical prescription and distribution of on-field training drills over weekly and seasonal cycles (Chapter Six), it has neglected to examine how coaches specifically manipulate the periodisation of tactical activities to prepare against oppositions of varying difficulty. Investigating how coaches manipulate training drills based on upcoming oppositions enhances our understanding of the tactical periodisation frameworks underpinning decision making and training design in professional rugby league. Accordingly, this study examined how coaches plan and prescribe the tactical elements of training based on the difficulty of upcoming opponents.

Results from this study revealed the majority of tactical variables were manipulated by training day, with two factors – *attacking predictability* and *technical complexity* – interacting with difficulty of upcoming opponent. Specifically, significantly higher ratings of *attacking predictability* were apparent on Day 4 training days leading into matches of high match difficulty (8.2 [0.4]) compared to low (5.5 [1.9]) and mid (6.3 [1.7]) difficulty matches. This is the first study to investigate how coaches prescribe the tactical elements of training based on difficulty of upcoming opponents, therefore direct comparisons to previous research proves challenging. Although speculative, explanations of increased attacking predictability ratings may be attributed to higher difficulty teams revealing characteristics relating to attacking set-pieces [30], tactical actions [115] and attacking performance indicators [37] contributing to positive match outcomes. Moreover, the influence of specific coaching philosophies and coach turnover may influence seasonal changes in game-plans within professional rugby league [32], characteristics of an attacking system may be relative to coaching and playmaker personnel.

Lower ratings of *technical complexity* were prescribed on Day 2 training days in the lead up to matches of high difficulty (7.0 [1.2]) compared to matches of low (7.8 [1.1]) and mid (7.9 [0.8]) difficulty. Several reports have documented the relationship between task complexity and performance; noting decreases in response accuracy, increases in decision-

making time and processing load and disruptions to the motor response as task complexity increases [190-192]. Causal arguments indicate greater attention is required for complex tasks to maintain performance which subsequently results in reduced processing capacity for secondary tasks. An example within rugby league demonstrated the proficiency of draw-and-pass skill performance (where an attacking players draws in a defender to disrupt the defence line and transfers the ball to an unmarked teammate) decreased as task complexity increased [193]. Furthermore, owing to greater attentional demands, a decrement in task performance was observed as additional tasks were required to be concurrently performed. Accordingly, coaches may seek to reduce the complexity of technical tasks leading into high difficulty matches to devote greater attention and focus to other match tasks to maintain tactical awareness, decision making and reduce error risk [9, 171, 193].

Within this study, the majority of significant differences in tactical ratings of training drills (*familiarity of strategies, attacking pressure, defensive pressure, speed of execution* and *predicted fatigue*) were observed between training days with no interaction in upcoming match difficulty. This finding suggests regardless of upcoming opposition, coaches may not greatly deviate from a template believed to tactically prepare their team for match performance. Accordingly, future research is encouraged to continue investigating the tactical prescriptive variables valued by coaches in other clubs and team sports to further examine the weekly and seasonal periodisation approaches. Understanding the structure and templates of how coaches prescribe training can assist sports science practitioners to incorporate holistic athlete and team monitoring strategies to apply a tactical-led approach. A notable observation of our findings displays increases in Day 4 ratings of *familiarity of strategies, defensive predictability, attacking pressure* and *defensive pressure* alongside increases in match difficulty. Although not statistically significant, this finding may be underpowered due to the smaller sample size caused by varying match turnarounds. Accordingly, future work including additional competition seasons is encouraged.

Previous research has described principles of tactical periodisation [20, 23, 24, 30] and quantified the tactical arrangement of training drills (Chapter Six). However, the present study is the first to examine how coaches tactically prepare and design training against upcoming oppositions using a specifically designed questionnaire validated by the coaches

themselves. It is acknowledged that the present analysis is prone to selection bias as it is a case study approach from one professional rugby league club and small sample size of participants. Additionally, the club analysed was very successful during the observation period (i.e., obtained win percentage of 66.7% for the regular competition [top 8 teams vs. bottom 8 teams: 64.6% vs. 35.4%] season and were NRL competition champions), thus coaching philosophies and approaches may not be generalisable to other rugby league clubs and team sports. Nevertheless, this study provides a novel approach to understanding how coaches tactically prepare their team for performance and can be utilised to inform monitoring and prescription strategies throughout the competition season.

Not only does this study contribute to understanding the tactical design of training, it also provides insight into the coaches' assessment of this preparation in relation to upcoming opposition. A previous study quantified the coaches' assessment of training displaying increases in ratings of *satisfaction*, *implementation* and *player execution* throughout the competition season (Chapter Six). Findings of this present study displayed lower ratings of *implementation* and *player execution* leading into matches of low difficulty compared to matches of mid difficulty. Similarly, coaches also provided lower ratings of *satisfaction* leading into low difficulty matches compared to mid and high difficulty matches. While psychological explanations of these ratings are beyond the scope of this investigation, these findings contribute to the complex and dynamic nature of coaching roles and athlete-coach relationships. It is common for successful coaches to implement strategies to avoid complacency and sense of entitlement during success to manage and maintain athlete preparation and focus [194]. Although theoretical, coaches may be more critical to avoid complacency of the team and of themselves resulting in reduced ratings of post training questions leading into lower difficulty opponents. In contrast, higher ratings of post training questions leading into mid and high difficulty oppositions could be reflective of coaches implementing efficacy strategies to guide athlete behaviour to adhere to heightened expectations [186], increase effort [195] and positively influence performance [196] against higher difficulty opponents. Future research identifying performance indicators contributing to *satisfaction*, *implementation* and *player execution* ratings would provide further assessment of planned prescription and quality of training output.

8.5 Conclusion

This study is the first to examine and describe the tactical arrangement of training drills leading into matches of varying difficulty. Main findings of this study revealed the majority of tactical variables differed by training day, with only two variables – *attacking predictability* and *technical complexity* – varying for difficulty of upcoming opponent. This reveals a concept where coaches may not greatly deviate from an implemented template to tactically prepare for match performance despite the difficulty of upcoming matches. Results from post training questions revealed coaches provided lower ratings of *satisfaction*, *implementation* and *player execution* leading into matches of lower difficulty, contributing insight into the complex coaching role of instilling motivation and efficacy to influence performance variables. Future research applying a similar framework to other professional rugby league clubs and team sports is warranted to further develop holistic monitoring and prescription strategies adopting a tactical-led approach.

CHAPTER NINE

Thesis Discussion

9.1 Thesis Aims

To adopt a holistic preparation approach within team sports such as rugby league, it is important for sport scientists to implement an evidence-based framework that aims to encompass the multifaceted elements of performance according to the context of training prescription and periodisation. Indeed, modern approaches endeavour to utilise a dynamic system to conceptualise preparation and performance, deviating from linear physical- and technical-led models commonly implemented in rugby league [34]. Understanding the relationships between the context and various demands of training (i.e., intention and outputs of training) can facilitate the assessment of preparation and can guide future training choices and approaches. However, prior to assessing these relationships, it is fundamental to understand the components within the preparation framework. Although it is generally considered that the multifaceted – physical, technical and tactical – demands are carefully integrated within training, a literature search revealed a current lack of evidence investigating the technical and tactical demands of rugby league training and absence of team-based training drills included within available studies investigating the physical demands (Chapter Two). Furthermore, while principles of tactical periodisation frameworks have been proposed, there is a current lack of empirical evidence supporting this concept [20]. Consequently, understanding how coaches plan and prescribe training to ensure tactical preparation according to their philosophical and periodisation approach remains anecdotal.

To meet these research gaps (as identified in Chapter Two of this thesis), a series of studies was developed to understand the multifaceted performance demands in rugby league training and investigate how coaches design and distribute the tactical elements of training to prepare for performance. Study two investigated how coaches plan and prescribe the tactical elements of training by developing an assessment tool to measure the periodisation of these factors. Study three and study four improved our understanding of the multifaceted nature of rugby league training by describing, classifying and examining the variability of the physical, technical and tactical demands of training drills. Study five investigated the prescription of tactical elements in training by developing and applying an assessment tool developed in study two. Subsequent, studies six and seven provided new information on whether coaches manipulate this prescription of training based on upcoming oppositions by developing a match difficulty index (MDI) for rugby

league and comparing the differences in tactical prescription with training day and difficulty of upcoming opponents.

9.2 Main Findings

Understanding the Multifaceted Demands of Rugby League Training Drills

This thesis provided the first studies to describe, classify and determine the variability of the physical, technical and tactical demands of professional rugby league training drills (i.e., Chapter Four and Chapter Five). A novel aspect of these investigations was the inclusion of team-based drills that are routinely implemented for tactical preparation and performance, extending on previous research from rugby league examining the suitability of select drills (i.e., small-sided games and conditioning drills) for physiological preparation [14, 15, 18]. Furthermore, rather than a siloed method (i.e., segregated cluster analysis of physical and technical aspects) that has been done to classify training drills in other team sports [162, 163], this study provided a holistic, integrated approach by applying a cluster analysis to physical, technical and tactical data. Applying this method to conceptualise the demands of rugby league training may enhance preparation by prescribing drills that are more representative of the integrated nature of the game.

Main findings identified eight overarching components; *defence technical*, *speed efforts*, *attack technical, contact efforts*, *errors*, *last play physical*, *last play technical* and *sprints* that encapsulate the physical, technical and tactical demands of rugby league training. The majority of technical and tactical factors included in the PCA theoretically grouped to form components relative to the moment in which they occur (attack, defence and transitions). The majority of physical variables segregated into *speed efforts* and *contact efforts*, which may reflect the high-intensity nature and collision characteristics experienced during all moments of the game [3]. Based on the similarities of these components, the cluster analysis identified six central types of drills conducted throughout the competition season; *Attack Whole*, *Part Practice*, *Attack Plays*, *Last Plays*, *Defence Whole* and *Organisation.* Additionally, larger variations of *contact efforts*, *attack technical*, *errors* and *sprints* components were observed within drill clusters, while *last play physical*, *last play technical* and *speed efforts* displayed lower variability. *Defence technical* showed the lowest variations in training drills. Understanding the characteristics

and discerning like-drills within training is important for various aspects of prescription such as training planning, drill selection and distribution within periodisation cycles.

