FACTORS AFFECTING PERFORMANCE IN PROFESSIONAL RUGBY LEAGUE

Thomas Kempton

Bachelor of Human Movement Studies (Honours)

Faculty of Health

University of Technology Sydney

Australia

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"Doctors and scientists said breaking the four-minute mile was impossible, that one would die in the attempt. Thus, when I got up from the track after collapsing at the finish line, I figured I was dead."

Roger Bannister

DECLARATION

I certify that the work contained in this thesis has not been previously submitted either in whole or in part for a degree at the University of Technology, Sydney or any other tertiary institution.

I also certify that the thesis has been written by me, Thomas Kempton. Any help that I have received in my research work and in the preparation of this thesis has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Thomas Kempton

5 February, 2016

Date

PREFACE

This thesis for the degree of Doctor of Philosophy is in the format of published or submitted manuscripts and abides by the 'Procedures for Presentation and Submission of Theses for Higher Degrees – University of Technology, Sydney; Policies and Directions of the University'. All manuscripts included in this thesis are closely related in subject matter and form a cohesive research narrative.

Based on the research design and data collected by the candidate, five manuscripts have been accepted for publication and a further two have been submitted in peer-reviewed journals. These papers are initially brought together by an *Introduction*, which provides background information, defines the research problem and the aim of each study. A *Literature Review* then follows to provide an overview of previous knowledge regarding physical, technical and tactical components of rugby league match performance. The body of the research is presented in manuscript form (*Chapter Three to Chapter Nine*), in a logical sequence following the development of research ideas in this thesis. Each manuscript outlines and discusses the individual methodology and the findings of each study separately. The *General Discussion* chapter provides an interpretation of the collective findings, makes some practical recommendations and acknowledges the limitations from the series of investigations that comprise this thesis. Finally, a *Summary and Recommendations* chapter presents the conclusions from each project and directions for future research to build on the findings of this thesis are suggested. The APA 6th reference style has been used throughout the document and the reference list is at the end of the thesis.

ACKNOWLEDGEMENTS

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LIST OF ARTICLES SUBMITTED FOR PUBLICATION

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- **Kempton, T**., Sirotic, A., Rampinini, E., & Coutts, A.J. (2015). Metabolic power demands of rugby league match-play. International Journal of Sports Physiology and Performance, 10(1), 23-28.
- **Kempton, T**., Kennedy, N., & Coutts, A.J. (2015). The expected value of possession in professional rugby league match-play. Journal of Sports Sciences, *in press*. doi: 10.1080/02640414.2015.1066511
- **Kempton, T**., & Coutts, A.J. (2015). Technical performance indicators related to winning professional rugby league matches. Journal of Sports Sciences, *in review*.
- **Kempton, T**., Sirotic, A., & Coutts, A.J. (2015). An integrated analysis of match-related fatigue in professional rugby league. Journal of Sports Sciences, 33(1), 39-47.
- **Kempton, T**., Sirotic, A., & Coutts, A.J. (2015). A comparison of physical and technical performance profiles between successful and less-successful professional rugby league teams. International Journal of Sports Physiology and Performance, *in review*.

ABSTRACT

Rugby league is a physically demanding, high-intensity team sport that is played professionally in several countries worldwide. In addition to high physical demands – which are characterised by high speed running, rapid accelerations and frequent collisions – rugby league players also require specific technical and tactical competencies during match-play. A conceptual model of performance for team sports has been proposed where match outcome is considered as the overall performance indicator, and it is thought to be contingent on three key constructs; technical, tactical and physical performance. This thesis contains seven independent studies which develop this conceptual model and investigate the factors that affect match performance in rugby league. *Study One* investigated the typical variability and smallest worthwhile changes in common performance indicators. These findings have implications for determining sample size, identifying reliable performance measures and selecting appropriate time periods for future applied studies that involve observational match analysis. The *second study* examined the independent effects of match-related and individual player characteristics on running performance in professional rugby league matches. There was a complex interplay of factors affecting match-running performance in rugby league. The results underline the importance of considering contextual factors when analysing rugby league match-activity profiles. The next three studies developed rugby league specific causal indicators of both physical, tactical and technical performance constructs. *Study Three* adopted a new "metabolic power" approach for analysing time-motion data which considers the cost of accelerated running efforts. The results showed that the analysis of metabolic power may complement traditional speed-based classifications and improve our understanding of the demands of rugby league match-play. *Study Four* estimated the expected point value for starting possessions in different field locations during rugby league match-play and calculated the mean expected points for each subsequent play during the possession. The results showed that possessions commencing close to the opposition's goal line had the highest expected point equity, which decreased as the location of the possession moved towards the team's own goal line. The expected point values framework from the model has applications for informing playing strategy and assessing individual and team performance in professional rugby league. *Study Five* examined the variability and association with the probability of winning for technical performance indicators over 384 matches from two National Rugby League seasons. This study identified important technical performance indicators related to winning rugby league matches which can be used to guide match analyses, and inform playing and training strategies. The *Sixth study* examined the changes in external outputs, including metabolic power variables, and internal response whilst considering contextual factors on physical performance variables during rugby league match-

play. The results showed temporal changes in physical performance, heart-rate response and collisions during rugby league match-play, although these are affected by contextual factors. *Study Seven* compared a range of physical, tactical and technical performance parameters between a successful and a less-successful rugby league team to determine which performance constructs are most related to winning. There were differences in physical and technical performance indicators between the two teams, with the successful team performing less running and fewer collisions but superior technical performance during the match. This thesis examined the physical, tactical and technical constructs of match performance in professional rugby league. It demonstrated that these constructs are often variable and contextual factors need to be considered when analysing match profiles. Indeed, valid and reliable parameters are required to represent the respective performance constructs when assessing overall match performance. Further, the validity of performance measures can be established by demonstrating their relationship with successful match performance. However, increased physical output is not associated with either winning individual matches or obtaining a high final competition ranking; rather, technical proficiency is likely a more important determinant of success in professional rugby league.

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LIST OF ABBREVIATIONS AND ACRONYMS

$\%HR_{peak}$	Percentage peak heart rate
χ^2	Chi square
ANOVA	Analysis of variance
$b \cdot min^{-1}$	Beats per minute
CI	Confidence interval
CV	Coefficient of variation
ES	Effect size
ESL	European Super League
GPS	Global positioning satellite
HSR	High-speed running
HSR:Trimp	High-speed running:training impulse ratio
HP	High-power
Hz	Hertz
ICC	Intra-class correlation coefficient
kg	Kilograms
$kJ \cdot kg^{-1}$	Kilojoules per kilogram
$km \cdot h^{-1}$	Kilometres per hour
LPM	Local position measurement
LSR	Low-speed running
m	Metres
m^2	Metres squared
min	Minutes
$m \cdot min^{-1}$	Metres per minute
$m \cdot s^2$	Metres per second squared
MRS	Maximal running speed
NRL	National Rugby League

NSW Cup	New South Wales Cup
NYC	National Youth Competition
P_{met}	Average metabolic power
r	Pearson's correlation coefficient
RHIE	Repeat high-intensity efforts
RMSE	Root-mean-square error
Q Cup	Queensland Cup
s	Seconds
SD	Standard deviation
SWC	Smallest worthwhile change
TD:TRIMP	Total distance:training impulse ratio
TRIMP	Training impulse
VHSR	Very high-speed running
$W \cdot kg^{-1}$	Watts per kilogram
y	Years
Yo-Yo IRT1	Yo-Yo Intermittent Recovery Test Level 1

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CHAPTER ONE

INTRODUCTION

BACKGROUND

Rugby league is a high-intensity, intermittent, collision-based team sport requiring well developed physical capacities and technical skill capabilities. Match performance in professional rugby league involves a complex interplay between physical, technical and tactical performance constructs. Sport scientists and analysts seek to develop valid and reliable physical and technical parameters to represent these different performance constructs. However, understanding the relationship between these parameters and their performance constructs, as well as the factors that influence them remains unclear.

While original methods from conducting time-motion analyses in team sports were laborious and time consuming (Carling, Bloomfield, Nelsen, & Reilly, 2008), in recent years there has been an uptake of micro-technologies such as global positioning satellite (GPS) systems by many National Rugby League (NRL) clubs – based in Australian and New Zealand – to monitor physical performance during training and matches, and time-motion profiles obtained from these devices are commonly used in applied rugby league research studies. Quantifying technical skill involvements during match-play was also traditionally a time consuming, labour intensive process requiring manual notation of individual player actions. The laborious methods for collecting skill involvement data presented a barrier for establishing large technical performance databases from competition matches. However, in recent years a number of commercial statistic services have emerged, and now provide detailed player action data for many team sports including rugby league. Increases in the availability of detailed match data permit more sophisticated analyses of technical and tactical data than was previously possible in team sports.

It has been suggested that match outcome in team sports such as rugby league is contingent on a combination of physical, technical (individual skills) and tactical (interaction with other individuals) performance (Impellizzeri & Marcora, 2009). There is an emerging body of applied rugby league research which has examined match performance by investigating the physical, technical and tactical constructs of rugby league match-play. These constructs of performance are difficult to measure directly; instead research has used causal indicators to represent relevant performance constructs. For example, speed-based distances derived from time-motion analysis during match-play have been employed as the causal indicator of the physical performance construct. While determining the typical activity profiles provides information regarding the demands of match-play, it is important to establish whether these causal indicators provide valid representations of their associated performance constructs (Impellizzeri & Marcora, 2009). However, few studies have examined the relationship between physical performance parameters

and match success during rugby league match-play. These studies have presented conflicting findings, with some suggesting that competitive advantage is linked to a team's ability to maintain a higher playing intensity than their opposition (Gabbett, 2013a), while other studies state that superior technical performance, not greater total and higher-speed running distances, are related to competitive success (Hulin, Gabbett, Kearney, & Corvo, 2015).

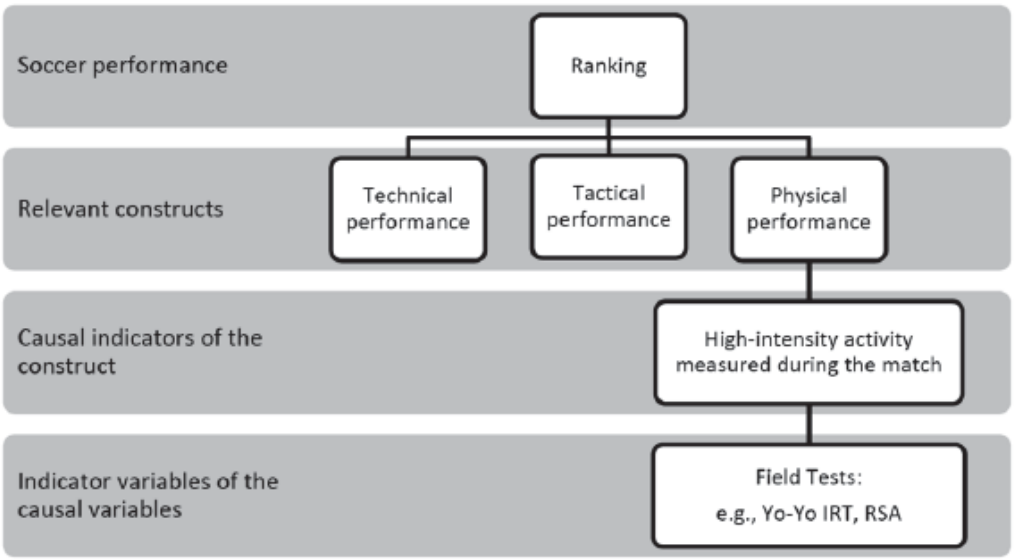

Figure 1.1: Conceptual model of soccer performance (Impellizzeri & Marcora, 2009)

Unfortunately, few studies have examined technical performance in professional rugby league, and the performance indicators that are related to successful match performance are yet to be elucidated. Furthermore, comparing physical and technical performance profiles between or within teams is challenging due to the large between-match variation in some performance measures, particularly higher-speed activities, which requires a large sample of match observations in order to detect true differences in performance variables (Gregson, Drust, Atkinson, & Di Salvo, 2010; Kempton, Sullivan, Bilsborough, Cordy, & Coutts, 2015). In addition, it is important to account for the confounding effects of contextual factors – such as match location, opposition strength and time in possession – which may influence performance indicators during team sport match-play (Carling, 2013). Moreover, many observational studies draw multiple samples from a single player over the course of a season which results in dependent data and violates the assumption of independence underpinning many statistical analyses (Wilkinson & Akenhead, 2013). To enhance current understanding of match performance constructs in rugby league, additional research using large match file samples and statistical methods that can account for dependent data samples are required.

RESEARCH QUESTION

Performance in team sports such as rugby league - measured using match-outcome or final league ranking – consists of physical, technical and tactical constructs. Despite an emerging body of research examining elements of match performance in rugby league, most of these studies have only observed physical performance profiles. There have been few studies to comprehensively examine technical and tactical components of performance in rugby league, despite evidence from other football codes suggesting that they may be more important determinants of match outcome than physical performance. Additionally, many studies of rugby league match performance have been limited by small sample sizes, the use of statistical techniques that are unable to account for dependency of match observation data, or were conducted in semi-professional competition matches. The purpose of this thesis is to develop an integrated model of match performance in professional rugby league. The model will consider physical, technical and tactical constructs of performance, whilst addressing some of the methodological limitations of previous applied rugby league match analysis studies.

RESEARCH OBJECTIVES

A series of applied research studies were conducted to develop a multi-factorial model of performance for professional rugby league. The first study examined the typical between-match variation of common physical performance parameters during rugby league match-play. The second study further explored this concept by examining the independent effects of a variety of match-related factors on selected measures of physical performance. Studies three, four and five developed new parameters to enhance current understanding of physical, tactical and technical performance during rugby league match-play, respectively. The sixth study adopted an integrated approach to examine the onset of match-related fatigue during rugby league competition. The final study determined the physical and technical/tactical parameters that were most related to successful match performance. The analyses in this thesis are a combination of single club case studies using data collected by the primary research team (studies one, two, three, six and seven) and broader analyses of all teams across the NRL competition using data obtained from commercial data coding providers (studies four and five).

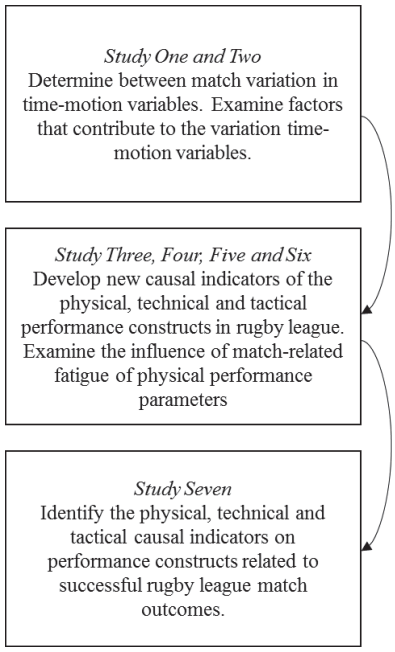

Figure 1.2: Research process linking the studies undertaken in this thesis.

STUDY 1: BETWEEN MATCH VARIATION IN PROFESSIONAL RUGBY LEAGUE COMPETITION

AIM:

The aims of this study were to: 1) determine the typical between match variability of common physical performance measures; and, 2) examine variability during sub-periods (i.e. 10 or 20 min epochs of play) of competition matches in professional rugby league.

SIGNIFICANCE:

These findings will have implications for determining sample size, identifying reliable performance measures, selecting appropriate time periods and assist in interpreting worthwhile changes in performance for analyses of rugby league match time-motion profiles.

STUDY 2: FACTORS AFFECTING EXERCISE INTENSITY IN PROFESSIONAL RUGBY LEAGUE MATCH-PLAY

AIM:

The purpose of this study was to use a mixed models approach to examine the independent effects of match location, season phase, recovery period length between matches, opposition strength (based on final ranking), match-outcome, time the ball is out of play, player technical

involvements and player fitness status on both total and high-speed relative distance during professional rugby league match-play.

SIGNIFICANCE:

An improved understanding of the influence of these factors on measures of physical performance is important to enhance the interpretation of time-motion analyses and assist teams in preparing for rugby league match-play.

STUDY 3: METABOLIC POWER DEMANDS OF RUGBY LEAGUE MATCH-PLAY

AIM:

The aims of this study were to: 1) describe the metabolic demands of rugby league match-play for different positional groups; 2) compare match distances obtained from traditional high-running speed classifications with those derived from metabolic power calculations; 3) estimate the energy expenditure during competition matches for different positional groups; and, 4) determine the between match variability of selected metabolic power derived parameters.

SIGNIFICANCE:

While several studies have estimated the metabolic demands of other team sports, no studies have assessed the metabolic demands associated with rugby league match-play. This information may provide greater insight into the positional demands of rugby league match-play and can assist in developing training programs.

STUDY 4: THE EXPECTED VALUE OF POSSESSION IN PROFESSIONAL RUGBY LEAGUE MATCH-PLAY

AIM:

The aims of this study were to: 1) establish the expected points value for the first play in possession for all field areas; 2) estimate mean expected points values based on distance from own goal-line for each of the five plays in a possession; 3) compare the actual points scored in a season to the expected points in an out of sample data set; and 4) examine the origin of tries scored according to the method of gaining possession.

SIGNIFICANCE:

While the expected value of possession has been investigated in team sports such as American football, Australian football and basketball, there is currently little understanding of the situational value of possession in rugby league. This type of information has important

applications for informing playing strategies and directing training programmes, assessing in-game decision making and for rating individual and team performances.

STUDY 5: TECHNICAL PERFORMANCE INDICATORS RELATED TO WINNING PROFESSIONAL RUGBY LEAGUE MATCHES

AIM:

The aims of the present study were to: 1) identify the association between technical performance indicators and the probability of winning NRL competition matches; 2) establish reference values for these performance indicators in NRL competition matches; and, 3) describe the typical between and within-team variation of these factors throughout the observation period.

SIGNIFICANCE:

While important technical performance indicators that affect the probability of winning have been identified in other football codes, no such information exists for professional rugby league. Although technical performance indicators relating to maintaining possession, gaining field position and defending opposition possessions are important in rugby league match-play, the effect of these actions on the probability of winning matches has not been established. A better understanding of the most important performance indicators can be used to guide the analysis of match performances, and may be extended to inform playing strategies and direct training programs.

STUDY 6: AN INTEGRATED ANALYSIS OF MATCH-RELATED FATIGUE IN PROFESSIONAL RUGBY LEAGUE

AIM:

The aims of this investigation were to: 1) examine the relationship between external demands and internal physiological (heart-rate) response during rugby league match-play; 2) describe temporal changes in metabolic power derived variables during rugby league match-play; and 3) examine the influence of contextual factors on physical performance variables during rugby league match-play.

SIGNIFICANCE:

While an increasing number of studies have examined match-related fatigue in rugby league and other team sports, a criticism of many studies of match-related fatigue is the failure to account for the numerous extrinsic factors influencing time-motion data such as opposition strength, substitutions, possession, and time the ball is in play on time course changes in physical outputs.

Research that integrates measures of the internal response (e.g. heart-rate) with changes in external outputs to show changes in exercise economy will enhance current understanding of match-related fatigue. Metabolic power outputs derived from accelerated and decelerated running efforts represent an important component of the physical demands of rugby league and have not been considered by previous studies of fatigue-related changes in physical performance. Research that addresses some of these methodological concerns from previous studies will enhance current understanding of match-related fatigue in professional rugby league competition.

STUDY 7: PHYSICAL, TECHNICAL AND TACTICAL DIFFERENCES BETWEEN SUCCESSFUL AND LESS-SUCCESSFUL RUGBY LEAGUE TEAMS

AIM:

The aims of this study were to: 1) compare the physical performance profiles of successful and less-successful NRL teams using a large sample size and a mixed model approach to account for data dependence; and 2) investigate the differences in technical performance variables between successful and less-successful NRL teams.

SIGNIFICANCE:

Previous research examining differences in physical and technical performance between successful and less-successful rugby league teams was conducted on semi-professional competition, which may not be representative of professional competition. Research using large a sample size, examining a variety of physical and technical performance parameters and statistical methods that can account for dependent data samples is required to understand the differences in performance profiles between successful and less-successful teams (based on final league ranking). These findings will provide new insights into the potential differences in physical and technical performance profiles between successful and less-successful professional rugby league teams and help identify the performance constructs most related to successful match outcomes.

CHAPTER TWO

LITERATURE REVIEW

INTRODUCTION

Rugby league is a physically demanding, high-intensity team sport that is played professionally in many countries worldwide. It is a complex invasion based team sport, where the aim is to secure and maintain possession, while advancing the ball forward and attempting to score points by crossing the opposition's goal-line (Gerrard, 2007). In addition to intense physical demands – which can be characterised by high speed running, rapid accelerations and frequent collisions – rugby league players also require specific technical and tactical competencies during match-play. With the multifaceted demands of rugby league match-play, match outcome is contingent on a combination of physical, technical (individual skills) and tactical (interaction with other individuals) performance (Impellizzeri & Marcora, 2009). An increasing number of studies have examined match performance by investigating the physical, technical and tactical constructs of rugby league match-play. These constructs of performance are difficult to measure directly; instead research has used causal indicators to represent relevant performance constructs. For example, speed-based distances derived from time-motion analysis during match-play have been employed as the causal indicator of the physical performance construct. While determining the typical activity profiles provides information regarding the demands of match-play, it is important to establish whether these causal indicators provide valid representations of their associated performance constructs (Impellizzeri & Marcora, 2009). However, few studies have examined the relationship between physical performance parameters and match success during rugby league match-play (Gabbett, 2013a, 2014; Hulin et al., 2015). These studies have presented conflicting findings, with some suggesting that competitive advantage is linked to a team's ability to maintain a higher playing intensity than their opposition (Gabbett, 2013a), while other studies stating that superior technical performance, not greater total and higher-speed running distances, are related to competitive success (Hulin et al., 2015). Unfortunately, relatively few studies have examined the technical performance and the performance indicators that are related to successful match performance in professional rugby league are yet to be elucidated.

Comparing physical and technical performance profiles between or within teams is challenging due to the large between-match variation in some performance measures, particularly higher-speed activities, which necessitates large sample sizes in order to detect true differences in performance variables (Gregson et al., 2010; Kempton, Sullivan, et al., 2015). In addition, it is important to account for the confounding effects of contextual factors – such as match location, opposition strength and time in possession – which may influence performance during team sport match-play (Carling, 2013). Moreover, many observational studies draw multiple samples from a single player over the course of a season which results in dependent data and violates the

assumption of independence underpinning many statistical analyses (Wilkinson & Akenhead, 2013). To enhance current understanding of match performance constructs in rugby league, additional research using large match file samples and statistical methods that can account for dependent data samples are required.

Relevant literature was obtained from an online search using the SportDiscus, PubMed and Google Scholar electronic databases. The following keywords were used in various combinations: 'rugby league', 'performance analysis' 'technical performance', 'physical performance', 'motion analysis', 'match demands'. Electronic database searching was supplemented by examining the reference lists of relevant articles. Only match analysis studies examining professional, semi-professional and elite-junior rugby league competitions were considered for review.

The purpose of this review was to examine the physical, technical and tactical constructs of performance in rugby league match-play. The review considered methods for performing time-motion analyses in team sports and the main parameters typically provided from these analyses. It also assessed the variation in these physical performance measures between matches and explored the main factors thought to affect these physical performance variables. Finally, the review examined components of technical and tactical performance in professional rugby league match-play.

PHYSICAL PERFORMANCE IN RUGBY LEAGUE

METHODS FOR MEASURING PHYSICAL PERFORMANCE IN TEAM SPORTS

Preliminary time-motion analyses of rugby league match-play were most commonly conducted by manually tracking an individual player's movement from a digital recording onto a calibrated representation of the field (Meir, Colla, & Milligan, 2001; Sirotic, Coutts, Knowles, & Catterick, 2009; Sirotic, Knowles, Catterick, & Coutts, 2011). While video-based tracking offers a reliable method for performing time-motion analyses, the process is both time consuming and labour intensive (Edgecomb & Norton, 2006). In recent years, there has been an uptake of micro-technologies such as global positioning satellite (GPS) systems and local position measurement (LPM) systems, which are able to record time-motion profiles during team sport competition and training with relative ease. Indeed, GPS systems are now widely used by many National Rugby League (NRL) clubs to monitor physical performance during

training and matches, and time-motion profiles obtained from these devices are commonly used in applied rugby league research studies.

Given the widespread use of GPS systems amongst professional football codes, several studies have attempted to establish the validity and reliability of different GPS devices. Caution is required when discussing the reliability and validity of GPS systems as the performance of devices will differ according to manufacturer firmware, proprietary software and sampling frequency (Buchheit et al., 2014; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010; Johnston, Watsford, Kelly, Pine, & Spurrs, 2013). Previous research has shown that a range of GPS devices provide acceptable validity and reliability for measuring movements over longer distances at low speeds (Jennings et al., 2010; Johnston et al., 2013; Waldron, Worsfold, Twist, & Lamb, 2011). Moreover, recent developments in GPS technology have provided new units with higher sampling frequencies (10-15 Hz), which outperform older, lower resolution (1-5 Hz) devices (Johnston et al., 2012). However, despite the advances in GPS technology, the accuracy and reliability for assessing high-speed movements that contain rapid changes in direction is still questionable (Johnston et al., 2012). Furthermore, while some have reported acceptable accuracy for assessing straight line acceleration and deceleration efforts (Varley, Elias, & Aughey, 2012), others have found that GPS recordings of changes in speed are highly variable and have questioned the usefulness of these measures (Buchheit et al., 2014). Similarly, while several GPS devices provide satisfactory measurements of average metabolic power output derived from accelerated running efforts during simulated team-sport running movements, they are less accurate for quantifying high metabolic power (>20 $W \cdot kg^{-1}$) movements (Rampinini et al., 2015). Collectively, it appears that GPS systems provide reasonable measures of total distances and overall metabolic power output during team sport movements, although they are less accurate for non-linear and higher-speed or rapid acceleration movements.