This thesis provides a novel approach to integrate the physical, technical and tactical demands by incorporating a PCA to reduce, integrate and simplify the complex nature of these elements. While this method is the first approach to incorporate the physical, technical and tactical demands of rugby league training, result outputs may be practically nebulous when compared to using raw data metrics and consequently difficult to interpret to / for coaches (e.g., SWC, cause of change in drill outputs). Additionally, it is acknowledged the application of PCA to reduce the dimensions of the dataset, consequently results in the component names and underlying construct of each component to be subject to interpretation. Future research is encouraged to consider other potential means of reduction techniques to confirm related concepts or reduce physical, technical and tactical data to raw metrics according to expert guidance. Nevertheless, this thesis provides an innovative novel example from one club which provides insight into the types of drills conducted throughout a competition season, and contributes empirical evidence to the framework utilised to support preparation in professional rugby league (figure 9.1). Methods quantifying the physical, technical and tactical demands of rugby league training within this thesis can be practically applied to promote holistic monitoring methods and analysis of training. It is acknowledged these studies utilised a case-study approach and may not be generalisable to other rugby league clubs. However, this is a common limitation within research involving professional sporting teams, and the findings contribute a greater understanding towards the multifaceted demands of rugby league training. Findings can be utilised by coaches to inform their own drill design (for example, drill selection or implement task constraints) to ensure appropriate preparation. For example, coaches and support staff can modify task constraints such as; reducing coaching time and feedback to increase the proportion of time spent in attack, defence or transition moments, extend or restrict drills to other areas of the field and provide instructions to increase technical frequency or physical outputs. Furthermore, such information can be used to develop evidence-informed methods to inform training session design with focus on various aspects such as drill selection, exposure to drills of different focal areas (i.e., technical, tactical and physical aspects) and the distribution of this exposure. For example, based on the current findings, if coaches desire to implement

drills with high focus on time in defence and ensure a high frequency of tackles are made, drills can be selected from *Defence Whole*.

Differences in drill cluster characteristics may be attributed to the drill design and representativeness to match-play as coaches implement drills to develop and practice game plans and strategies in accordance with performance moments (attack, defence, transitions) and desired game-style [24]. Indeed, representativeness of training drills to matches is important for skill transfer, decision making, tactical awareness and physical preparation [197-199]. For example, lower means of physical and technical variables present within the *Organisation* cluster may suggest these drills are implemented for the purposes of tactical and strategic learning such as; applying new strategies, making team or positional adjustments and providing feedback. However, reasonings for these differences remains theoretical without an understanding of how coaches plan and prescribe training. Accordingly, subsequent studies in this thesis were conducted to provide empirical evidence on how coaches prescribe training and investigate whether this prescription can be measured and monitored.

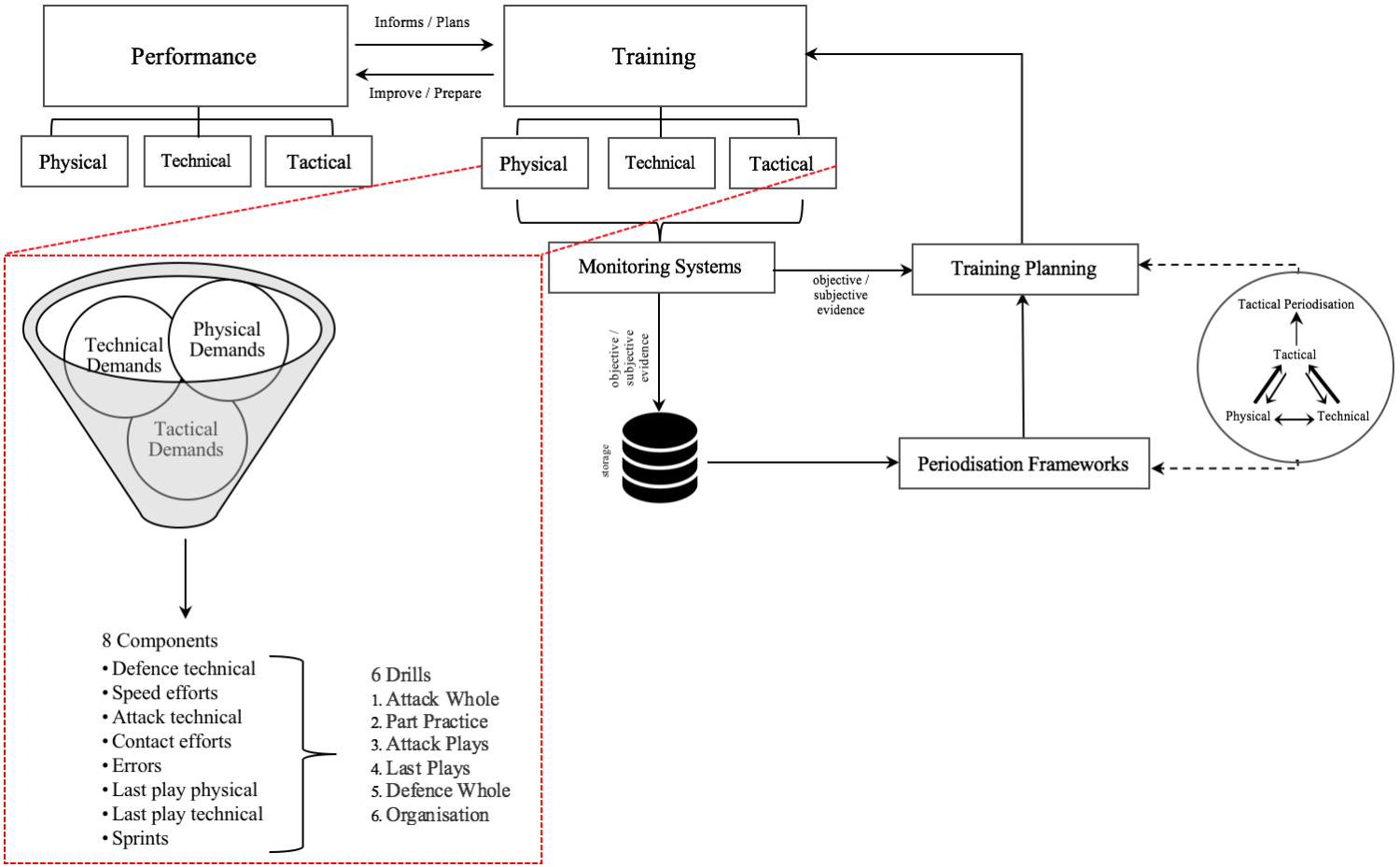


Figure 9.1 The holistic framework for training, periodisation and performance in professional rugby league (study three and study four).

Understanding how Coaches Plan and Prescribe the Tactical Elements of Training

This thesis describes a new approach to identify and measure how coaches plan and prescribe the tactical elements of training. Indeed, the implementation of semi-structured interviews to attain such information is key to further understanding the applied rugby league environment. Periodisation approaches are often a collaborative process between coaching, performance and medical staff. Whilst there is usually a collective approach to developing training content, the implementation of tactical elements to ensure strategic preparation of the team is coach-led. Coaches spend considerable time developing a training matrix to ensure selected game principles and plans are instilled and practiced in accordance with the desired style-of-play [30]. Indeed, models of tactical periodisation have become of popular interest within team sports, with outlines and principles of tactical periodisation proposed [20]. However, there is a current lack of empirical evidence investigating tactical periodisation frameworks, including how it is applied or manipulated based on the upcoming opposition. Accordingly, information on how coaches plan and prescribe the tactical elements within training are not well understood yet is fundamental within preparation frameworks. Therefore, studies in this thesis were designed to examine the coaches' tactical prescription of rugby league training, and assess the prescription across weekly and seasonal cycles competition cycles against varying oppositions.

Main findings revealed coaches categorise training drills by; *moment of performance* (attack, defence and transitions), *period of performance* (0 – 20 min, 20 – 40 min, 40 – 60 min, 60 – 80 min), *design* (structure, execution, scenario) and *focus* (individual, team, group). During competition, the weekly microcycle was periodised to conduct attack drills early in the week (i.e., furthest from the match) whilst the majority of defensive drills were implemented two days prior to match-play. Training drills were often designed to practice team structure across the whole match regardless of training day and an increased occurrence of scenario targeted drills (i.e., predicted match events or scenes) were apparent in the training days closer to match performance. Other important contextual factors were revealed to be considered when prescribing and assessing the effectiveness of training drills. This includes general themes of; *familiarity of strategies*, *attacking predictability*, *defensive predictability*, *attacking pressure*, *defensive pressure*, *speed of execution*, *fatigue at commencement*, *spine combination* and *technical complexity*. Two weekly trends of tactical arrangement were observed; *familiarity of*

strategies and *predictability of attack and defence* progressively increased in the days leading up to a match, and ratings of *attacking and defensive pressure, speed of execution, predicted fatigue* and *technical complexity* synonymously increased to peak two days prior to match performance. It was also revealed only two factors – *attacking predictability* and *technical complexity* – interacted with difficulty of upcoming opponent (as calculated using the MDI model developed in study six). Specifically, higher ratings of *attacking predictability* and lower ratings of *technical complexity* were apparent on Day 4 and Day 2 training days respectively leading into matches of high match difficulty. Explanations may be attributed to attacking characteristics relating to positive match outcomes being revealed by higher difficulty teams [30] and the aim to reduce the complexity of technical tasks to devote greater attention to other match tasks, reducing error risk [190]. This information could be utilised to assist monitoring and assessment of training factors such as coaches' drill design (e.g., exposure in defence) and skill performance of the team (e.g., errors).

It was also identified coaches evaluate training drills post session, examining factors such as *overall satisfaction, drill implementation* and *player execution.* Main findings displayed increased ratings in all post-training variables throughout each third of the competition season, possibly attributed to continual successful match performance and outcomes, player combinations and team synergy and perceived display of desired game-style [173, 175]. Findings also showed coaches provided lower ratings of *satisfaction* leading into low difficulty matches compared to mid and high difficulty matches. While psychological explanations and key performance indicators of these ratings are beyond the scope of this investigation, these findings contribute to the complex nature of coaching roles and athlete-coach relationships to manage efficacy and motivation [186, 200, 201]. For example, higher ratings of *satisfaction* leading into mid and high difficulty opponents could be reflective of coaches implementing efficacy strategies [186] to positively influence performance [196]. Future research identifying performance indicators contributing to post-training ratings would provide further assessment of planned prescription and quality of training output.

Taken collectively, these findings suggest that even with varying oppositions of predicted difficulty, coaches examined in this thesis may not greatly deviate from a template and follow a consistent framework of tactical prescription believed to best prepare their team

for match performance. Furthermore, these findings demonstrate an example of the representative design of implemented team-based drills to tactical periodisation frameworks. For example, these drills were intentionally prescribed according to the moments of the game (i.e., attack, defence and transitions) and to acquire or learn a particular way of playing within weekly microcycles (as indicated by the daily increase in ratings of 'game plan' variables'). Furthermore, high ratings of 'intensity' variables on Day 2 training provide an example of utilising team-based drills to allow experiential learning within situations where players solve problems (e.g., *scenario* prescribed drills at 'game-like' intensity). This extends on previous research involving SSG as a means to prepare for competition, providing information on the large proportion of drills that envelop training sessions or weekly periodisation cycles during competition. While data from this study may not be generalisable to other rugby league clubs due to differences in coaching philosophies and small sample size, it is the first approach to quantify the tactical elements of professional rugby league training. Previous studies have described evasion strategies in attack and defence within rugby union [114, 115] and game-style frameworks in professional soccer [30] providing important information on outcome metrics to quantify how a team plays, such as technical outcomes, time and space (e.g., running patterns or field location). However, the methodology applied in this thesis differs as it examined and quantified the coaches' intentional tactical plan and periodisation framework for training. Indeed, this thesis is the first to provide a practical assessment tool to routinely measure the tactical prescription by coaches, displaying satisfactory validity and reliability. Applying the methods developed within this study to other rugby league clubs and other team sports is encouraged to further investigate and contribute information on how coaches arrange and prescribe training.

It is acknowledged that this thesis is a case-study derived from one competing team. To overcome selection bias, future work is encouraged to apply similar frameworks to different clubs to account for different coaching philosophies and team personnel. Nonetheless, this thesis provides unique information as it is the first to investigate the tactical prescription approach in relation to upcoming opponents. Such information enhances our understanding of implemented tactical periodisation frameworks underpinning decision making and training design in professional rugby league and contributes empirical evidence to the framework applied to support holistic preparation in professional rugby league using a tactical-led approach (figure 9.2). From a practical

perspective, studies in this thesis provide an example of how tactical information can be routinely collected and measured to assist coaches and support staff in strategically manipulating physical – technical loads and tactical approaches to training.

Contribution to Preparation Frameworks in Professional Rugby League

Collectively, the findings from this thesis provide empirical evidence within a framework commonly utilised to support training and periodisation in professional rugby league. Studies within this thesis include the first descriptions of the physical, technical and tactical demands of rugby league training. Additionally, these studies present a new and innovative approach to incorporating these demands within a holistic approach to monitoring and designing training. This thesis also adopts a new approach to objectively measure, describe and understand how coaches' prescribe training according to a tactical periodisation approach. Indeed, understanding all these aspects is important given the prevalence of physical, technical and tactical elements in team sport [62] and their symbiotic relationship within tactical periodisation design [20]. This thesis provides a foundation for future work to extend investigations to examine whether there are physical, technical and tactical factors that underpin the coaches' prescription and implementation of periodisation frameworks in professional rugby league. Indeed, contemporary frameworks of performance in rugby league seek to incorporate a dynamic approach rather than siloed methods to accommodate the interactive nature between the environment and individuals [34]. Accordingly, conceptualising training according to tactical periodisation approaches may provide symbiotic development and preparation of the physical, technical and tactical actions required [20]. Future work examining the relationship between tactical prescription and the physical, technical and tactical demands of training and performance could present further evidence of implemented tactical periodisation frameworks and assessment of the coaches intention versus objective outputs.

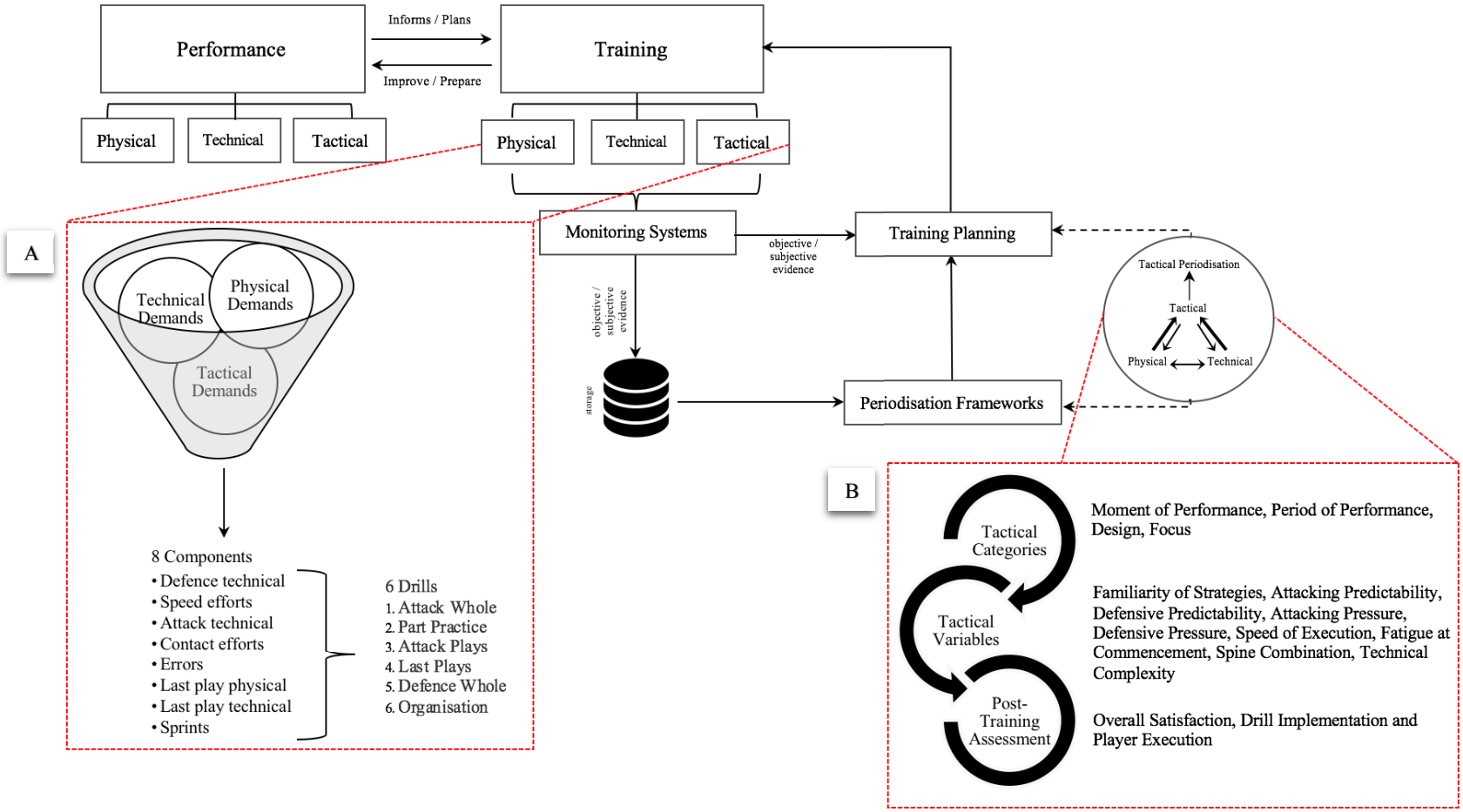


Figure 9.2 Contribution of studies A. three, four and B. two to the framework to support training, periodisation and performance in professional rugby league.

9.3 Limitations

Collectively, the studies in this thesis developed and provided a new approach towards understanding the multifaceted demands of rugby league training and how coaches prescribe training to best prepare their players. This thesis also provided the first empirical evidence on tactical periodisation models through the examination of coaches' tactical plans and prescription of training drills within weekly / seasonal cycles and against oppositions of varying difficulty. Given the novel investigations included in this thesis, there are several limitations which arise from the applied nature of this research and need to be acknowledged.

Firstly, data used from study two, study three, study four, study five and study seven is prone to selection bias and data was drawn from participants (i.e., high performance rugby league coaches and professional rugby league players) at a single NRL club during one competition season. Accordingly, the results may only be applicable to this population and not generalisable to the wider rugby league community. This is a common limitation within research involving not just professional rugby league, but other team sports within high performance settings. To overcome this, it is encouraged to collaborate with other teams and combine data to provide a more representative sample of the results.

Study three and study four implemented a PCA and cluster analysis to describe, classify and determine the variability of physical, technical and tactical factors of professional rugby league on-field training drills. While this is a novel approach to incorporate a PCA to reduce, integrate and simplify the complex nature of the multifaceted demands present in rugby league, result outputs may be practically difficult to interpret and relay to coaches. Furthermore, while the names of PCA and drill clusters were collectively agreed on between researchers, they may be subject to interpretation. Future research may consider other means of reduction techniques of the physical, technical and tactical data or reduce metrics according to expert guidance. The addition of team-based drills is a unique inclusion compared to previous research describing the physical and technical demands of rugby league training (Chapter Two). However, training is often also comprised of other drills such as; warm ups, athletic development drills, individual / group skills, small sided games which are important for the preparation for performance but not assessed in this thesis. While drills included within these studies made up the vast

majority of training sessions, future research should aim to encompass all training drills to provide a robust understanding of the multifaceted demands in rugby league training.

Study two developed an assessment tool (training drill questionnaire) to identify the coaches tactical arrangement of on-field training drills. This tool was subsequently applied in study five to measure and quantify the tactical prescription of training. However, it is acknowledged that high performance coaches may have distinct philosophies, game-style, tactical strategies and training approaches based on past experiences and personal beliefs which may limit the wider application of this tool. A common barrier in high performance environments is the privacy of intellectual property and sharing of information. However, to overcome the small sample size (i.e., four high performance coaches), further validation of this tool with retired coaches or cross-referencing results with coaches from parallel competitions such as the English Super League is warranted. Additionally, due to the high-profile and competitive nature of the industry, a non-disclosure agreement was arranged to allow the primary researcher to take written notes in real-time during the interviews to capture collective responses. As recording devices were not used, methods were implemented to encourage accurate and quality data collection, however audio and video recordings would have provided full transcripts and negate the possibility of any missing data [139]. Also, key performance indicators (e.g., physical and technical) of coaches' tactical prescription and psychological explanations of coaches' ratings are beyond the scope of investigations within this thesis. Indeed, information on spatiotemporal characteristics, coordinated team movements and social network theories may be incorporated within future investigations to provide further outputs on tactical aspects within rugby league. While identifying key performance indicators may not be likely due to the complex interaction of tactics, physical, technical and psychological aspects within tactical periodisation frameworks, future research exploring whether key performance indicators can be utilised may be anticipated by coaches to discern whether manipulations and ratings tactical prescription elicits the desired outcomes.