Physical collisions represent an important component of the demands of match-play in contact sports such as rugby league, rugby union and Australian football. Yet, time-motion analyses of competition match-play are limited in that they are unable to account for the substantial energetic demands associated with these actions. To overcome this limitation, some researchers have used manual notational analysis techniques from video recordings of matches to quantify the contact demands of rugby league match-play, although this method is both time consuming and labour intensive (Sirotic et al., 2009). With the recent proliferation in the use of GPS systems to provide time-motion data from training and competition matches, these devices are also fitted with tri-axial accelerometers which are able to measure gravitational force (G force)

on three planes. Several studies have reported the occurrence of "impacts" in different G force zones derived from accelerometer outputs during rugby league match-play (Cummins & Orr, 2015; McLellan, Lovell, & Gass, 2011a). Unfortunately no studies have externally validated this method for measuring collisions, and the number of "impacts" observed typically outnumber the total tackle events that occur during a match, suggesting that these "impacts" may also be recorded from other actions apart from collisions (Gabbett, 2013c). Some newer GPS models also include gyroscopes and magnetometers which offer the potential to automatically detect physical collisions with greater precision. Recent research has validated the ability of some micro-technology units (minimaxX, Catapult Innovations, Melbourne, Australia) to quantify physical collisions against video coding of the actual collisions during rugby league training (Gabbett, Jenkins, & Abernethy, 2010a). It has been suggested that the gyroscopes and magnetometers contained in these units are critical for detecting physical collisions (Gabbett, 2013c), however, an algorithm has recently been developed which permits the accurate, automatic detection of collisions using accelerometer data produced from GPS units (SPI-Pro, GPSports, Canberra, Australia) that don't contain either gyroscopes or magnetometers (Kelly, Coughlan, Green, & Caulfield, 2012). While preliminary research indicates that the automatic detection of physical collisions through micro-technology offer a valid, time efficient method for quantifying these actions, this technology requires further validation for a range of different collision events during match-play.

OVERVIEW OF PHYSICAL PERFORMANCE PARAMETERS

Time-motion analyses of team sport match-play provide information on the time spent and distances covered at different speeds and the frequency changes in speed. In addition, recent developments in micro-technology now permit the automatic detection of the number and severity of physical collisions during match-play in contact sports such as rugby league. A combination of these parameters form the basis for the majority of recent applied rugby league match analysis studies.

SPEED-BASED RUNNING DISTANCES

The total distance covered provides a reliable, overall measurement of physical performance during team sport match-play. However, in order to better understand the physical demands of match-play, time-motion analyses are normally separated into time spent and distance covered at different speeds. These discrete locomotion categories can be broadly defined as low-speed running (LSR), high-speed running (HSR), very high-speed running (VHSR) and sprint distances. The majority of time spent and distance covered during intermittent team sports such

as rugby league occurs at low-speed (Gabbett, Jenkins, & Abernethy, 2012; Sirotic et al., 2011; Waldron, Twist, Highton, Worsfold, & Daniels, 2011). However, these low speed activities are frequently punctuated by brief high-speed running and sprint activities, which represent an important component of rugby league match-play due to their association with critical moments in the match (Austin, Gabbett, & Jenkins, 2011b), and sensitivity to match-related fatigue (Sykes, Twist, Nicholas, & Lamb, 2011). Unfortunately, while current GPS systems display acceptable accuracy for measuring long distances at low speeds, they are less precise when assessing short, high-speed movements involving rapid changes in direction (Petersen, Pyne, Portus, & Dawson, 2009; Waldron, Worsfold, et al., 2011). Furthermore, research from other team sports has shown that higher-speed activities vary substantially between matches, which must be considered when interpreting changes or comparing differences in these parameters (Gregson et al., 2010; Kempton, Sullivan, et al., 2015). An additional methodological concern arising from applied time-motion analyses of rugby league match-play is that the speed thresholds employed for each category often vary amongst these studies. Indeed, some previous studies have used a range of different absolute speed thresholds, while others have used individualised zones derived from individual player physiological performance profiles. While general recommendations have been made for absolute speed thresholds for use in time motion studies (Abt & Lovell, 2009), there remains considerable inconsistency in the use of speed-based categories, meaning that caution is often required when comparing studies where different thresholds are used.

ACCELERATIONS AND METABOLIC POWER

Accelerations are defined as a change in movement speed and occur frequently in team sports such as rugby league. There are significant metabolic costs associated with rapid accelerations which are often greater than constant speed movement (Osgnach, Poser, Bernardini, Rinaldo, & di Prampero, 2010). These high-intensity actions represent an important component of physical performance in rugby league due to the spatial constraints and brief, repeated running movements required during match-play. Furthermore, rapid accelerations can occur from relatively low starting speeds, and while these efforts have high metabolic demands, they may be neglected by traditional high-speed threshold categories as the conclude prior to reaching the designated speed threshold (Varley & Aughey, 2013). Despite research from other football codes highlighting the importance of accelerations during match-play (Akenhead, Hayes, Thompson, & French, 2013; Varley & Aughey, 2013), comparatively few studies have analysed acceleration efforts in rugby league match-play (Sirotic et al., 2009). In recent times, a novel "metabolic power" approach has been proposed for analysing time-motion data which considers the cost of accelerated running efforts in team sports (Di Prampero et al., 2005). The model considers accelerated running on a flat surface to be metabolically equivalent to incline running

at a constant speed, where the angle of the incline is equal to the extent of forward acceleration. This method provides an "equivalent slope" which is used to calculate an instantaneous measure of the energy cost of accelerated running and an estimate of metabolic power output (Di Prampero et al., 2005). While several studies have examined the metabolic demands of soccer and Australian football (Coutts et al., 2014; Osgnach et al., 2010), no studies have assessed the metabolic demands associated with rugby league match-play. Given the importance of accelerated running efforts arising from the spatial constraints and brief, repeated running movements required during match-play, future research should apply this metabolic power approach to enhance current understanding of the accelerated running demands of rugby league match-play.

COLLISIONS

Physical collisions, which usually occur when making a tackle or being tackled, are an important component of rugby league match-play. Indeed, the ability to dominate physical collisions and "win" the tackle contest is thought to be critical to the outcome of the game (Gabbett et al., 2010a). In addition, bouts of physical contact in rugby league are physiologically demanding and contribute to the onset of match-related fatigue (Johnston, Gabbett, Seibold, & Jenkins, 2014a). Further, the majority of injuries sustained by professional rugby league players occur as a result of physical collisions (Gabbett, 2004). Due to the high energetic requirements of physical collisions and their association with injury, quantifying the occurrence and severity of these actions is important in contact sports such as rugby league. Given that some GPS devices appear to provide a valid, time efficient method for the detection of physical collisions, future research should utilise these advances in technology to better understand the collision demands of rugby league match-play.

REPEAT HIGH-INTENSITY EFFORTS

While time-motion studies of rugby league match-play have typically reported on the occurrence and characteristics of high-speed activities, accelerations and collisions, the distribution of these activities – particularly when they occur in rapid succession – has also been examined in previous research. The occurrence of repeat sprint sequences (defined as three or more sprints with less than 21 seconds between each effort) has been proposed as an important physical demand in hockey and other team sports (Spencer et al., 2004), yet research suggests that these actions rarely occur in rugby league (Gabbett, 2012). This is likely because sprint activities are infrequent for some positional groups and when sprints do occur they are often followed by an extended recovery period (Gabbett, 2012). However, rapid accelerations and physical collisions are two physically demanding actions that occur more frequently in

rugby league match-play, and they, along with sprint efforts have been incorporated to provide a more rugby league specific measure of the most intense periods of play known as repeat, high-intensity efforts (RHIE). They are defined as three or more accelerations, sprint or contact efforts separated by less than 21 seconds between each effort (Gabbett et al., 2012). Analyses of RHIE bouts have been included in several recent applied rugby league studies (Black & Gabbett, 2014; Gabbett et al., 2012; Hulin et al., 2015), although RHIE are a proprietary variable which is only provided by one GPS system manufacturer (Catapult Innovations, Melbourne, Australia), and the manual processing of the raw data from devices that do not provide this variable would be a labour-intensive process requiring the application of complex algorithms to the raw GPS and accelerometer data.

VARIATION IN PHYSICAL PERFORMANCE VARIABLES

Match-play in high-intensity, intermittent team sports such as rugby league is dynamic with a complex interplay between individuals on the same and opposing teams. As such, common measures of physical performance can show large variation between matches. The sources of variation in physical performance within individual players over successive matches may be related to internal factors (e.g. individual fitness status, motivation) and external factors such as opposition, tactics, location and environment (Mohr, Krustup, & Bangsbo, 2003; Mohr et al., 2010; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007). Previous research has reported that global measures of physical performance such as absolute total distance and relative distance ($m \cdot min^{-1}$) are relatively stable, whilst higher-speed activities show greater variability between matches in soccer (Gregson et al., 2010; Rampinini et al., 2007), Australian football (Kempton, Sullivan, et al., 2015) and rugby union (McLaren, Weston, Smith, Cramb, & Portas, 2015). In addition to establishing the reliability of certain physical performance measures, some studies have examined the factors that influence the observed variation of these measures. For example, studies from both soccer and Australian football have reported that the magnitude of the variability between matches may be influenced by playing position (Gregson et al., 2010; Kempton, Sullivan, et al., 2015). While research from other football codes has observed large variation in physical performance measures – particularly for higher speed activities, no studies have examined the between match variation in professional rugby league. A better understanding of the typical variation in these measures can be useful for designing applied research studies, selecting reliable measures for assessing physical performance and to assist interpreting worthwhile changes in performance. Moreover, research to further investigate the factors affecting the variation in physical performance measures in team sports such as rugby league is warranted.

FACTORS AFFECTING PHYSICAL PERFORMANCE

PLAYING LEVEL

The two main professional rugby league competitions are the NRL, comprising clubs based in Australia and New Zealand, and the European Super League (ESL), consisting of clubs from the United Kingdom and France. The NRL comprises 16 professional clubs and is the highest standard rugby league competition in Australia. Each NRL club also fields an elite junior team in the National Youth Competition (NYC), which acts as a development pathway for elite players (aged less than 20 years) to the NRL. In addition to the NRL and NYC, there are two semi-professional competitions in Australia; the New South Wales Cup (NSW Cup) and Queensland Cup (Q Cup), which operate as feeder competitions for the professional NRL clubs. In recent years, several studies have compared the physical demands between the various standards of competition. No differences have been reported for relative total and low-speed running (LSR) distances between NRL and semi-professional match-play; however NRL players perform more relative higher-speed activities per minute compared to their semi-professional counterparts (McLellan & Lovell, 2013; Sirotic et al., 2009). Similarly, there were no differences in either relative total or LSR distances between NRL and NYC players (McLellan & Lovell, 2013). While some have also reported greater HSR in NRL matches compared to NYC, others found no difference between the two competition standards (Gabbett, 2013b; McLellan & Lovell, 2013). The lack of agreement between these two studies may be attributable to differences in the HSR threshold used in the respective studies and the large between-match variation observed for higher-speed activities in team sports (Gregson et al., 2010; Kempton, Sullivan, et al., 2015). Further, the majority of studies that have compared the physical profiles from different playing standards are limited by the small number of match samples drawn from teams in the same club.

The differences in the collision demands between different playing standards are not well understood. One study showed that NRL forwards are involved in more collisions per minute of playing time compared to NYC forwards, with no differences in collisions observed for backs (Gabbett, 2013b). Only one study has directly compared the physical profiles of NRL and ESL matches, reporting that while NRL players actually performed less relative total and LSR distances, they performed more HSR activities than ESL players (Twist et al., 2014). These studies have not assessed the intensity of collisions, and future research is warranted to better understand differences in the nature of collisions between competition levels. Collectively, it appears that NRL players perform more high-speed running activities compared to their European, semi-professional and elite junior counterparts, and this ability to perform HSR activities during match play differentiates between playing standard (Figure 2.3). While there

may be some differences in the collisions experienced between different playing standards, future research is required to further understand this component of physical performance.

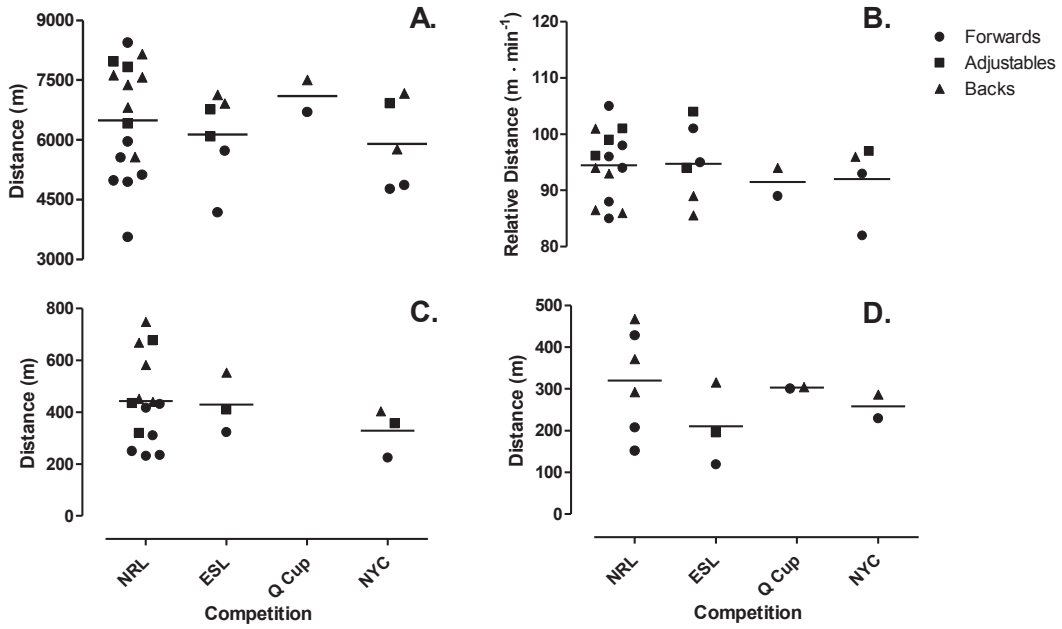

Figure 2.3: Summary of A) Total distance; B) Relative distance; C) HSR distance and D) Sprint distances in rugby league competitions.