9.4 Practical Applications

This thesis used an exploratory research design to initiate the provision of empirical evidence on tactical periodisation approaches and provide a systematic framework that can be applied by sport scientists to facilitate holistic preparation and monitoring within professional rugby league. The main practical applications from the findings of this thesis are:

- Study two describes a new approach to identify key metrics of how coaches plan and prescribe the tactical elements of training. Sports scientists can apply this approach to develop a practical tool that can be routinely implemented and integrated within the training preparation process to describe the magnitude and distribution of these elements. This allows new insights into the coaches' intention of training, and improves the collaboration between coaches and staff to design training and interpret training outputs.
- Study three of this thesis expands on previous research by providing descriptions of the physical, technical and tactical characteristics of training drills. Methods to monitor these aspects can be applied to inform high performance coaches on the evaluation of skill demands (e.g., the proportion of successful passes) and inform / manipulate training design according to tactical aims (e.g., the volume of time spent in attack, defence, transition and deadball periods or field position analysis).
- Sport scientists can apply statistical methods (i.e., principal component analysis and cluster analysis) to reduce complex data sets into integrated (i.e., 'holistic') components and discern the similarities and differences of the multifaceted demands between training drills. This information can be utilised for training planning, drill selection and distribution within periodisation phases.
- The development of a Match Difficulty Index (MDI) model within rugby league settings that can be applied by sports scientists and coaches to provide contextual information that may support periodisation and strategic approaches. For example, coaches may schedule player rotations within matches against low predicted difficulty opponents to manage individual player loads throughout the competition, or allow emerging players opportunity for professional game time.
- Identification of coaches' post-training responses may allow practitioners to be continually informed on improvement areas, enhancing coach – staff collaboration and player performance. For example, lower ratings of player execution responses may highlight the need for improvement in skill areas (e.g.,

kicking technique) or athletic development areas (e.g., agility in defensive movements).

- Quantifying the physical, technical and tactical demands of training drills and the coaches' prescription of tactical elements can collectively be applied to support a holistic preparation approach in professional rugby league. This is useful for practitioners as it considers the many aspects of performance in the way they are executed (i.e., integrated rather than siloed) and integrates important coach-led processes towards tactical training and preparation.

CHAPTER TEN

Thesis Summary and Recommendations

10.1 Thesis Summary

At the professional level, coaches and support staff in rugby league clubs collaborate to thoroughly prepare players for the specific demands and improve performance through careful prescription and manipulation of training. In particular, coaches emphasise tactical preparation, practice and execution of strategies within training due to its importance to successful match performance. Accordingly, training periodisation strategies concurrently develop the multifaceted physical, psychological and technical requirements of competition, and also have tactical principles as the central focus. When implemented effectively, this approach ensures that training is designed to meet the philosophies, strategy and game style desired by coaches (i.e., tactical periodisation). Anecdotally, these approaches are popular within team sports [20], but to date there is little empirical evidence describing or assessing the efficacy of this approach.

While there are many studies describing the physical demands of rugby league performance and others that have highlighted the importance of specific technical and tactical features for successful performance, Chapter Two identified gaps in understanding the multifaceted – physical, technical and tactical – demands of rugby league training. It was also apparent that there had been no investigations on how coaches plan and prescribe the tactical elements of training for preparation of performance according to their desired game style and philosophical approach. To address these shortcomings, study two (Chapter Three) developed a questionnaire tool to quantify and measure how coaches prescribe the tactical elements of training. Studies three (Chapter Four) and four (Chapter Five) investigated the multifaceted demands within rugby league training by describing and examining the variability of physical, technical and tactical components within team-based training drills. The questionnaire developed in study two was subsequently applied in study five (Chapter Six) to describe the coaches' tactical prescription during a competition season. Finally, studies six (Chapter Seven) and seven (Chapter Eight) extended on study five by examining the tactical prescription by coaches in in relation to difficulty of upcoming opponent. Figure 10.1 presents a summary of the main findings from the series of investigations included within this thesis.

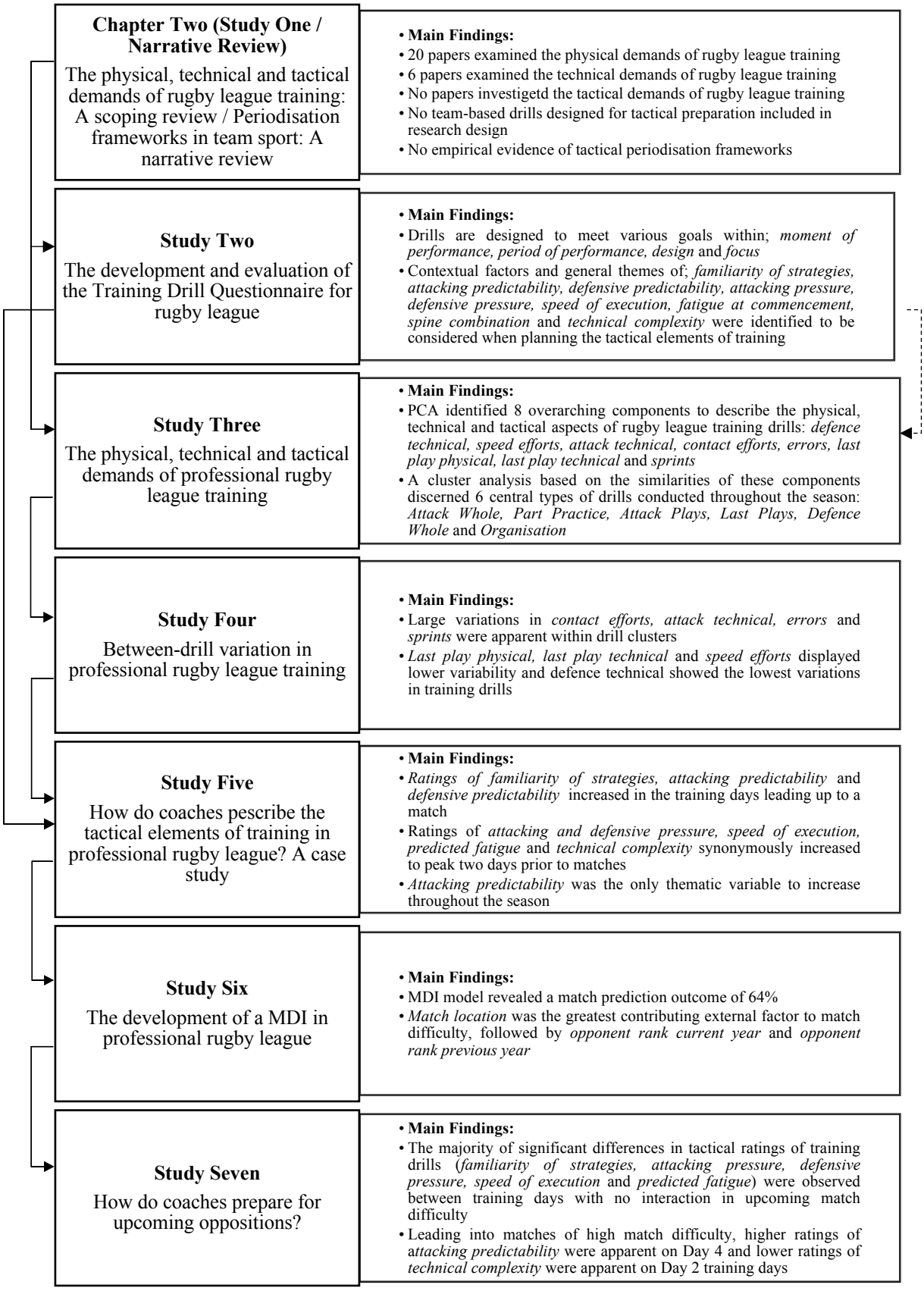


Figure 10.1 Summary of findings from the studies investigated in this thesis.

PCA principal component analysis, MDI Match Difficulty Index

Collectively, the findings from this thesis contribute new information to facilitate a holistic approach to the preparation for performance in professional rugby league (figure 10.2). Studies three and four extend on the previous knowledge base of physical and technical demands of rugby league training by including team-based training drills and incorporating the multifaceted – physical, technical and tactical – demands within their investigations. This thesis also provides novel insight into how coaches tactically plan, prescribe and arrange rugby league training through the implementation of semi-structured interviews. Previous research in team sport have noted key principles for the tactical periodisation framework [23, 24], but no empirical evidence existed. Accordingly, study two and study five provide innovative investigations to provide quantifiable evidence and descriptions of an implemented tactical prescription approach within rugby league. To provide further information how on contextual factors may influence this tactical prescription approach, study six developed a match difficulty index (MDI) model for professional rugby league and examined its relationship with upcoming oppositions of varying difficulty (i.e., study seven). This extends on previous MDI models developed in Australian Football and rugby union, and enhances our understanding on how coaches manipulate and account for external influences within their tactical prescription design. Accordingly, findings from this thesis can be utilised to support and inform training, monitoring and periodisation approaches to holistically prepare for rugby league performance.

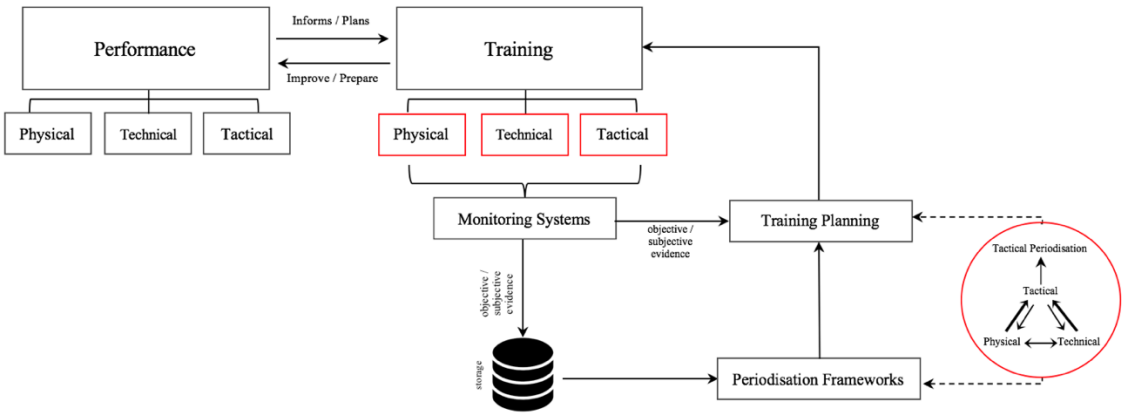


Figure 10.2 Highlighted contributions of this thesis (outlined in red) to the framework utilised to support training, periodisation and performance within professional rugby.

10.2 Impact Statement

This thesis provided a series of unique investigations to understand the physical, technical and tactical demands of rugby league training and examine how coaches tactically prescribe training for preparation throughout the competition season. Indeed, findings of this thesis contribute empirical evidence to support holistic training preparation frameworks in rugby league. The majority of data utilised in this study was collected from one, highly successful team of the National Rugby League competition. Accordingly, continual feedback on research findings and observations was provided to assist in the preparation of the team in order to optimise performance. During the data collection process, coaches reported that they were provided with detailed information within areas that haven't previously been collected or monitored in sports science practice.

Specifically, coaches were provided with reports (e.g., team technical statistics in training) and heat maps on the distribution of field positions within training drills to locate prominent practice areas or identify other focal areas are needed (e.g., possession areas of the field). Additionally, the time spent in different moments of the game (i.e., attack, defence, transition from defence to attack, transition from attack to defence) was provided to coaches to examine the time exposure players experience in training – something that "hasn't been done before" and has been continued to be utilised to ensure appropriate training dose within these areas.

Collecting and storing information gathered from the Training Drill Questionnaires provided a data log of tactical prescription, which was particularly useful to forecast periodisation design (e.g., when versing the same opponent for a second time in the competition) with many metrics continued to be implemented within session designs. Coaches also provided positive feedback when completing the Training Drill Questionnaires, stating the process assisted the review and "self-reflection" of their prescription and "enhanced accountability" in their training role. Furthermore, it was reported the process continually prompted feedback and conversations of how training was completed, generating proactive conversations to improve the design and delivery of future sessions, enhancing preparation.

10.3 Future Research Directions

Research questions within this thesis have been formed by identifying emerging themes and gaps within literature, and collaborative discussions with high performance coaches. The included studies sought to contribute to a holistic understanding and preparation approach within professional rugby league. Indeed, this thesis provides an investigative and innovative research approach and has provided significant information on the multifaceted demands of rugby league training as well as the investigating applied tactical prescription and periodisation frameworks. Future research is encouraged to expand on the current findings in this thesis and thereby contributing further information to support training, monitoring and periodisation approaches.

- This thesis provides new information to contribute a holistic preparation framework within professional rugby league. Such information can be utilised to inform monitoring, periodisation and training planning approaches (figure 10.2). However, it is acknowledged that findings are derived from one professional team within the National Rugby League (NRL) competition and may not be generalisable to other rugby league populations and team sporting contexts. Accordingly, it would be of interest for future research to employ the methods of these studies to different sport contexts including competition levels, other team sports (e.g., Australian Football, soccer, hockey) and collaborating with other NRL clubs.
- The Training Questionnaire tool developed in study two provides novel insight into how high performance coaches tactically theme and arrange training drills in rugby league. Furthermore, methods of this study provide a practical approach for future investigations to extract information on how coaches tactically plan and periodise training within other team sport contexts. However, directly applying the findings to the wider rugby league sporting community may be challenging due to the small sample size of participants included, differences in coaching philosophies, and approaches to training design. Accordingly, future research is encouraged to consider approaches to further validate aspects of the measurement tool. For example, including a variety of coaches from differing clubs and levels to provide robust understanding of tactical prescription and periodisation design.
- This thesis provides novel descriptions of an implemented tactical prescription and periodisation approach, however does not investigate its relationship to physical

and technical outputs. Future research identifying valid key performance indicators of the coaches prescription (e.g., relationship between collision intensity and rated opposition pressure) would allow direct assessment of coaches' intention with objective outcomes, establish meaningful changes and further validate tactical prescription variables.

- One of the tactical aims in professional rugby league is to establishing optimum field possession in attack, and protect this field territory in defence [2]. While study one provides field position descriptions of on-field training drills, it may be important to examine tactical behaviour strategies utilised to achieve field position. This could incorporate behaviours such as movements and patterns of playmakers, attacking shapes of positional groups and line spacing and player distribution in defence.
- A Principal Component Analysis (PCA) was conducted in study three to reduce physical, technical and tactical data to broad overarching components. While this technique is effective to encapsulate and simplify the complex interplay and quantity of factors, it does present some practical limitations for interpretation to coaches. Future research may consider other means of reduction techniques or collaborate with experts to reduce metrics, allowing practical information such as benchmarks and smallest worthwhile changes to be easily recognised and established.
- Data collection was conducted throughout one NRL competition season. Applying the methods of study two to study five to pre-season training phases would provide a greater contribution to understanding tactical preparation frameworks in rugby league. This is due to coaches introducing fundamental tactical principles and skills for individuals and team practice prior to the commencement of competition.
- Currently, empirical evidence of tactical periodisation frameworks and prescription remains in its infancy. Accordingly, this thesis presents a creative and innovative approach to understand its implementation in professional rugby league. Future research investigating this concept in rugby league as well as other team sports by validating the approach utilised in this thesis will help establish a viable tactical periodisation and preparation model in team sport.

SUPPLEMENTARY MATERIAL

Rugby League Training Drill Questionnaire

Pre-Training

Drill Name: _____ Coach Initials:

Section 1: Tactical Descriptor – *Place '1' to all that apply*

What quarter of match-play is this drill prescribed for?	First: 0 – 20 minutes	Second: 20 – 40 minutes	Third: 40 – 60 minutes	Last: 60 – 80 minutes
What moment of performance is this drill prescribed for?	Attack	Transition from Attack to Defence	Defence	Transition from Defence to Attack
Please indicate drill design	Scenario	Structure	Execution	
Which focus group is this drill predominately prescribed for?	Individual	Group	Team	

Figure S1 Excerpt from developed Training Drill Questionnaire (Hausler et al., 2022 study two).

Table S1 Physical velocity demands of rugby league on-field training drills.

Drill	Duration	Relative Distance	Maximum Velocity	High Speed Distance	Very High Speed Distance	Sprinting Distance	Minutes > 100 m·min^{-1}
	(min)	(m·min^{-1})	(m·s^{-1})	(m·min^{-1})	(m·min^{-1})	(m·min^{-1})	(n·min^{-1})
1	7.8 (2.9)	58.4 (17.3)	6.2 (1.2)	5.1 (3.8)	0.8 (1.3)	0.01 (0.05)	0.0 (0.0)
2	13.0 (5.4)	55.0 (19.0)	6.5 (1.1)	4.1 (3.4)	1.1 (1.5)	0.06 (0.25)	0.1 (0.1)
3	24.2 (9.1)	60.2 (15.0)	7.0 (0.7)	5.3 (3.1)	1.3 (1.7)	0.04 (0.22)	0.1 (0.1)
4	10.3 (0.4)	47.9 (15.5)	6.4 (1.2)	4.5 (3.9)	1.2 (1.8)	0.05 (0.26)	0.1 (0.1)
5	5.4 (0.0)	94.9 (19.6)	6.4 (0.6)	7.4 (4.3)	0.5 (0.7)	0.00 (0.00)	0.8 (0.2)
6	8.0 (0.0)	69.5 (16.4)	6.6 (1.2)	5.3 (4.3)	2.1 (2.6)	0.03 (0.15)	0.1 (0.1)
7	15.2 (0.0)	49.1 (15.9)	6.8 (1.0)	5.3 (4.3)	1.3 (2.6)	0.20 (0.84)	0.1 (0.1)
8	10.5 (0.0)	48.6 (3.8)	5.7 (0.6)	1.5 (1.1)	0.0 (0.1)	0.00 (0.00)	0.0 (0.0)
9	14.1 (3.8)	49.8 (20.8)	6.5 (0.9)	3.7 (3.2)	0.6 (1.0)	0.01 (0.08)	0.2 (0.1)
10	10.2 (6.1)	67.1 (21.0)	6.3 (1.1)	4.7 (3.7)	0.9 (1.5)	0.03 (0.20)	0.3 (0.2)
11	8.0 (3.8)	80.3 (20.2)	6.5 (0.9)	8.2 (5.2)	1.1 (1.9)	0.01 (0.13)	0.3 (0.2)
12	13.1 (0.0)	58.2 (15.4)	6.3 (0.7)	4.1 (3.8)	0.5 (1.0)	0.00 (0.00)	0.2 (0.2)
13	11.3 (2.5)	69.4 (16.0)	6.6 (0.6)	5.8 (3.4)	0.7 (1.1)	0.00 (0.04)	0.3 (0.2)
14	5.8 (1.6)	74.0 (14.2)	5.6 (0.9)	3.2 (3.7)	0.2 (0.7)	0.00 (0.00)	0.1 (0.1)
15	7.3 (0.0)	88.1 (6.9)	6.1 (0.7)	6.0 (5.3)	0.5 (1.1)	0.00 (0.00)	0.2 (0.2)
16	10.7 (0.0)	50.5 (10.1)	5.6 (0.6)	0.8 (1.7)	0.0 (0.0)	0.00 (0.00)	0.0 (0.1)
17	17.1 (10.5)	50.2 (16.6)	4.9 (0.7)	0.5 (1.3)	0.0 (0.0)	0.00 (0.00)	0.0 (0.1)
18	16.4 (2.6)	60.8 (13.8)	6.7 (0.8)	4.2 (3.0)	0.8 (1.4)	0.02 (0.12)	0.1 (0.1)
19	13.7 (4.7)	73.4 (14.4)	6.2 (0.8)	3.5 (3.4)	0.4 (0.6)	0.01 (0.07)	0.2 (0.2)
20	6.4 (1.7)	69.6 (19.2)	5.6 (1.0)	3.2 (4.4)	0.3 (1.2)	0.00 (0.05)	0.3 (0.2)
21	13.8 (0.0)	49.6 (18.1)	5.7 (0.7)	1.2 (1.5)	0.2 (0.4)	0.00 (0.00)	0.1 (0.1)
22	4.9 (0.0)	78.6 (17.2)	5.8 (0.5)	3.2 (2.6)	0.0 (0.0)	0.00 (0.00)	0.3 (0.2)
24	13.2 (3.3)	68.1 (21.7)	6.6 (1.0)	4.6 (3.3)	0.9 (1.4)	0.05 (0.25)	0.4 (0.2)

Table S2 Physical accelerometer demands of rugby league on-field training drills.