TEAM RANKING

In addition to examining physical performance characteristics between levels of competition, several studies have also analysed differences between high and low-ranked teams within rugby league competitions. It was reported that a successful NRL team performed less total and HSR distances compared with a less-successful team, while players from the adjustables and forwards positional groups were involved in more collisions than their less-successful counterparts (Hulin et al., 2015). In contrast to these findings, analysis of semi-professional competition showed that less-successful teams were involved in more collisions than higher ranked teams, despite no differences between teams in total, LSR, HSR and sprint distances, accelerations or RHIE (Gabbett, 2014). The lack of agreement between these two studies may arise due to differences in playing standard between the two competitions, or alternatively technical error related to the automated collision detection algorithms may contribute to the observed differences (Gabbett, 2013c). In addition to examining team ranking on the physical performance, others have analysed the influence of opposition ranking on the physical demands of NRL match-play (Gabbett, 2013a). While the reference team in one such study performed more HSR against lower ranked opponents, there were no differences reported in total distance, accelerations, collisions or RHIE. Collectively, these studies suggest that the league ranking of

successful teams is not contingent on higher match running outputs, and other components such as the occurrence of collisions and technical performance warrant further investigation.

MATCH OUTCOME

While recent studies have compared time-motion profiles from successful and less-successful teams, others have examined the influence of match result on physical performance parameters in professional and semi-professional competitions. It was reported that both total and LSR distances were higher in matches won compared to matches lost, although there were no difference in HSR distances (Black & Gabbett, 2014; Gabbett, 2013a). While there were no differences in the number of collisions, there were more accelerations and more frequent RHIE in matches won compared with matches lost (Black & Gabbett, 2014; Gabbett, 2013a). On the basis of these results, the authors suggested that the competitive advantage of successful NRL teams is closely linked to their ability to maintain a higher playing intensity than their less successful counterparts (Gabbett, 2013a). A limitation of these studies is that they were not able to account for the potential confounding effects of other factors – such as the strength of the reference team or their opposition – which may occlude the independent effects of match outcome on physical performance profiles. Furthermore these observations were drawn from a single reference team and were limited by the small number of match samples. While some, but not all, measures of physical performance were higher in matches won compared to matches lost, further research is required to examine the independent effects of match outcome on physical performance profiles in professional rugby league.

TIME OUT OF PLAY, ATTACK AND DEFENCE

During rugby league match-play, teams spend time attacking when in possession of the ball and time defending when the opposition is in possession of the ball. The ball is "in play" for an average of 55 mins during an 80 minute game (Gabbett, 2011), meaning that the time when the ball is out of play – due to penalties, scrums, goal-line drop outs and tries – represents a substantial component of overall match-time. Indeed, the time that the ball is in play during a match will likely affect the physical demands and should therefore be considered when analysing physical performance in rugby league match-play (Carling, 2013). Only one study to date has compared the activity profiles between entire matches with periods when the ball is "in play" (Gabbett, 2015). The analysis of 22 semi-professional rugby league matches reported higher relative total, LSR, HSR, sprint distances, relative accelerations and collisions when the ball was only "in play" compared to throughout the entire match (which included all stoppage periods). Interestingly, while there were significant differences in absolute total and LSR distance between the two analyses, the absolute HSR and sprint distances, as well as absolute

accelerations, collisions and RHIE bout were similar (Gabbett, 2015). This indicates that player movements during stoppages generally occur at low speeds and that higher speed activity and collisions only occur while the ball is in play.

Several studies have further analysed the time "in play" phases of rugby leagues competition matches by separately examining the physical demands when attacking with the ball and defending against the opposition (Gabbett, Polley, Dwyer, Kearney, & Corvo, 2013; Sykes, Twist, Hall, Nicholas, & Lamb, 2009). They have shown that the physical demands of defending against the opposition are higher compared with when in possession of the ball. Specifically, the relative total, LSR and HSR distances, as well as collisions and RHIE bouts were all higher for professional rugby league forwards when defending than when in possession of the ball (Gabbett, Polley, et al., 2013). Furthermore, the location on the field in which the play occurs also influences the demands associated with attacking and defending. However, this study was limited in that it only considered the time-motion profiles of forwards and did not examine other positional groups including adjustables and outside backs. Interestingly, a study that did observe all positional groups found that while defending was more demanding than attacking overall, as evidenced by shorter work-to-rest ratios, this was only the case for forwards and adjustables, and there was no difference for outside backs (Sykes et al., 2009). A limitation of that study was that only 78 player observations drawn from three matches were analysed, and due to the large between-match variation in physical performance in team sports, a greater number of match samples may be needed to obtain a true representation of the differences between phases of play (Gregson et al., 2010). Collectively, these studies suggest that the physical demands of defending are greater than when attacking, although future studies are required to confirm these findings using a larger sample of matches drawing players from all positional groups.

POSITION

Rugby league players have specialist positions which can be broadly categorised into forwards and backs, and may also be further divided into sub-groups such as hit-up forwards and wide-running forwards, and adjustables (or pivots) and outside backs. There are differing physical profiles between positional groups, with forwards generally heavier and stronger, whilst backs are leaner and faster (Comfort, Graham-Smith, Matthews, & Bamber, 2011; Meir, Newton, Curtis, Fardell, & Butler, 2001). In addition to differences in the physical characteristics between positional groups, the role they are required to play during matches also varies. Specifically, hit-up forwards typically operate in the middle of the field and are frequently involved in hit-ups and making tackles (Sirotic et al., 2011). Adjustables are responsible for

providing attacking structure and usually control the area around the ruck. They mainly distribute the ball and run support lines rather than take hit-ups directly (Sirotic et al., 2011). The middle areas of the field where both hit-up forwards and adjustables operate are usually congested and there is limited space between attacking and defensive lines. Wide-running forwards and outside backs operate on the lateral areas of the field, which are comparatively less congested.

In order to assist with the preparation of players for the physical demands of rugby league match play, several studies have examined the match profiles for specific position groups during competition. Most research has shown that backs and adjustables cover greater absolute distances compared to forwards (Austin & Kelly, 2013; Gabbett et al., 2012; Waldron, Twist, et al., 2011). However, these differences in absolute distances are likely related to total playing time as forwards are often interchanged and tend to spend less time on the field compared to other positions (Gabbett et al., 2012). Indeed, when examining the relative total distances ($m \cdot min^{-1}$) during match-play, most previous studies have reported similar intensities between positional groups (King, Jenkins, & Gabbett, 2009; Sirotic et al., 2011), although some have reported lower relative distances for outside backs (Waldron, Twist, et al., 2011). The lower relative intensities observed in outside backs may arise from their specific match role and positioning on the flanks of the field, or alternatively it may be attributable to fatigue related reductions in the later periods of the match given that these positions are rarely interchanged as opposed to other positional groups (Sykes et al., 2011). Collectively, previous research has shown that relative total distances are similar between positional groups, and differences observed in absolute distances are likely due to time on field.

In addition to total distance, research has examined differences in higher speed activities between positional groups. Previous studies have shown that absolute HSR distances are greater for backs and adjustables compared to forwards (Austin & Kelly, 2013; Gabbett et al., 2012), and in contrast to overall exercise intensity, these differences between positions also extend to relative HSR distances (Sirotic et al., 2011; Waldron, Twist, et al., 2011). Furthermore, outside backs typically perform greater sprint distances compared to other position groups (McLellan, Lovell, & Gass, 2011b), while other factors such as average sprint length, activity preceding each sprint and recovery time between sprint efforts also vary by playing position (Gabbett, 2012). The greater HSR distances observed from this group may be attributable to their frequent involvement in the kick-chase, where they are responsible for following the ball into the opposition's territory following a kick at the end of the possession, and conversely, when they are required to retrieve a kick from the opposition into their own territory. It is likely that a

combination of physical characteristics – such as enhanced speed qualities – as well as the specific match roles and greater space available on the flanks of the field explains the greater higher speed running profiles of outside backs compared to other positional groups.

Physical contact actions such as tackling, wrestling and being tackled represent a substantial component of the physiological demands of rugby league match-play. However, few studies have attempted to describe the nature of these activities during match-play, possibly due to difficulties in quantifying their occurrence. Preliminary research used manual analysis techniques from video recordings of matches to describe the contact demands of match-play, although this method is both time consuming and labour intensive. It was reported that forwards were involved in physical contact actions more than adjustables and outside backs, who were involved in the least contact activities (King et al., 2009; Sirotic et al., 2011). More recently, automatic collision detection algorithms have been refined for use with microtechnologies – such as GPS devices – that are commonly used to measure time-motion profiles in team sport match-play (Gabbett, 2013c) and several studies have now utilised this microtechnology to quantify collision demands in rugby league. Significant differences were reported in the frequency of relative, but not absolute collisions between forwards, adjustables and outside backs during NRL match-play (Gabbett et al., 2012). Similar findings have been reported elsewhere, although that study only used a small number of player observations drawn from a single trial match (Gabbett et al., 2010a). Taken together, physical collisions are a demanding component of rugby league match-play, the nature and occurrence of which likely differs between playing positions. With recent advances in automatic collision detection technology, future studies using this technology are warranted to further understand the physical contact requirements of rugby league match-play. In addition, no studies have quantified the energetic demands arising from these collision activities.

INDIVIDUAL PLAYER CHARACTERISTICS

Fitness characteristics are considered important determinants of physical performance in team sports (Impellizzeri & Marcora, 2009), yet few studies have examined the association between physical qualities and match performance in rugby league competition. Gabbett et al. (2013) found players with higher repeat sprint ability performed more HSR during professional rugby league match-play. Players with better prolonged, high-intensity intermittent running capacity (assessed using a repeated 12-second sprint-shuttle test) spent more time on the field, and covered more absolute but not relative total, LSR and HSR distance, yet engaged in fewer collisions and RHIE bouts. Finally, maximal aerobic power (determined from the multi-stage fitness test) was positively correlated with absolute and relative collisions. However, a

limitation of this study was that it did not account for the influence of playing position on the relationship between individual player physical qualities and match physical performance. Indeed, previous research has shown that playing time and absolute distances covered are strongly influenced by playing position in rugby league match-play (Gabbett et al., 2012). Moreover, research from Australian football has shown that playing position moderates the relationship between physical characteristics and match running performance (Mooney et al., 2011). Accordingly, player position should be accounted for when examining the relationship between physical qualities and match performance in team sports such as rugby league. In one study that did control for playing position, only lower-body strength was positively related to total, LSR and HSR distance and RHIE bouts during semi-professional rugby league match-play (Gabbett & Seibold, 2013). No other tests of physical qualities including upper-body strength, upper-body strength endurance, lower-body power and prolonged high-intensity, intermittent running ability were related to match physical performance in this cohort. It appears from previous research that some individual physical qualities are correlated with match performance, however future research should account for playing position to better understand this relationship in professional rugby league match play.

FATIGUE

Temporal changes in physical performance measures have been used as evidence of match-related fatigue in professional rugby league (Kempton, Sirotic, Cameron, & Coutts, 2013; Sykes et al., 2011; Waldron, Highton, Daniels, & Twist, 2013). These studies have focused on both reductions in physical performance towards the end of matches and transient fatigue following brief periods of high-intensity activity. Multiple mechanisms may underpin these reductions in physical performance including glycogen depletion (Krustup et al., 2006), accumulation of extracellular potassium (Bangsbo, Madsen, Kiens, & Richter, 1996; Nordsborg et al., 2003) and central factors (Kent-Braun, 1999). Alternatively, it has been suggested that reductions in physical performance may be a consequence of pacing strategies employed by athletes to ensure that they are able to complete the match (Drust, Atkinson, & Reilly, 2007; Duffield, Coutts, & Quinn, 2009).

Studies examining accumulated match-related fatigue in rugby league have reported that while total distance was maintained across 20 min playing quarters, there were diminutions in HSR distance, particularly in the final quarter of the match (Sykes et al., 2011; Waldron et al., 2013). Temporal changes in total distance have also been analysed in shorter 5 to 10-min epochs, showing reductions in total distance towards the end of the match when compared with the opening periods of each half (Austin & Kelly, 2013; Kempton, Sirotic, Cameron, et al., 2013).

However, some have questioned whether it is appropriate to compare the opening and final periods of soccer match-play to identify the occurrence of match-related fatigue due to the frantic nature of the opening period where teams may attempt to "engage" their opponents (Carling, 2013). Several studies have examined pacing during rugby league match-play, suggesting that whole game and interchange players adopt different pacing strategies and that these strategies differ between winning and losing teams (Black & Gabbett, 2014; Waldron et al., 2013). However, these studies are limited by small sample size and it is difficult to confirm the existence of deliberate pacing strategies because perturbations in physical performance may also be due to the onset of match-related fatigue and other match-related contextual factors (Carling, 2013; Waldron et al., 2013).