Drill	Player Load	Collisions	Impacts	Change of Direction	Accelerations	Decelerations	RHIE Bouts
	(AU·min^{-1})	(n·min^{-1})	(n·min^{-1})	(n·min^{-1})	(n·min^{-1})	(n·min^{-1})	(n·min^{-1})
1	4.8 (1.4)	0.10 (0.18)	0.04 (0.10)	0.31 (0.32)	0.36 (0.26)	0.07 (0.10)	0.11 (0.15)
2	4.7 (1.5)	0.07 (0.13)	0.05 (0.07)	0.27 (0.25)	0.34 (0.25)	0.10 (0.11)	0.16 (0.13)
3	5.3 (1.3)	0.14 (0.22)	0.12 (0.12)	0.43 (0.24)	0.57 (0.24)	0.18 (0.12)	0.22 (0.13)
4	4.2 (1.3)	0.09 (0.13)	0.09 (0.12)	0.34 (0.33)	0.38 (0.24)	0.11 (0.11)	0.11 (0.12)
5	8.8 (1.9)	0.29 (0.32)	0.33 (0.38)	0.59 (0.54)	0.60 (0.34)	0.17 (0.16)	0.38 (0.20)
6	6.0 (1.4)	0.08 (0.28)	0.08 (0.12)	0.26 (0.25)	0.57 (0.37)	0.13 (0.12)	0.26 (0.20)
7	4.3 (1.5)	0.09 (0.15)	0.05 (0.05)	0.29 (0.29)	0.40 (0.24)	0.18 (0.20)	0.19 (0.19)
8	4.0 (0.4)	0.04 (0.06)	0.02 (0.06)	0.16 (0.18)	0.33 (0.23)	0.16 (0.12)	0.06 (0.08)
9	4.5 (1.8)	0.02 (0.05)	0.03 (0.05)	0.24 (0.28)	0.25 (0.20)	0.13 (0.13)	0.14 (0.11)
10	6.0 (2.0)	0.11 (0.19)	0.09 (0.18)	0.41 (0.39)	0.35 (0.27)	0.15 (0.17)	0.19 (0.16)
11	7.3 (2.2)	0.11 (0.19)	0.10 (0.16)	0.35 (0.35)	0.36 (0.27)	0.15 (0.17)	0.18 (0.15)
12	4.9 (1.5)	0.02 (0.04)	0.02 (0.05)	0.22 (0.19)	0.21 (0.18)	0.11 (0.12)	0.12 (0.09)
13	6.4 (1.8)	0.17 (0.22)	0.17 (0.20)	0.49 (0.39)	0.38 (0.24)	0.14 (0.14)	0.27 (0.14)
14	6.6 (1.4)	0.09 (0.21)	0.05 (0.12)	0.48 (0.40)	0.39 (0.32)	0.06 (0.12)	0.11 (0.15)
15	8.0 (1.0)	0.11 (0.34)	0.04 (0.07)	0.45 (0.26)	0.39 (0.30)	0.07 (0.12)	0.19 (0.17)
16	4.4 (0.9)	0.02 (0.10)	0.01 (0.03)	0.12 (0.21)	0.12 (0.15)	0.02 (0.05)	0.02 (0.06)
17	5.2 (2.1)	0.06 (0.19)	0.02 (0.04)	0.25 (0.19)	0.22 (0.17)	0.03 (0.05)	0.07 (0.09)
18	5.6 (1.2)	0.19 (0.18)	0.16 (0.15)	0.58 (0.30)	0.52 (0.25)	0.14 (0.12)	0.26 (0.15)
19	6.8 (1.5)	0.14 (0.13)	0.07 (0.09)	0.55 (0.27)	0.37 (0.17)	0.08 (0.08)	0.23 (0.12)
20	7.1 (2.1)	0.23 (0.27)	0.13 (0.21)	0.63 (0.54)	0.35 (0.29)	0.12 (0.16)	0.19 (0.17)
21	5.0 (1.6)	0.14 (0.27)	0.08 (0.10)	0.53 (0.35)	0.29 (0.15)	0.03 (0.04)	0.19 (0.12)
22	7.7 (1.9)	0.30 (0.30)	0.20 (0.27)	0.77 (0.66)	0.45 (0.24)	0.12 (0.17)	0.22 (0.20)
24	6.5 (2.2)	0.20 (0.24)	0.17 (0.18)	0.52 (0.34)	0.35 (0.21)	0.12 (0.12)	0.26 (0.13)

Table S3 Tactical variables of rugby league on-field training drills.

Drill	Attack		Defence		Transition from Defence to Attack		Transition from Attack to Defence		Deadball	
	(min)	(%)	(min)	(%)	(min)	(%)	(min)	(%)	(min)	(%)
1	0.3 (0.4)	4 (7)	0.0 (0.1)	0 (1)	0.0 (0.0)	0 (0)	2.9 (1.6)	36 (16)	4.0 (1.5)	52 (14)
2	5.5 (0.6)	49 (18)	0.2 (0.1)	2 (1)	0.0 (0.1)	1 (1)	0.3 (0.2)	3 (3)	10.7 (0.6)	97 (38)
3	6.1 (2.3)	25 (1)	3.8 (2.8)	14 (10)	0.0 (0.0)	0 (0)	0.2 (0.3)	1 (1)	15.7 (3.5)	68 (9)
4	2.7 (0.9)	26 (8)	0.0 (0.1)	0 (0)	0.0 (0.0)	0 (0)	0.0 (0.0)	0 (0)	7.9 (1.1)	77 (12)
5	2.0 (0.0)	38 (0)	1.9 (0.0)	35 (0)	0.0 (0.0)	0 (0)	0.6 (0.0)	11 (0)	0.1 (0.0)	2 (0)
6	2.6 (0.0)	32 (0)	0.0 (0.0)	0 (0)	0.0 (0.0)	0 (0)	0.0 (0.0)	0 (0)	5.4 (0.0)	68 (0)
7	3.4 (0.0)	22 (0)	0.0 (0.0)	0 (0)	0.0 (0.0)	0 (0)	0.0 (0.0)	0 (0)	11.8 (0.0)	78 (0)
8	3.4 (0.0)	33 (0)	0.0 (0.0)	0 (0)	0.0 (0.0)	0 (0)	0.0 (0.0)	0 (0)	7.0 (0.0)	66 (0)
9	6.0 (0.0)	34 (0)	0.1 (0.0)	0 (0)	0.2 (0.0)	1 (0)	0.5 (0.0)	3 (0)	10.9 (0.0)	62 (0)
10	4.0 (2.2)	41 (6)	0.1 (0.2)	2 (2)	0.0 (0.0)	0 (0)	0.3 (0.2)	4 (2)	5.3 (4.3)	51 (26)
11	2.8 (1.0)	39 (17)	0.2 (0.2)	4 (4)	0.2 (0.2)	3 (1)	0.5 (0.2)	6 (2)	4.1 (2.9)	47 (19)
13	4.1 (1.0)	40 (16)	0.6 (0.7)	6 (7)	0.2 (0.1)	2 (1)	0.4 (0.3)	5 (3)	7.2 (2.5)	67 (33)
14	0.4 (0.2)	7 (3)	0.4 (0.3)	7 (4)	1.1 (0.3)	18 (5)	0.8 (0.5)	15 (8)	3.8 (1.3)	65 (6)
15	0.9 (0.0)	12 (0)	1.3 (0.0)	18 (0)	1.0 (0.0)	13 (0)	0.0 (0.0)	0 (0)	4.3 (0.0)	59 (0)
16	2.0 (0.0)	19 (0)	0.0 (0.0)	0 (0)	1.4 (0.0)	13 (0)	0.0 (0.0)	0 (0)	7.1 (0.0)	67 (0)
17	0.1 (0.1)	1 (1)	4.9 (0.1)	41 (21)	0.0 (0.0)	0 (0)	0.0 (0.0)	0 (0)	11.8 (10.1)	56 (21)
18	3.6 (1.8)	22 (12)	4.4 (0.9)	27 (7)	0.0 (0.1)	1 (1)	0.0 (0.0)	0 (0)	10.9 (2.6)	67 (15)
19	0.4 (0.2)	3 (1)	3.3 (1.6)	24 (7)	0.4 (0.3)	3 (3)	0.0 (0.0)	0 (0)	8.3 (5.4)	56 (37)
20	0.4 (0.5)	5 (5)	3.3 (0.9)	55 (18)	0.2 (0.3)	3 (3)	0.0 (0.0)	0 (0)	2.3 (1.4)	35 (18)
21	0.1 (0.0)	1 (0)	4.4 (0.0)	31 (0)	0.7 (0.0)	5 (0)	0.0 (0.0)	0 (0)	8.6 (0.0)	62 (0)
22	0.0 (0.0)	0 (0)	2.4 (0.0)	47 (0)	0.4 (0.0)	9 (0)	0.0 (0.0)	0 (0)	2.1 (0.0)	42 (0)
24	3.2 (1.0)	25 (6)	2.2 (1.1)	17 (7)	0.2 (0.2)	2 (1)	0.3 (0.2)	2 (2)	6.7 (2.0)	50 (7)

Table S4 Technical demands of rugby league on-field training drills.

Drill	Tackles Made	Successful Tackles	Tackles Received	Passes	Successful Passes	Receives	Play-The-Balls	Grubber Kicks	Attacking Kicks	Territory Kicks	Technical Errors	Tries Scored	Opposition Tries Scored
	(n·min^{-1})	(%)	(n·min^{-1})	(n·min^{-1})	(%)	(n·min^{-1})	(n·min^{-1})	(n·min^{-1})	(n·min^{-1})	(n·min^{-1})	(n·min^{-1})	(n·min^{-1})	(n·min^{-1})
1	0.0 (0.1)	58 (23)	0.0 (0.0)	6.7 (2.5)	97 (3)	8.3 (3.6)	2.7 (1.4)	1.0 (0.5)	1.4 (0.7)	0.2 (0.4)	0.1 (0.2)	2.0 (0.8)	0.0 (0.0)
2	0.1 (0.1)	28 (45)	1.9 (1.3)	8.3 (2.8)	95 (3)	8.7 (3.0)	3.6 (1.4)	0.2 (0.2)	0.3 (0.1)	0.1 (0.1)	0.1 (0.1)	0.6 (0.2)	0.0 (0.0)
3	1.4 (1.0)	25 (21)	1.9 (0.9)	4.9 (1.0)	91 (6)	5.0 (1.0)	2.2 (0.1)	0.1 (0.0)	0.0 (0.1)	0.0 (0.0)	0.2 (0.1)	0.4 (0.0)	0.0 (0.0)
4	0.1 (0.1)	31 (46)	1.7 (1.0)	5.0 (0.6)	92 (3)	5.1 (0.6)	2.0 (0.5)	0.1 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.0)	0.6 (0.2)	0.0 (0.0)
5	0.0 (0.0)	0 (0)	3.9 (0.0)	4.7 (0.0)	100 (0)	4.9 (0.0)	4.7 (0.0)	0.0 (0.0)	0.4 (0.0)	0.4 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
6	0.0 (0.0)	0 (0)	0.9 (0.0)	6.5 (0.0)	98 (0)	6.5 (0.0)	2.8 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
7	0.0 (0.0)	0 (0)	2.4 (0.0)	4.3 (0.0)	94 (0)	4.3 (0.0)	1.6 (0.0)	0.1 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.0)	0.0 (0.0)
8	0.0 (0.0)	0 (0)	0.0 (0.0)	4.6 (0.0)	98 (0)	4.5 (0.0)	2.9 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
9	0.1 (0.0)	0 (0)	2.7 (0.0)	5.1 (0.0)	96 (0)	5.3 (0.0)	2.3 (0.0)	0.1 (0.0)	0.2 (0.0)	0.0 (0.0)	0.2 (0.0)	0.1 (0.0)	0.0 (0.0)
10	0.1 (0.2)	29 (44)	2.3 (1.4)	6.8 (1.5)	95 (3)	7.1 (1.5)	2.6 (0.5)	0.2 (0.1)	0.2 (0.1)	0.0 (0.0)	0.1 (0.1)	0.4 (0.2)	0.0 (0.0)
11	0.3 (0.4)	64 (44)	2.2 (2.7)	6.1 (2.6)	97 (1)	6.6 (2.8)	3.2 (1.2)	0.1 (0.1)	0.1 (0.1)	0.4 (0.1)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)
13	0.9 (1.0)	37 (38)	1.8 (1.2)	5.8 (3.0)	97 (3)	6.1 (3.2)	3.1 (1.2)	0.1 (0.0)	0.1 (0.1)	0.2 (0.1)	0.1 (0.1)	0.3 (0.3)	0.0 (0.0)
14	1.2 (0.5)	30 (25)	0.4 (0.4)	3.4 (1.5)	82 (20)	4.9 (1.8)	1.6 (0.7)	0.9 (0.5)	0.4 (0.3)	0.0 (0.1)	0.3 (0.3)	0.0 (0.0)	0.0 (0.1)
15	1.5 (0.0)	73 (0)	0.0 (0.0)	0.7 (0.0)	60 (0)	1.8 (0.0)	0.3 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
16	0.8 (0.0)	22 (0)	1.4 (0.0)	1.8 (0.0)	90 (0)	2.4 (0.0)	1.2 (0.0)	0.0 (0.0)	0.1 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
17	1.5 (0.6)	77 (26)	0.0 (0.0)	0.1 (0.1)	57 (50)	1.7 (1.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
18	2.7 (0.9)	55 (13)	1.4 (0.8)	3.2 (2.0)	80 (26)	3.5 (2.0)	1.5 (0.9)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.1 (0.1)
19	2.2 (0.9)	61 (11)	0.3 (0.2)	0.2 (0.1)	100 (0)	0.4 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
20	4.3 (1.9)	67 (12)	0.4 (0.4)	0.3 (0.4)	29 (46)	0.8 (0.6)	0.2 (0.4)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.1 (0.1)
21	2.9 (0.0)	65 (0)	0.1 (0.0)	0.0 (0.0)	0 (0)	0.1 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.0)
22	3.2 (0.0)	75 (0)	0.0 (0.0)	0.0 (0.0)	0 (0)	0.2 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.0)	0.0 (0.0)	0.0 (0.0)
24	1.4 (0.6)	76 (21)	1.8 (0.7)	3.0 (1.1)	92 (14)	3.5 (1.0)	1.7 (0.5)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.2 (0.1)	0.1 (0.1)

Table S5 Principal Component Analysis factor loadings and correlation efficient of physical, technical and tactical variables (Hausler et al. 2022, study three).

Component:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Variance Explained:	15.18	13.09	9.73	9.08	6.54	6.02	5.57	5.04
Tackles Made	0.85							
Successful Tackles	0.68							
Total Passes	-0.65		0.59					
Grubber Kicks	-0.54				0.62			
Defence Minutes	0.85							
Try Scored	-0.76							
Opposition Try Scored	0.55				0.50			
Maximum Velocity		0.78						
High Speed Distance		0.83						
Very High Speed Distance		0.65						
Accelerations		0.72						
Decelerations		0.64						
Repeated High Intensity Efforts		0.53		0.60				
Tackles Received			0.84					
Attack Minutes			0.90					
Collisions				0.73				
Change of Direction				0.72				
Impacts				0.71				
Errors					0.83			
TDA Minutes						0.81		
Player Load						0.57		
Passing Percentage							-0.76	
Territory Kicks							0.71	
Sprinting Distance								0.87

TDA: Transition from defence to attack minutes, Component 1: Defence Technical, Component 2: Speed Efforts, Component 3: Attack Technical, Component 4: Contact Efforts, Component 5: Errors, Component 6: Last play Physical, Component 6: Last Play Technical, Component 8: Sprints

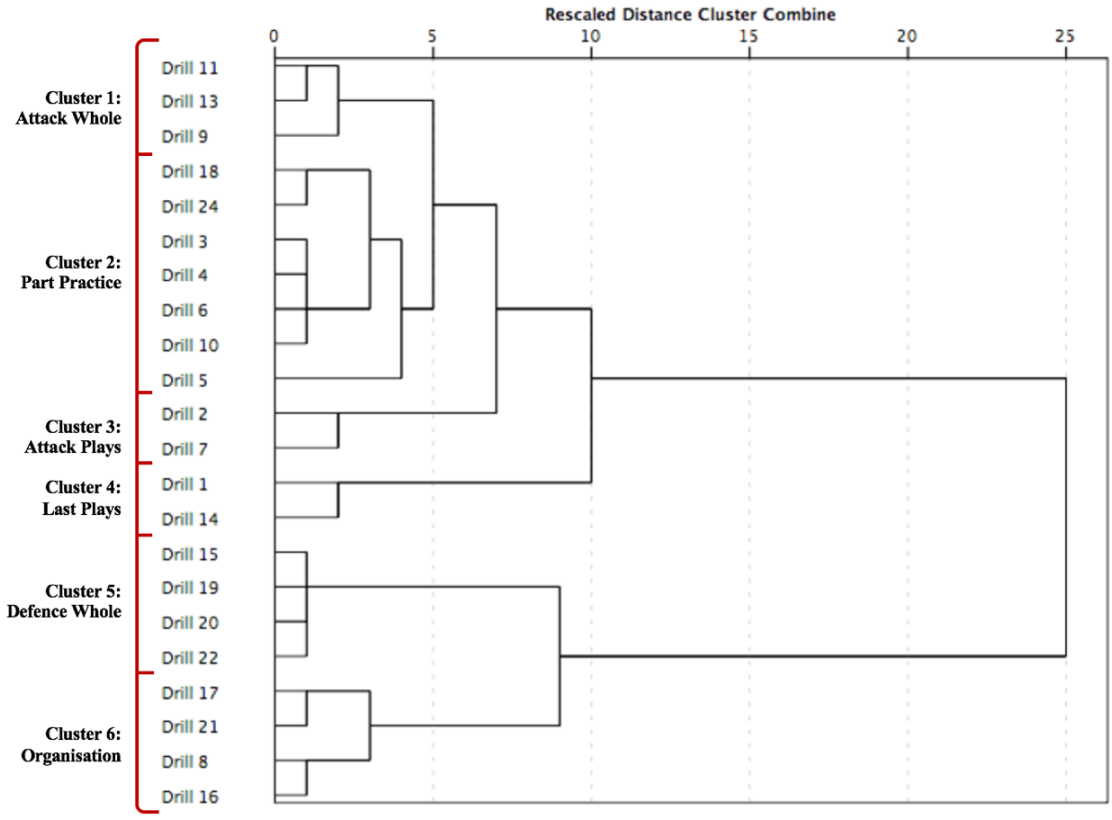


Figure S2 Wards agglomerative hierarchical cluster analysis illustrated by dendrogram for the six identified components (Hausler et al. 2022, study three).

Table S6 Categories, sub-categories and definitions of how training drills are assigned.

Category	Sub-Categories	Definition
Period of Performance	0 – 20 minutes	First quarter of the match
	20 – 40 minutes	Second quarter of the match
	40 – 60 minutes	Third quarter of the match
	60 – 80 minutes	Fourth or final quarter of the match
	0 – 80 minutes	Whole match
Moment of Performance	Attack	In possession of the ball
	Defence	When the opposition is in possession of the ball
	Transition from Attack to Defence	The moment of transferring possession of the ball to the opposition
	Transition from Defence to Attack	The moment of receiving possession of the ball from the opposition
Drill Design	Structure	Arrangement of the team
	Execution	Carrying out the skill elements necessary for the tactical action
	Scenario	Preparation for predicted match events or scenes
Drill Focus	Team	All members
	Group	A number of persons classed together e.g., forwards, outside backs
	Individual	Particular persons

Table S7 Descriptors of tactical variables included in the Training Drill Questionnaire.