Temporary reductions in physical performance following brief periods of high-intensity activity have been reported in rugby league (Hulin et al., 2015; Kempton, Sirotic, Cameron, et al., 2013) and other team sports (Mohr et al., 2003). Specifically, the running and collision demands in the most intense 5-min period of rugby league match-play are greater than both the subsequent and mean of all other 5-min periods (Hulin et al., 2015; Kempton, Sirotic, Cameron, et al., 2013). Caution is required when interpreting these findings though as the higher physical output observed in the peak 5-min period is at least partially due to more opportunities for physical activity due to the greater amount of time the ball is in play compared to other periods (Carling & Dupont, 2011; Kempton, Sirotic, Cameron, et al., 2013).

Match-related fatigue appears to be implicated in reductions of physical performance observed towards the end of rugby league matches and following brief periods of high-intensity activity. However, these diminutions may also be related to prior physical output, individual player motivation and pacing strategies, match role and also a complex interplay of contextual match factors including the score line, team tactics and the time the ball is in play (Carling, 2013; Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Waldron et al., 2013). Future research should account for contextual factors such as time in possession and time the ball is in play when assessing time-course changes in physical performance. While previous research has examined temporal changes in speed-based distances and physical collisions as physical performance parameters, they only represent part of the physical demands of team sport match-play (Osgnach et al., 2010), and future research should also examine metabolic power outputs derived from accelerated and decelerated running efforts when examining fatigue-related changes in physical performance (Carling, 2013). Finally, to enhance current understanding of time-course changes in external measures of physical output (such as speed-based distances, metabolic power and collisions), they should be integrated with internal load measures (such as

heart-rate) to provide information regarding changes in exercise economy during rugby league match-play (Akubat, Barrett, & Abt, 2013; Carling, 2013).

Table 2.1: Summary of published studies examining physical performance in rugby league match-play.

Author	Level	Games	Files	Technology	Variables	Factors	Purpose
Austin and Kelly (2013)	NRL	28	185	SPI Elite (5Hz)	Speed-based distances	Position; Time-course changes	Describe movement analysis for backs and forwards and examine time-course changes.
Austin and Kelly (2014)	NRL	28	135	SPI Elite (5Hz)	Speed-based distances	Position	Quantify the movement demands of 9 individual playing positions.
Black and Gabbett (2014)	Q Cup	26	90	MinimaxX (10Hz)	Speed-based distances; RHIE	Time-course changes; Match-role; Result	Investigate pacing strategies for whole-game and interchanged player for winning and losing teams.
Cummins and Orr (2015)	NRL	-	359	SPI Pro (15 Hz)	Collisions	Position	Investigate collision events in professional rugby league
Gabbett (2012)	NRL	16	104	MinimaxX (5Hz)	Speed-based distances	Position	Investigate sprint characteristics of NRL matches.
Gabbett (2013a)	NRL	16	-	MinimaxX (5Hz)	Speed-based distances; RHIE; Collisions	Opposition strength; Result	Investigate influence of opposition standard and match result on activity profiles.
Gabbett (2013b)	NRL NYC	16 14	76 63	MinimaxX (5Hz)	Speed-based distances; RHIE; Collisions	Position, Competition level	Compare the physical match-demands between NRL and NYC competitions.
Gabbett (2014)	Q Cup	26	386	MinimaxX (10Hz)	Speed-based distances; Accelerations; RHIE; Collisions	Team strength; Time-course changes	Compare physical (and technical) performance variables that differentiate between high and low ranked semi-professional teams.
Gabbett (2015)	Q Cup	22	199	MinimaxX (10Hz)	Speed-based distances; RHIE; Collisions	Time in play	Investigate the activity profiles of match-play when accounting for ball “in” and “out of play” periods.

Table 2.1. Cont.

Author	Level	Games	Files	Technology	Variables	Factors	Purpose
Gabbett et al. (2012)	NRL	16	104	MinimaxX (5Hz)	Speed-based distances; RHIE; Collisions	Position	Investigate physical demands of NRL matches and compare to training activities.
Gabbett, Polley, et al. (2013)	NRL	23	226	MinimaxX (10Hz)	Speed-based distances; RHIE	Phase of play; Field location	Investigate difference in physical demands between attack and defence and different field locations.
Gabbett, Stein, et al. (2013)	NRL	16	-	MinimaxX (5Hz)	Speed-based distances; RHIE; Collisions	Player fitness characteristics	Examine relationship between physical qualities and match performance.
Gabbett and Seibold (2013)	Q Cup	5	-	MinimaxX (10Hz)	Speed-based distances; RHIE; Collisions	Player fitness characteristics	Investigated the relationship between tests of physical qualities and physical match performance.
Hulin et al. (2015)	NRL	25	200	MinimaxX (10Hz)	Speed-based distances; RHIE; Collisions	Time-course changes; Team strength	Examine time-course changes in activity profiles between high and low-ranked teams.
Kempton, Sirotic, Cameron, et al. (2013)	NRL	22	63	SPI Pro (5 Hz)	Speed-based distances	Time-course changes; Competition level	Compare match-related fatigue and technical performance between NRL and NYC.
	NYC	23	55				
King et al. (2009)	NRL	3	9	Computer-based tracking	Speed-based distances	Position	Provide time-motion analysis of NRL match-play for positional groups.
Meir, Colla, et al. (2001)	NRL	2	8	Computer-based tracking	Speed-based distances	Position	Describe gross match play activities for positional groups.
McLellan et al. (2011b)	NRL	5	75	SPI Pro (5 Hz)	Speed-based distances; Heart-rate	Position; Time-course changes	Examine physical and physiological responses for positional groups
McLellan and Lovell (2013)	NRL	5	60	SPI Pro (5 Hz)	Speed-based distances	Position, Competition level	Compare the physical demands of NRL, NYC and Q Cup match-play.
	NYC	5	65				
	Q Cup	5	60				

Table 2.1. Cont.

Author	Level	Games	Files	Technology	Variables	Factors	Purpose
Murray, Gabbett, and Chamari (2014)	NRL	30	-	MinimaxX (5Hz)	Speed-based distances; RHIE; Collisions	Position; Between-match recovery time	Examine different between-match recovery cycles on physical profiles.
Sirotic et al. (2009)	NRL	16	39	Computer-based tracking	Speed-based distances; Accelerations	Position; Competition level	Compare physical (and technical) performance demands between NRL and NSW Cup.
	NSW Cup	14	35				
Sirotic et al. (2011)	NRL	16	39	Computer-based tracking	Speed-based distances	Position	Examine physical (and technical) demands of match-play for positional groups.
Sykes et al. (2009)	NRL	3	26	Pro-zone	Speed-based distances	Position; Phase of play	Describe physical demands for positional groups and phase of play
	ESL		52				
Sykes et al. (2011)	NRL	3	59	Pro-zone	Speed-based distances	Position; Time-course changes	Examine changes in locomotive rates relative to playing position.
	ESL						
Twist et al. (2014)	NRL	-	88	SPI Pro (5 Hz)	Speed-based distances	Position; Competition level	Compare the movement demands of players competing in matches from the NRL and ESL competitions.
	ESL	-	104				
Varley, Gabbett, and Aughey (2013)	NRL	11	94	MinimaxX (5Hz)	Speed-based distances; RHIE; Collisions		To compare match activity profiles between rugby league, soccer and Australian football.
Waldron et al. (2013)	ESL	14	35	SPI Pro (5 Hz)	Speed-based distances; Heart-rates	Time-course changes; Match role	Investigate pacing strategies for whole-game and interchanged players.
Waldron, Twist, et al. (2011)	ESL	12	39	SPI Pro (5 Hz)	Speed-based distances; Heart-rates	Position	Profile the movement and physiological match-demands for positional groups.

NRL: National Rugby League; NYC: National Youth Competition; Q Cup: Queensland Cup; NSW Cup: New South Wales Cup; ESL: English Super League. CBT: computer-based tracking. RHIE: Repeat, high-intensity efforts.

TECHNICAL PERFORMANCE IN RUGBY LEAGUE

Technical skill performance is an important component of match-play in team sports such as rugby league. However, despite research from other football codes including soccer and Australian football reporting that technical proficiency may be more important determinants of match success than physical output (Rampinini, Impellizzeri, Castagna, Coutts, & Wisloff, 2009; Sullivan, Bilsborough, Hocking, Cordy, & Coutts, 2014), relatively few studies have examined technical skill performance in rugby league match-play (Gabbett, 2014; Kempton, Sirotic, Cameron, et al., 2013; Sirotic et al., 2011). The lack of research in this area may be due to difficulties in capturing specific technical and tactical actions that occur during match-play (Gerrard, 2007). A second difficulty arises from the complex interplay between participants in team sports and how to attribute these often joint actions to individual players. However, in recent years a number of commercial statistic services have emerged, and now provide detailed player action data for many team sports including rugby league. Increases in the availability of detailed match data have allowed more complex analyses of team technical and tactical performance than was previously possible in team sports including rugby league.

Initial investigations into technical performance of rugby league match play have used simple manual notation to describe the occurrence of a range of technical skill involvements including tackles, ball carries and play-the-balls for different position groups (Sirotic et al., 2011) and between successful and less-successful teams (Gabbett, 2014). These studies have been limited to one or several reference teams and therefore have not been able to report on technical performance profiles across all games throughout the entire league. There have also been several performance analysis research studies which have examined patterns of play and outcomes related to particular rugby league specific technical skills components in substantial detail. These studies have analysed factors associated with the execution of technical skills including offloads, line breaks, play the ball speed and tackling (Austin, Gabbett, & Jenkins, 2011a; Eaves & Broad, 2007; Eaves & Evers, 2007; Wheeler, Wiseman, & Lyons, 2011). Such analyses provide insight into the technical requirements for different positions and may inform training programs to prepare players for the demands of competition.

Technical data may also be used to assess the performance of a team or individual players during match-play. Indeed, frequency counts of different technical skill involvements offer one method of match performance analysis, particularly when compared against certain established benchmarks (James, Mellalieu, & Jones, 2005). In order to provide a more sophisticated analysis of technical performance, others have attempted to develop a “performance indicator”

score by assigning a subjective weighting – provided by an expert coach or analyst – to a range of important technical skill involvements in team sports such as rugby union and Australian football (Heasman, Dawson, Berry, & Stewart, 2008; Lim, Lay, Dawson, Wallman, & Aanderson, 2009). These analyses are useful for assessing player performance and when individual scores are aggregated to team level, they are able to differentiate between successful and less-successful teams and matches won and lost. However, they are limited in that the weightings applied to each technical skill involvement are based on the subjective opinion of the coaching staff, and may therefore reflect the actions that are deemed important by the coach and not necessarily reflect the true contribution of the action to match outcome. To overcome the limitations arising from subjective weightings of technical actions, several studies have employed statistical modelling techniques such as linear regression in order to obtain an objective evaluation of the relative contribution of various actions to successful match outcomes in team sports such as soccer (Gerrard, 2001; McHale, Scarf, & Folker, 2012) and Australian football (Stewart, Mitchell, & Stavros, 2007). The weightings derived from these analyses can then be applied to the frequency of occurrence of skill involvements for individual players in order to rate players by their contribution to a team winning. Taken together, research from other football codes demonstrates how both subjective and objective statistical analysis can be used to weight the contribution of specific game actions to winning matches and these weightings can be used to value individual player performances.

Other match analysis research has used logistic regression models to examine the technical performance factors that are most related to winning in team sports including rugby sevens (Higham, Hopkins, Pyne, & Anson, 2014a, 2014b) and soccer (Liu, Gomez, Lago-Peñas, & Sampaio, 2015). These studies have established reference scores for selected performance indicators and identified the effects of changes in these variables on the probability of winning matches. An understanding of the most important technical actions related to winning matches can be used to inform the development of tactical strategies and direct training programs. While several studies have identified the key performance indicators that are related to the probability of winning matches in rugby sevens and soccer, no studies have identified these factors in professional rugby league.

Despite the importance of technical skill performance in rugby league, there has been limited research in this area. This may be due in part to difficulties in capturing specific technical and tactical actions and attributing these often joint actions to an individual player in a complex team sport (Gerrard, 2007). Furthermore, analysis of large technical performance data sets often requires sophisticated analytic techniques. Nonetheless, despite the complexities of team sport

match-play, an increasing number of research studies have employed sophisticated statistical techniques to examine technical performance in other team sports including soccer, basketball, American football and rugby sevens. The application of some of these analytic techniques seen in other team sports would enhance current understanding of technical performance in rugby league match-play. Specifically, future studies are required to develop objective methods for assessing technical performance during rugby league match-play. In addition, further research into the association between important technical performance indicators and the probability of winning rugby league matches is warranted.

TACTICAL PERFORMANCE IN RUGBY LEAGUE

The contribution of the tactical component as a construct of overall performance in team sports is a complex issue. Firstly, team tactics are closely related with technical performance, and in many cases it is difficult to delineate between the two constructs of performance. Some preliminary research in soccer has shown that the playing formation of both the reference team and the opposition can influence the distribution of some technical but not physical performance measures (Bradley et al., 2011; Carling, 2011). While these studies in soccer have considered playing formation as an indicator of tactical performance, in rugby league there is less tactical flexibility in terms of playing formation as positional roles are generally fixed. Indeed, beyond playing formation, other metrics for describing team tactics may include the tempo of play, direction of attack (e.g. predominately down the left or right edge, or through central areas) and defensive strategies. To date, no studies have investigated the tactical performance construct of rugby league performance. While information on player technical actions – which can now be obtained from commercial providers – may assist in analysing tactical performance during match play, this process is still subject to several important limitations. Firstly, the tactics of a reference team may not be made publicly available and interpreting the tactical approach of teams may require a high level of expertise. Secondly, it is likely that team tactics are dynamic and can change during a match depending on the score or the tactics utilised by the opposition. Nonetheless, future studies are required to examine tactical behaviours of professional rugby league teams, with particular reference to the patterns of play associated with successful teams.

Rugby league is a complex invasion based team sport, with some similarities to other football codes such as rugby union and American football. In these sports, the aim is to secure and maintain possession, whilst advancing the ball forward and attempting to score points by crossing the opposition's goal-line (Gerrard, 2007). Given the importance of maintaining possession and field position during match-play in these sports, several studies have developed a framework for estimating the expected value of having possession in a given location on the

field. These studies have employed a probabilistic model to estimate the expected point outcome for an average team in possession of the ball in a given situation. The expected value of possession has been investigated in team sports such as American football (Carter & Machol, 1971; Romer, 2006), Australian football (O'Shaughnessy, 2006) and basketball (Cervone, D'Amour, Bornn, & Goldsberry, 2014), although there is currently little understanding of the situational value of possession in rugby league. This type of information has important applications for informing playing strategies and directing training programmes, assessing in-game decision making and for rating individual and team performances.

Recent research has however presented another potential approach for measuring and understanding team tactics, which may have applications across other team sports including rugby league. A novel playing tracking system, known as local position measurement (LPM), is able to provide highly accurate, instantaneous positions for all players on the field during match-play (Frencken, Lemmink, Delleman, & Visscher, 2011). This information can be used to construct profiles of the positioning and distribution of players between attacking and defending units within both teams. While this type of technology is not yet widely used during competition play in soccer or other team sports including rugby league, it provides a potential avenue for future investigations of tactical performance.

Tactical performance as a construct of overall match performance is clearly a complex issue, partly due to difficulties in separating tactical performance from technical performance. Furthermore, there are complications in the process of identifying causal indicators of this construct. While advances in technology and collection of more detailed data may assist in solving these problems, the role of tactical performance as a construct of overall match performance warrants further investigation. Specifically, the expected point framework that has been applied in other team sports could provide useful information on the situational value of possession in rugby league.

CONCLUSIONS

An increasing number of research studies have examined the physical, technical and tactical constructs of performance in rugby league match-play. This has been facilitated by increases in the use of micro-technologies such as GPS units to provide efficient time-motion analysis of competition matches and the emergence of commercial statistics services that now provide

detailed information regarding technical skill performance of match-play. While many studies now use speed-based distances to describe the physical demands, few studies have examined the accelerated running requirements of match-play, and the adaptation of the "metabolic power" approach for assessing these actions may enhance current understanding of physical performance in rugby league. Similarly, traditional time-motion analyses neglect the significant physiological demands associated with collisions during rugby league match play, and with recent improvements in micro-technology allowing the automated detection of these events, future research is required to better understand this component of rugby league match-play. Furthermore, while research from other football codes has shown that common physical performance measures vary between matches, no studies have examined the variation of these measures between rugby league competition matches. A better understanding of the typical variation in these measures can be useful for designing applied research studies, selecting reliable performance measures for applied studies and to assist interpreting worthwhile changes in performance. In addition, further research is required to examine the factors that contribute to the observed variation in measures of physical performance. Indeed, it is important to account for independent effects of contextual factors – such as match location, opposition strength and time in possession – which may influence performance during rugby league match-play. Finally, an integrated approach combining both internal (e.g. heart rate) and external outputs (e.g. speed-based distances) is required to better understand fatigue-related changes in physical performance during rugby league matches.

In comparison to the emerging body of research examining the physical activity profiles, there is a paucity of studies investigating technical and tactical components of rugby league match-performance. This is despite research from other football codes reporting that technical and tactical proficiency may be more important determinants of match success than physical output. The lack of research in this area may be due to difficulties in capturing specific technical and tactical actions that occur during match-play, which involves a complex interplay between individual players (Gerrard, 2007). However, in recent years a number of commercial statistic services have emerged which provide detailed player action data for rugby league and allows more complex analyses of technical performance. Future studies should expand on simple notational analyses of match-play and utilise this abundant technical performance data to develop methods for rating individual player and team performances, identify match statistics that are most related to winning games, and understand the situational value of possession in rugby league match-play. These types of analyses have important applications for informing playing strategies and directing training programmes, assessing in-game decision making and for rating individual and team performances.

Identifying reliable and valid representations of physical, technical and tactical performance constructs enhances understanding of rugby league match-play. Indeed, identifying factors that differentiate between successful and less-successful teams, or between matches won and lost within the same team, assists in establishing their relationship with overall match performance. It is important to recognise that these performance constructs are often related and should not be assessed in isolation. Finally, most longitudinal observational studies of match performance draw multiple samples from individual players over the course of a season, which results in dependent data and violates the assumption of independence underpinning many common statistical analyses. More sophisticated statistical approaches – such as linear mixed-modelling – may be required to overcome the dependent data commonly obtained for match analysis studies. An integrated approach which considers the contribution of physical, technical and tactical constructs to successful match performance has important applications for informing playing strategies and tactics, directing training programs and managing playing rosters in professional rugby league.

CHAPTER THREE

BETWEEN MATCH VARIATION IN PROFESSIONAL RUGBY LEAGUE COMPETITION

Kempton, T., Sirotic, A., & Coutts, A.J. (2013). Between match variation in professional rugby league competition. Journal of Science and Medicine in Sport, 17(4), 404-407.

ABSTRACT

Objectives: To assess between match variability of physical performance measures over both the total and sub sections of the match in professional rugby league competition.

Design: Longitudinal observational study.

Methods: Global positioning system (GPS) data were collected from 24 players from the same team competing in the National Rugby League (NRL) competition over 23 matches during 2011 season. The GPS data were categorised into total distance, high-speed running (>15 km h^{-1}) and very high-speed running (>21 km h^{-1}) distance for discrete reference periods (10 min, 20 min, 40 min and 80 min). The data was then log transformed to provide the coefficient of variation (CV) and the between subject standard deviation (both expressed as percentages).

Results: The data show that the between match variability is greater for high-speed (CV 14.6 %) and very-high speed (CV 37.0 %) running compared to total distance (CV 3.6 %). Within each speed category, the variability of performance tended to increase as the duration of the reference period decreased.

Conclusions: The results show that while global measures of physical performance such as total distance are relatively stable, higher-speed activities exhibit a large degree of between match variability. In addition, when segmenting the match into short periods of time for analysis, all physical performance measures increased in variability. These findings have implications for determining sample size, identifying reliable performance measures and selecting appropriate time periods for future applied studies that involve observational match analysis.

CHAPTER FOUR

FACTORS AFFECTING EXERCISE INTENSITY IN PROFESSIONAL RUGBY LEAGUE MATCH-PLAY

Kempton, T, & Coutts, A.J. (2015). Factors affecting exercise intensity in professional rugby league match-play. Journal of Science and Medicine in Sport, *in press*.

ABSTRACT

Objectives: To examine the effects of match-related and individual player characteristics on running performance in professional rugby league matches.

Design: Longitudinal observational study.

Methods: Global positioning system (GPS) and technical performance measures (attacking involvements and tackles made) were collected from 23 players competing in the National Rugby League (NRL) over 24 matches during a season. The GPS data were categorised into relative total distance ($m \cdot min^{-1}$) and relative high-speed running distance (HSR $m \cdot min^{-1}$, >14.4 $km \cdot h^{-1}$). Each match was classified according to season phase, location, recovery length, opposition strength and result. Individual player fitness status was obtained from a 1.2-km shuttle run test conducted prior to the start of the season. Two separate linear mixed models were constructed to examine the influence of match-related and individual player characteristics on relative total and HSR distances.

Results: Matches played away from home, early in the season and following short recovery cycles were associated with reduced relative total and HSR distances. Matches won contained less relative total and HSR distance; whereas only HSR distance was higher against weaker opposition. The total time the ball was out of play reduced relative total but not HSR distances. The number of defensive but not attacking involvements influenced both physical performance measures. Finally, player fitness was positively related to both relative total and HSR distances.

Conclusions: There appears to be a complex interplay of factors affecting match-running performance in rugby league. The results underline the importance of considering contextual factors when analysing rugby league match-activity profiles.

CHAPTER FIVE

METABOLIC POWER DEMANDS OF RUGBY LEAGUE MATCH-PLAY

Kempton, T., Sirotic, A., Rampinini, E., & Coutts, A.J. (2015). Metabolic power demands of rugby league match-play. International Journal of Sports Physiology and Performance, 10(1), 23-28.

ABSTRACT

Purpose: To describe the metabolic demands of rugby league match-play for positional groups, and compare match distances obtained from high-speed running classifications with those derived from high metabolic power.

Methods: Global positioning system (GPS) data were collected from 25 players from a team competing in the National Rugby League (NRL) competition over 39 matches. Players were classified into positional groups (adjustables, outside backs, hit-up forwards, and wide-running forwards). The GPS devices provided instantaneous raw speed data at 5Hz, which was exported to a customised spreadsheet. The spreadsheet provided calculations for speed-based distances (e.g. total distance; high-speed running, >14.4 km h^{-1}; and very high-speed running, >18.1 km h^{-1}) and metabolic power variables (e.g. energy expenditure; average metabolic power; and high-power distance, >20 W kg^{-1}).

Results: The data show that speed-based distances and metabolic power varied between positional groups, although this was largely related to differences in time spent on field. The distance covered at high-running speed was lower compared to that obtained from high-power thresholds for all positional groups; however, the difference between the two methods was greatest for hit-up forwards and adjustables.

Conclusions: Positional differences existed for all metabolic parameters, although these are at least partially related to time spent on the field. Higher speed running may underestimate the demands of match-play when compared to high power distance – although the degree of difference between the measures varied by position. The analysis of metabolic power may complement traditional speed-based classifications and improve our understanding of the demands of rugby league match-play.

Kempton, T., Sirotic, A., Rampinini, E., & Coutts, A.J. (2015). Metabolic power demands of rugby league match-play. International Journal of Sports Physiology and Performance, 10(1), 23-28.

CHAPTER SIX

THE EXPECTED VALUE OF POSSESSION IN PROFESSIONAL RUGBY LEAGUE MATCH-PLAY

Kempton, T., Kennedy, N., & Coutts, A.J. (2015). The expected value of possession in professional rugby league match-play. Journal of Sports Sciences, *in press*.

ABSTRACT

This study estimated the expected point value for starting possessions in different field locations during rugby league match-play and calculated the mean expected points for each subsequent play during the possession. It also examined the origin of tries scored according to the method of gaining possession. Play by play data were taken from all 768 regular season NRL matches from 2010-2013. A probabilistic model estimated the expected point outcome based on the net difference in points scored by a team in possession in a given situation. An iterative method was used to approximate the value of each situation based on actual scoring outcomes. Possessions commencing close to the opposition's goal line had the highest expected point equity, which decreased as the location of the possession moved towards the team's own goal line. Possessions following an opposition error, penalty or goal-line drop out had the highest likelihood of a try being scored on the set subsequent to their occurrence. In contrast, possessions that followed an opposition completed set or a re-start were least likely to result in a try. The expected point values framework from our model has applications for informing playing strategy and assessing individual and team performance in professional rugby league.

Kempton, T., Kennedy, N., & Coutts, A.J. (2015). The expected value of possession in professional rugby league match-play. Journal of Sports Sciences, 34(7), 645-650.

CHAPTER SEVEN

TECHNICAL PERFORMANCE INDICATORS RELATED TO WINNING PROFESSIONAL RUGBY LEAGUE MATCHES

Kempton, T., & Coutts, A.J. (2015). Technical performance indicators related to winning professional rugby league matches. Journal of Sports Sciences, *in review*.

ABSTRACT

This study examined the variability and association with the probability of winning for technical performance indicators from 384 matches during two National Rugby League seasons. A mixed model reliability analysis with random effects for team identity was employed to obtain the mean and between and within-team variation for each performance indicator. A logistic regression model with a random effect for team identity was employed to examine the influence of each individual performance indicator on the probability of winning a match. The effect of a two within-team SD change in the performance indicator on the probability of winning a match was obtained. The factors that were clearly related to an increased probability of winning a match were total run metres, line breaks, tackle breaks, total kick metres, play-the-balls, kick receives, metres per run, handles, interceptions and forced error in tackle. Tackles, missed tackles and errors were associated with a decreased probability of winning matches. Offloads, drop outs forced, penalties conceded, one on one steals and 40/20 kicks had trivial effects on the probability of winning. This study identified important performance indicators related to winning rugby league matches which can be used to guide match analyses, and inform playing and training strategies.

Kempton, T., & Coutts, A.J. (2015). Technical performance indicators related to winning professional rugby league matches. Journal of Sports Sciences, *in review*.

CHAPTER EIGHT

AN INTEGRATED ANALYSIS OF MATCH-RELATED FATIGUE IN PROFESSIONAL RUGBY LEAGUE

Kempton, T., Sirotic, A., & Coutts, A. (2015). An integrated analysis of match-related fatigue in professional rugby league. Journal of Sports Sciences, 33(1), 39-47.