Tactical Variable	Descriptor
Familiarity of Strategies	How well-known is the desired plan of action for the team in this drill?
Attacking Predictability	As a defender in this drill, how well do you know or pre-empt how the opposition will attack? This can be related to set pieces, strengths and weaknesses, style-of play and common characteristics of the opposition
Defensive Predictability	As an attacker in this drill, how well do you know or pre-empt how the opposition will defend? This can be relating to set pieces, strengths and weaknesses, style-of play and common characteristics of the opposition
Spine Combination	Is this drill targeted for interaction and coordination between the playmaker positions of the team (hooker, fullback, halfback and five-eight)?
Attacking Pressure	When in defence, how difficult does the opposition's attack (i.e., by push, force, player presence) make it to execute the drill?
Defensive Pressure	When in attack, how difficult does the opposition's defence (i.e., by push, force, player presence) make it to execute the drill?
Speed of Execution	How fast is this drill required to be carried out?
Fatigue of Commencement	How much physical and/or mental exhaustion do you anticipate players to be at the start of this drill?
Technical Complexity	How difficult, or how much risk is associated with the skill actions required in this drill? Technical actions can include, passes, receives, tackles, kicks and play-the-balls

Rugby League Training Drill Questionnaire

Pre-Training

Drill Name: _____ Coach Initials:

Section 1: Tactical Descriptor – *Place '1' to all that apply*

What quarter of match-play is this drill prescribed for?	First: 0 – 20 minutes	Second: 20 – 40 minutes	Third: 40 – 60 minutes	Last: 60 – 80 minutes
What moment of performance is this drill prescribed for?	Attack	Transition from Attack to Defence	Defence	Transition from Defence to Attack
Please indicate drill design	Scenario	Structure	Execution	
Which focus group is this drill predominately prescribed for?	Individual	Group	Team	

Section 2: Tactical Variables – *mark a small vertical dash to represent the intensity of each variable*

Familiarity of required strategies	*Completely new*	_____	*Autonomous*
Attacking Predictability	*Unpredictable*	_____	*Predictable*
Defensive Predictability	*Unpredictable*	_____	*Predictable*
Attacking Pressure	*Unopposed*	_____	*Game-like*
Defensive Pressure	*Unopposed*	_____	*Game-like*
Speed of Execution	*Static*	_____	*Greater than match-pace*
Fatigue at Commencement of Drill	*RPE 0/10*	_____	*RPE 10/10*
Spine Combination	*No connection*	_____	*Connection between all members*
Technical Complexity	*Extremely easy*	_____	*Extremely difficult*

Post-Training

Section 3: Post-Training – *mark a small vertical dash to represent the intensity of each variable*

1. *Overall how satisfied are you with the training drill?*

Extremely unsatisfied _____ Extremely satisfied

2. *Was the training drill implemented as intended?*

Nothing went as planned _____ Everything went exactly as planned

3. *Did players execute as expected within this drill?*

Did not execute as expected _____ Exceeded expectation

Figure S3 Training Drill Questionnaire.

Table S8 Lower and Upper VAS End-points for tactical variables and post training questions included in the Training Drill Questionnaire.

Lower VAS End-point	Variable	Upper VAS End-point
Completely new	**Familiarity of required strategies**	Autonomous
Unpredictable	**Attacking predictability**	Predictable
Unpredictable	**Defensive predictability**	Predictable
Unopposed	**Attacking pressure**	Game-like
Unopposed	**Defensive pressure**	Game-like
Walk-through/static	**Speed of execution**	Greater than game-pace
RPE 0/10	**Fatigue at commencement of drill**	RPE 10/10
No connection between spine positions	**Spine combination**	Connection between all spine positions
Extremely easy	**Technical Complexity**	Extremely difficult
Extremely unsatisfied	**Overall satisfaction of the training drill**	Extremely satisfied
Nothing went as planned	**Was the training drill implemented as intended?**	Everything went exactly as planned
Did not execute as expected	**Did players execute as expected in this training drill?**	Execution exceeded expectations

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APPENDIX

Appendix One: Human Research Ethics Committee Approval

HREC Approval Granted – ETH16-1074

Dear Applicant

Thank you for your response to the Committee's comments for your project titled, "Factors Affecting Preparation and Performance in Professional Rugby League". Your response satisfactorily addresses the concerns and questions raised by the Committee who agreed that the application now meets the requirements of the NHMRC National Statement on Ethical Conduct in Human Research (2007). I am pleased to inform you that ethics approval is now granted.

Your approval number is UTS HREC REF NO. ETH16-1074.

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

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

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

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

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

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

Yours sincerely,

Associate Professor Beata Bajorek
Chairperson
UTS Human Research Ethics Committee
C/- Research & Innovation Office
University of Technology, Sydney
E: Research.Ethics@uts.edu.au

Appendix Two: Participant Consent Form

INFORMED CONSENT FORM
***FACTORS AFFECTING PREPARATION AND PERFORMANCE IN RUGBY LEAGUE*,**
UTS HREC REF NO. ETH16-1074

I,_____ *(participant's name),* agree to participate in the research project **"Factors affecting preparation and performance in professional rugby league"**, being conducted by Joanne Hausler and supervised by Professor Aaron Coutts, University of Technology Sydney.

I understand the purpose of this study is to investigate the physical, technical and tactical constructs of rugby league training and performance to help facilitate training periodization and recovery processes.

I understand that physical performance data will be collected during training and competitive match-play during the 2017-19 season. I understand that participants in this study are required to wear Global Positioning System (GPS) devices and heart rate monitors during training and competition matches. I understand I will be required to provide physiological samples (i.e. a small capillary blood sample), biological material (urine and saliva), nutrition and sleep characteristics. I understand that participants in this study will be required to complete regular performance tests to assess speed, strength, power and aerobic fitness. I acknowledge that the procedures and any associated risks of the listed above have been provided to me in the 'Participant Information Sheet'.

I agree to be: ☐ Video recorded

I am aware that I can contact Joanne Hausler (ph: [redacted], email: JoanneH@sydneyroosters.com.au) or Professor Aaron Coutts (ph: [redacted], email Aaron.Coutts@uts.edu.au) at any time if I have any concerns about the research. I understand that participation is voluntary and I am free to withdraw my research participation at any time without giving a reason. Furthermore, my withdrawal from the research project will not prejudice my selection or current standing within the Eastern Suburbs District Rugby League Football Club.

I agree that Joanne Hausler and/or Professor Aaron Coutts have answered all my questions fully and clearly. I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

_____ _____
Signed by Date

_____ _____
Witnessed by Date

NOTE: This study has been approved by the University of Technology Sydney Human Research Ethics Committee (UTS HREC). If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretary on ph: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au, and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

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Appendix Three: Participant Information Sheet

PARTICIPANT INFORMATION SHEET
FACTORS AFFECTING PREPARATION AND PERFORMANCE IN PROFESSIONAL RUGBY LEAGUE
UTS HREC REF NO. ETH16-1074

WHO IS DOING THE RESEARCH?
The research is conducted by Joanne Hausler who is a PhD Student at the University of Technology, Sydney. Joanne is supervised by Professor Aaron Coutts.

WHAT IS THIS RESEARCH ABOUT?
This research project will examine the physical, technical and tactical constructs of training load and recovery strategies on player performance in rugby league. It is the hope that this project will help facilitate training periodisation and recovery processes.

IF I SAY YES, WHAT WILL IT INVOLVE?
In addition to the usual training monitoring tools that are completed on a daily basis (i.e. pre-screening, wellness and RPE questionnaires, GPS and HR analysis, video recording) participants may also be required to provide:

- A small capillary blood sample retrieved by pricking the fingertip or earlobe with a standard lancet. Approximately 30uL (or 3 droplets) is obtained.
- Saliva samples. These are provided via s swab from the inside of the mouth to determine hormone concentrations such as cortisol and testosterone.
- Nutrition characteristics. Body composition will be analysed using the Dual Energy X-Ray Absorptiometry (DEXA) scan. Dehydration will be assessed through a Refractometer.
- Sleep characteristics provided through 'ActiGraph' sleep watches

Participants will also be required to complete regular performance tests to assess speed (e.g. 10, 20 and 40m sprint), strength (e.g. 1RM and 3RM tests), power (e.g. countermovement jump) and aerobic fitness (e.g. Yo-yo intermittent recovery test).
Retrieval of the above does not exceed the common and general practices performed within professional sporting organisations, clubs and institutes.

ARE THERE ANY RISKS/INCONVENIENCE?
Yes, there are some risks/inconvenience.
There is a risk of infection from the blood sample however is very small. Slight pain or discomfort may be experienced. Some participants may experience dizziness or nausea at the sight of blood, as such participants will be pre-screened and monitored closely. Proper protocols for collection disposal and hygiene will be adhered to.
DEXA scans involve the use of ionizing radiation to obtain body composition and therefore exposure is unavoidable. However, the occurring effect of the dose in this project is negligible. Participants will be exposed to at most 0.5% of the cumulative effect dose recommended in one year.

WHY HAVE I BEEN ASKED?
You have been asked to participate because you are a contracted player with the Eastern Suburbs District Rugby League Football Club (ESDRLFC) and the club has funded this project.

DO I HAVE TO SAY YES?
You don't have to say yes. Participation in this research is completely voluntary.

WHAT WILL HAPPEN IF I SAY NO?
Nothing. I will thank you for your time so far and won't contact you about this research again. Furthermore, it will have no effect on your selection or current standing within the ESDRLFC.

IF I SAY YES, CAN I CHANGE MY MIND LATER?
You may withdraw from this research project at any time without prejudice. Furthermore, it will have no effect on your selection or current standing within the ESDRLFC.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?
If you have concerns about the research please feel free to contact Joanne Hausler (ph [redacted], email: JoanneH@sydneyroosters.com.au) or Professor Aaron Coutts (ph [redacted] email: Aaron.Coutts@uts.edu.au).

If you would like to talk to someone who is not connected with the research, you may contact the Research Ethics Officer on 02 9514 9772, and quote this number **ETH16-1074**

This information sheet is for you to keep THINK.CHANGE.DO

Appendix Four: Module 1 Certification of Completion

Research Integrity for Students

Certificate of Completion

This is to certify that

Jo Hausler

has successfully completed

Module 1: Research Integrity and Code of Conduct

Production Note:
Signature removed
prior to publication.

Professor Lori Lockyer,
Dean, Graduate Research School

University of Technology Sydney

Date: *29/05/2018*

Appendix Five: Module 2 – 5 Certification of Completion

Research Integrity for Students

Certificate of Completion

This is to certify that

Jo Hausler

has successfully completed

Module 2: Plagiarism and Misconduct
Module 3: Risk Assessment
Module 4: Risk Management and Health & Safety
Module 5: Project Management

Production Note:
Signature removed
prior to publication.

Professor Lori Lockyer,
Dean, Graduate Research School

University of Technology Sydney

Date: *29/05/2018*