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ABSTRACT

This study examined the changes in external outputs, including metabolic power variables, and internal response whilst considering contextual factors on physical performance variables during rugby league match-play. Physical performance (total distance, high-speed running and high-power distances, average metabolic power), heart-rate (percentage heart-rate peak and training impulse), collisions (attacking and defensive) and contextual (time in attack, time in defence, time out of play) data were collected from 18 rugby league players during 38 games throughout two National Rugby League seasons. Physical variables were highest in the first 10-min period of each half ($P < 0.001$). Heart-rate indices peaked in the second 10 min period and were lower during second half periods ($P < 0.001$). Few differences existed in collisions and contextual factors across 10-min periods. Physical variables were highest during the first 5-min period compared to the final ($P < 0.001$). There was no difference in heart-rate response, attacking collisions or contextual factors between these periods. Following the peak 5-min period in the match, there were reductions in physical, heart-rate, defensive collisions and contextual factors ($P < 0.001$). The data show temporal changes in physical performance, heart-rate response and collisions during rugby league match-play, although these are affected by contextual factors.

Kempton, T., Sirotic, A., & Coutts, A. (2015). An integrated analysis of match-related fatigue in professional rugby league. Journal of Sports Sciences, 33(1), 39-47.

CHAPTER NINE

PHYSICAL, TECHNICAL AND TACTICAL DIFFERENCES BETWEEN SUCCESSFUL AND LESS-SUCCESSFUL RUGBY LEAGUE TEAMS

Kempton, T., Sirotic, A., & Coutts, A. (2015). A comparison of physical and technical performance profiles between successful and less-successful professional rugby league teams. International Journal of Sports Physiology and Performance, *in review*.

ABSTRACT

Purpose: This was the first study to examine differences in physical and technical performance profiles using a mixed model analysis of a large sample of match observations drawn from one successful and one less-successful professional rugby league team.

Methods: Match activity profiles were collected using global positioning satellite (GPS) technology from 29 rugby league players from a successful team during 24 games and 25 players from a less-successful team during 18 games throughout two separate competition seasons. Technical performance data were obtained from a commercial statistics provider. A progressive magnitude based statistical approach was used to compare differences in physical and technical performance variables between the reference teams.

Results: There were no clear differences in playing time, nor absolute and relative total distances or LSR distances between successful and less-successful teams. The successful team had possibly to very likely lower higher-speed running demands and likely fewer physical collisions than the less-successful team, although they likely to most likely demonstrated more accelerations and decelerations and likely higher average metabolic power. The successful team very likely gained more territory in attack, very likely had more possession and likely committed fewer errors. In contrast, the less-successful team was likely required to attempt more tackles, most likely missed more tackles and very likely had a lower effective tackle percentage.

Conclusions: In the present study, successful match performance was not contingent on higher match running outputs or more physical collisions, rather proficiency in technical performance components may differentiate between successful and less-successful teams.

Kempton, T., Sirotic, A., & Coutts, A. (2015). A comparison of physical and technical performance profiles between successful and less-successful professional rugby league teams. International Journal of Sports Physiology and Performance, *in review*.

CHAPTER TEN

GENERAL DISCUSSION

MAIN FINDINGS

Match performance in professional rugby league involves a complex interplay between physical, technical and tactical performance constructs. Sport scientists and performance analysts seek to develop valid and reliable physical and technical parameters to represent these different performance constructs. However, understanding of the relationship between these parameters and their performance constructs as well as the factors that influence them remains unclear. Therefore, a series of applied research studies were conducted to develop a better understanding of the factors affecting performance in professional rugby league match-play (Figure 10.9). This thesis identified the typical between-match variation of common physical and technical performance parameters during rugby league match-play and examined the independent effects of a variety of match-related factors on these measures of physical performance. Three separate studies contributed new causal indicators to enhance current understanding of physical, tactical and technical performance constructs during rugby league match-play, respectively. The final study determined the variables that were most related to successful match performance in professional rugby league.

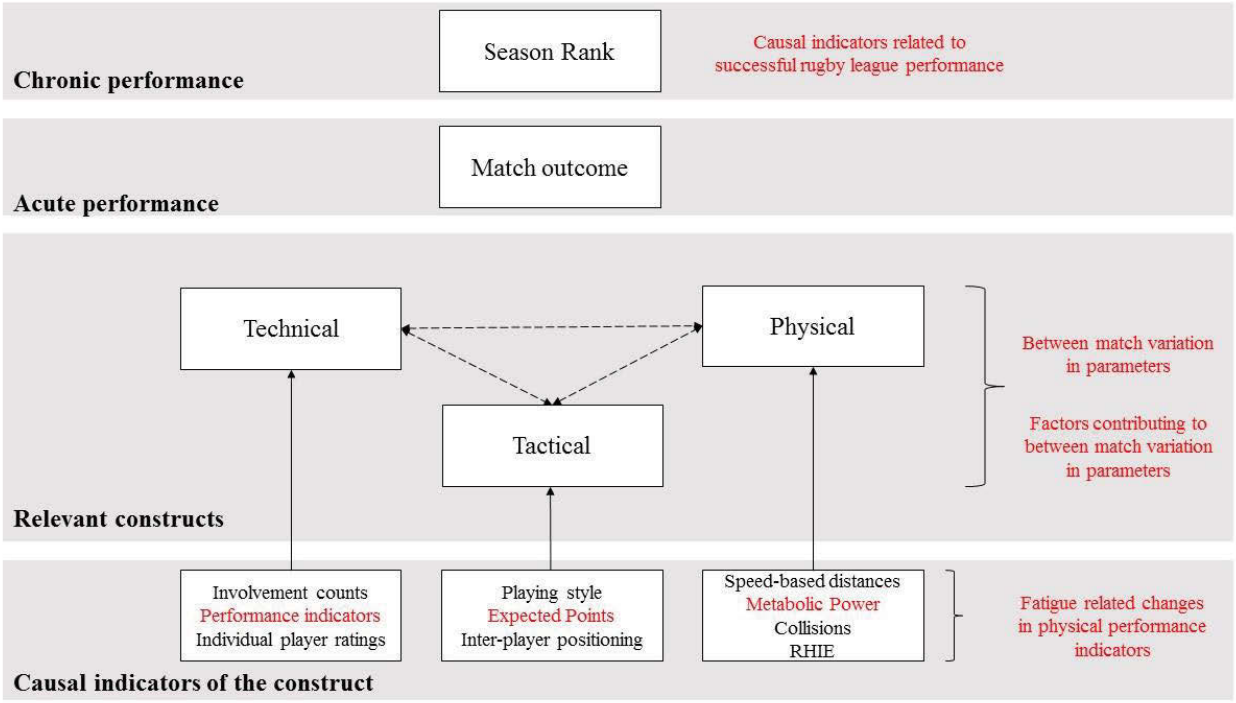

Figure 10.9: Conceptual model of rugby league match performance. New contributions to the model provided by this thesis are shown in red.

BETWEEN MATCH VARIATION AND FACTORS AFFECTING PHYSICAL PERFORMANCE IN PROFESSIONAL RUGBY LEAGUE

The complex nature of competition matches in team sports such as rugby league means that measures of physical performance are dynamic and vary between matches throughout the course of the season. The first two studies in this thesis examined the typical between match variations in these physical performance parameters and identified match-related factors that contribute to this variation. The data from *Study One* showed that while global measures of physical performance such as total distance are relatively stable (CV 3.6 %), higher-speed activities exhibit a large degree of between match variability (HSR: CV 14.6%; VHSR: CV 37.0 %). Additionally, within each speed category, the variation in performance tended to increase as the duration of the reference period decreased. The between-match variation observed in physical performance measures is due to a complex interplay of factors that affect match-running performance in rugby league. Indeed, *Study Two* demonstrated that factors including match location, season phase, match outcome, opposition strength and individual player characteristics affect relative total and HSR distances during NRL match-play. The results of *Study Two* underline the importance of considering contextual factors when analysing rugby league match-activity profiles. Given the large variation observed for some physical performance parameters and confounding effects of match contextual factors, the use of a progressive inferential statistical approach based on establishing the CV and SWC may assist with selection of appropriate sample sizes and interpreting the magnitude in change these measures. Furthermore, multilevel mixed models represent a statistical approach which permits analysis of the independent effects of such factors and can account for the data dependency that commonly occurs when multiple observations are drawn from the same cohort.

PHYSICAL PERFORMANCE IN PROFESSIONAL RUGBY LEAGUE MATCH-PLAY

Most time-motion analyses of rugby league match-play have used speed-based bands – such as low-speed running (LSR), high-speed running (HSR), very high-speed running (VHSR) and sprint distances – to describe the physical demands of competition. However, accelerations are common in rugby league due to the spatial constraints and brief, repeated running movements required during match-play. Accelerations incur significant metabolic costs which are often greater than constant speed movement and can occur from relatively low starting speeds. While these acceleration efforts have high metabolic demands, they may be neglected by traditional high-speed threshold categories. However, few studies have examined acceleration efforts during rugby league match-play. *Study Three* demonstrated that the metabolic power approach can be applied to describe the accelerated running demands of rugby league match-play. The

distance covered at high-speed was lower compared to that obtained from high-power thresholds for all positional groups. These results confirm that spatial constraints imposed by opposition players may limit the opportunity for high running speeds during rugby league match-play. Furthermore, HSR distance may underestimate the demands of match-play, as the distance covered during acceleration activities – which can be physically demanding even at low speeds – are often neglected by this method. While there are methodological limitations associated with the metabolic power approach, it may complement traditional speed-based analyses and improve our understanding of the demands of rugby league match-play.

MATCH-RELATED FATIGUE IN PROFESSIONAL RUGBY LEAGUE

A limitation of previous research into match-related fatigue in rugby league was the failure to account for the numerous extrinsic factors influencing time-motion data such as opposition strength, substitutions, possession, and time the ball is in play. Accordingly, *Study Six* examined temporal changes in physical performance variables, internal responses, exercise economy and the influence of contextual factors during rugby league match-play. The main findings were that both traditional speed-based and metabolic power derived indices displayed similar time-dependent reductions during the match. Secondly, the integration of internal load and external outputs demonstrated temporal changes in exercise economy. This study also confirmed the importance of assessing contextual factors such as total time in attack, defence and when the ball is out of play, as these differed between selected time periods during the match.

MEASURING TECHNICAL AND TACTICAL PERFORMANCE IN PROFESSIONAL RUGBY LEAGUE MATCH-PLAY

Despite research from other football codes reporting that technical and tactical proficiency may be more important determinants of match success than physical output, relatively few studies have examined technical skill performance in rugby league match-play. It is thought that successful rugby league match performance requires teams to dominate ball possession and field position in order to accumulate points. To investigate this hypothesis, *Study Four* developed a model to estimate the expected point value of possession according to field location and play number in professional rugby league match-play. Results show that expected points equity is highest when in possession close to the opposition's goal-line and decreases gradually as the location moves towards the team's own goal-line. The expected outcomes model demonstrate that teams should avoid conceding penalties and turning over possession as these actions increase the point equity of the opposition. Conversely, it is possible to reduce the point equity of the opposition by completing your own possessions and forcing them to start their sets closer

to their own goal-line. Although expected point outcome decreases as each play in a possession is used up, earning penalties and repeat sets represent an opportunity to improve point equity.

While *Study Four* established the expected outcomes from possession in various field positions, *Study Five* examined the specific technical performance indicators that are most strongly associated with winning NRL competition matches. Gaining territory – through running or kicking the ball, breaking tackles and the defensive line, and reducing errors all increased the chances of winning the match. In contrast, increased time spent in defence – represented by having to complete a greater number of tackles – and missing more tackles reduced the probability of winning. Forcing errors and intercepting passes from the opposition were two methods for improving the chances of winning when defending. The results from both the expected point values model and the investigation of key technical performance indicators demonstrate that gaining territory and minimising errors when in possession and minimising opposition attacking opportunities is critical for successful match outcomes. These findings have applications for informing playing strategy and assessing individual and team performance in professional rugby league.

DIFFERENCES IN PHYSICAL AND TECHNICAL PERFORMANCE BETWEEN SUCCESSFUL AND LESS-SUCCESSFUL PROFESSIONAL RUGBY LEAGUE TEAMS

The validity of physical and technical parameters as constructs of match performance can be established by comparing these measures between matches won and matches lost within the same team, or between successful and less-successful teams throughout an entire season. While several studies have examined differences in physical performance between successful and less-successful professional rugby league teams, the only study to compare technical performance parameters was conducted in a semi-professional competition. *Study Seven* used a large sample of match observations to investigate the physical and technical performance variables that differentiate between successful and less-successful NRL teams. There were no differences in playing time, nor absolute and relative total distances or LSR distances between successful and less-successful teams. The successful team had less higher-speed running demands and fewer physical collisions than the less-successful team, although they performed more accelerations and decelerations and produced higher average metabolic power. The successful team gained more territory in attack, had more possession and committed fewer errors. In contrast, the less-successful team was required to attempt more tackles, missed more tackles and, as a result, had a lower effective tackle percentage. The results demonstrate that successful match performance

was not contingent on greater match running outputs or more physical collisions, rather proficiency in technical performance components may differentiate between successful and less-successful teams.

LIMITATIONS

This thesis has adopted an observational approach to longitudinal physical and technical performance data to study factors relating to match performance in professional rugby league. There are several limitations arising from the applied nature of the research studies comprising this thesis that need to be acknowledged. Firstly, the data used for *Study One*, *Study Two*, *Study Three* and *Study Six* were drawn from a single NRL club, and as such the results that we obtained may only be directly applicable to this playing group. *Study Seven* identified factors that differentiated between a successful and a less-successful NRL team, however these factors may not be representative of all successful and less-successful teams. These limitations are typical for many applied research studies that involve GPS match performance data collected from only a single team. A potential way of overcoming these limitations is for future studies to combine data from multiple teams to provide a more representative sample of physical match performance. To overcome these limitations of single club case-studies, the technical performance data in *Study Four* and *Study Five* was provided by a commercial statistics provider for all teams competing in the NRL during the observation period. Unfortunately the commercial statistics provider has not published information regarding the validity and reliability of their data collection methods, and so the accuracy of the data analysed in those studies has not been established.

The use of GPS technology to obtain time-motion profiles is common in rugby league match-play. Current GPS devices provide acceptable validity and reliability for measuring movements over long distances at low speeds, however, they are less precise when assessing short, high speed activities and rapid changes in direction (Petersen et al., 2009; Waldron, Worsfold, et al., 2011). The technical error of GPS devices when measuring physical performance profiles is a limitation given the importance of these actions in rugby league match-play. Physical collisions represent an important component of the physiological demands of rugby league match-play, however they are neglected by traditional time-motion analyses obtained from GPS systems. Indeed the metabolic power approach for describing the physical demands of rugby league match-play utilised in *Study Three* was limited in that it was unable to account for the substantial energetic costs arising from physical collisions. There are also methodologic limitations associated with the metabolic power approach relating to the location of centre of

mass of the body, the influence of limb movement on running energetics, the validity of the equation for assessing high equivalent slopes and the influence of air resistance (Di Prampero et al., 2005; Osgnach et al., 2010). Recent developments in micro-technology means that some GPS devices are now able to detect collisions automatically, however, this function requires further validation in a range of contact scenarios.

CONTRIBUTION OF THESIS

This thesis applied a conceptual model of performance – originally proposed for soccer – and expanded it to enhance current understanding of factors relating to performance in professional rugby league. The series of research studies that inform the thesis demonstrate how aspects of the conceptual model can be applied in the analysis of rugby league match-play, with specific reference to dimensions of physical, technical and tactical performance. The application of this model through a range of research studies has enunciated several important themes that should be considered when analysing match performance in rugby league and other team sports.

Firstly, it is important to continue to develop casual indicators of the relevant performance constructs (physical, technical and tactical) which are able to improve current understanding of overall match performance. These indicators may be adapted from other sports or developed within the sport through innovative processes – often in consultation with expert coaches or analysts. It is important to validate these new metrics and establish their reliability, however it must also be acknowledged that in certain instances, innovative analytic techniques may be adopted for use before they have been fully validated, which is not to discount their utility, however if these metrics are to be embraced for long term use then a thorough validation and analysis of reliability is necessary to cement their proof of concept. Improvements in the validity of current match analysis technology (such as GPS devices) and increasing availability of data from competition matches in rugby league and other team sports will facilitate the development of new metrics for analysing constructs of performance. As new metrics are developed or adapted to a sport, in addition to establishing their validity and reliability, it is critical to establish whether it is related to overall match success, which is perhaps the ultimate indicator of the utility of any performance metric.

With the availability of progressively larger data sets describing components of physical (e.g. time-motion analyses) and technical/tactical (e.g. detailed play-by-play data) performance during match-play, sport scientists and performance analysts increasingly require knowledge of

advanced statistical procedures to properly analyse these data. Emerging statistical methods such as multilevel modelling can be useful for analysing the data commonly derived from match observations, and importantly are able to account for the data dependency that occurs when multiple observations are drawn from a group of individual subjects over an extended period of time. Several of the studies in this thesis have utilised advanced procedures such as multilevel modelling and expected equity equations to analyse components of rugby league match performance, and the continued use of such advanced statistical methods to interrogate large data sets will enhance current understanding of match performance.

An important theme emerging from several of the studies in this thesis is the importance of accounting for contextual factors – such as time in play, opposition strength and match location – when analysing rugby league match performance. These factors have been shown to effect match running outputs and therefore must be accounted for when assessing these metrics. In addition, several of the studies presented in this thesis have shown that technical and tactical dimensions of performance are more closely associated with successful match outcomes than physical performance (i.e. match running outputs). This is not to discount the utility of time-motion analyses of rugby league match-play, however, it is important to move towards integrating physical performance data with technical performance in order to provide a more comprehensive understanding of the interplay between these constructs of performance. Indeed, rather than considering physical performance metrics in isolation, it may be beneficial to examine these measures in specific contexts of play (e.g. running performance when in possession of the ball or when employing certain tactical phases of play). As the individual constructs of match performance (i.e. physical, technical and tactical) are closely linked and do not occur in isolation, continued efforts to integrate these measures of performance and interpret outcomes in relation to the context in which they occur will yield further important insights into overall match performance in professional rugby league.

This thesis has also identified some important limitations in current rugby league match analyses – particularly relating to technical limitations of GPS micro-technology, accurately representing technical performance through coding of match-play and reliance on single club case studies for many analyses. While these limitations are typical for many applied match analysis research projects and do not diminish the contribution of the individual studies contained within this thesis, it is important to consider the outcomes of this research in light of these constraints. Finally, in the following chapter there is a summary of directions for future research in order to expand on current the body of work presented in this thesis and continue to develop understanding of match performance in professional rugby league.

PRACTICAL APPLICATIONS

The studies contained in this thesis have provided practical recommendations regarding the analysis of physical, technical and tactical performance in rugby league match-play:

- Total distance is a relatively stable performance measure; however, the variability is increased for high and very-high speed running measures.

- Researchers and practitioners should establish the between match CV specific to their athlete population. Progressive statistical approaches which use the CV may assist in designing applied research studies and interpreting the magnitude of change between match observations.

- The results from *Study Two* show that players with aerobic higher fitness levels produce greater match-running output. Therefore, pre-season training programs should focus on improving aerobic fitness characteristics as this is associated with greater match-running performance. While it is desirable for players to have the capacity to perform increased levels of running during matches when required, caution is required with this application, as high match running outputs are not linked to success in professional rugby league match-play. Similarly, specific contact-based conditioning activities are required to attenuate the reduction in match running profiles arising from the physical demands of defensive collisions observed in *Study Two*.

- The metabolic power approach may be useful for understanding the energetic demands of match-play as it accounts for the accelerated running actions that occur commonly in rugby league. Caution is required when interpreting GPS data using traditional speed-based classifications as they may underestimate the true metabolic costs of rugby league match-play.

- Given possessions commencing close to the opposition's goal line have the highest expected point equity (~2 points), teams should practice their attacking set-plays in these advanced areas at training in order to maximise their scoring efficiency in these high-value situations.

- For teams to maximise their expected points equity they should avoid turning possession over before they have been able to complete their set and ensure that their opposition are forced to start their sets close to their own goal-line. It is suggested that

teams adopt a conservative approach when commencing sets close to their own-goal line in order to minimise the risk of turning over possession in these critical areas.

- Teams should focus on strategies to maximise territorial gain whilst in possession, with particular attention to methods for creating line breaks, while errors when in possession should be minimised. In addition, a strong kicking game to ensure that possession is returned to the opposition close to their goal-line will improve the probability of winning.

- A team is more likely to lose when required to make more tackles, so game management strategies are required to ensure that the team maintains at least a similar share of possession to their opponent. When in defence, a team can improve its probability of winning by minimising missed tackles and attempting to force the opposition to turn over the ball.

- It is important to consider contextual factors such as total time in attack, defence and time that the ball is out of play when examining fatigue-related changes in physical output, as these factors differ between certain stages of the match.

- Successful match performance in professional rugby league is not linked to maintaining high match-running output. Technical importance is important for differentiating between successful and less-successful teams. In particular, teams should employ match tactics to maximise territorial gain and avoid making errors when in possession, and should engage defensive strategies to reduce the number of missed tackles.

CHAPTER ELEVEN

SUMMARY AND RECOMMENDATIONS

SUMMARY

This thesis contains seven original research studies (*Chapters Three* to *Nine*) that develop a framework of rugby league match performance incorporating physical, technical and tactical components. The first study examined the typical between-match variation of common physical performance parameters during rugby league match-play. The second study further explored this concept by examining the independent effects of a variety of match-related factors on selected measures of physical performance. Studies three, four and five developed new parameters to enhance the current understanding of physical, tactical and technical performance during rugby league match-play, respectively. The sixth study adopted an integrated approach to examine the onset of match-related fatigue during rugby league competition. The final study compared a variety of physical, technical and tactical parameters between a successful and less-successful rugby league team in order to determine which variables were most related to successful match performance. A summary of the main findings from each study is presented in Table 11.1.

Table 11.1: Summary of the studies conducted as part of this thesis.

Chapter	Study Title	Games	Files	Variables	Findings
3	Between match variation in professional rugby league competition	23	345	Speed-based distance	Greater variability for higher speed running compared to total distance. There was increased variability in these measures as reference period length decreased.
4	Factors affecting exercise intensity in professional rugby league match-play	24	352	Speed-based distance	Matches played away from home, early in the season and following short recovery cycles had reduced relative total and HSR distances. Matches won had less total and HSR distance; HSR distance higher against weaker opposition. Time the ball out of play reduced relative total but not HSR distances. Number of defensive but not attacking involvements reduced both physical performance measures. Player fitness positively related to relative total and HSR distances.
5	Metabolic power demands of rugby league match-play	39	384	Speed-based distance Metabolic power	Speed-based distances and metabolic power varied between positional groups. HSR distance was lower compared to distance from HP thresholds.
6	The expected value of possession in professional rugby league match-play	768	-	Play location Possession outcome Try origins	Possessions close to the opposition's goal line had highest expected point equity. Possessions following an opposition error, penalty or goal-line drop out had the highest likelihood of a try from the subsequent set.

Table 11.1. Cont.

Chapter	Study Title	Games	Files	Variables	Findings
7	Technical performance indicators related to winning professional rugby league matches	384	-	Technical performance indicators	Total run metres, line breaks, tackle breaks, total kick metres, play-the-balls, kick receives, metres per run, handles, interceptions and forced error in tackle were positively related to winning matches. Tackles, missed tackles and errors were associated with decreased probability of winning matches. Offloads, drop outs forced, penalties conceded, one on one steals and 40/20 kicks had trivial effects on the probability of winning
8	An integrated analysis of match-related fatigue in professional rugby league	38	165	Speed-based distance Metabolic power Collisions Heart-rate	Physical variables were highest in the first 10-min period of each half. Heart-rate indices peaked in the second 10 min period and were lower during second half periods. Few differences in collisions and contextual factors across 10-min periods. There were reductions in physical, heart-rate, defensive collisions and contextual factors following the peak 5-min period
9	A comparison of physical and technical performance profiles between successful and less-successful professional rugby league teams	42	645	Speed-based Distance Metabolic power Collisions Technical performance indicators Expected points	No clear differences in playing time, nor absolute and relative total distances or LSR distances between successful and less-successful teams. The successful team had less HSR and fewer collisions than the less-successful team, although more accelerations and decelerations and higher average metabolic power. The successful team gained more territory, had more possession and committed fewer errors. The less-successful team attempted more tackles, missed more tackles and had a lower effective tackle percentage.

HSR: high-speed running; HP: high-power; LSR: low-speed running.

FUTURE DIRECTIONS

This thesis has developed a framework for understanding the physical, technical and tactical constructs of match performance in professional rugby league. To expand on the findings of the studies presented in this thesis, it is recommended that further research investigates the following areas:

- Physical collisions contribute substantially to the physiological demands of rugby league match-play, however few studies have reported on these actions. This is likely due to difficulties in quantifying the occurrence and severity of physical collisions. With recent developments in micro-technology now facilitating the automatic detection of collision events, future research should validate this technology in a variety of contact settings - such as tackling and being tackled - for common GPS systems. Once the validity of this technology has been well established, further research is warranted to further examine collisions during rugby league match-play.

- While some limited research has identified relationships between physical characteristics and performance measures in rugby league, future research should examine relationships between a comprehensive array of physical qualities and common physical and technical performance parameters during rugby league match-play. Establishing the association between tests of physical traits and components of match performance will provide construct validity for common physical tests of these traits.

- To date no study has examined the relationship between physical characteristics and match-related fatigue during professional rugby league match-play. Identifying whether certain physical characteristics (as measured by tests of specific intermittent running capacity) can attenuate fatigue-related reductions in physical output during rugby league match-play has important implications for the preparation of professional rugby league players. Furthermore, future studies could also examine the complex interaction of physical profiles of both teams in the same match and the onset of match-related fatigue.

- While we have identified key technical performance indicators that are associated with successful match outcomes in professional rugby league, future research should develop a framework for objectively measuring an individual player's technical performance based on their contribution to the match outcome. Research in other

football codes has used linear weightings to create an objective player rating system and this type of analysis would have important applications for measuring individual player performance during games and may be used to guide recruitment and player retention decisions.

- Relatively few studies have examined tactical performance during rugby league match-play. With the recent emergence of commercial statistics providers which now provide detailed technical performance data, future research should utilise this source of information to better understand the tactical dimension of rugby league match performance. Indeed, additional studies are warranted to identify and describe different patterns of play employed by rugby league teams, particularly those associated with more successful teams. Researchers should consider enlisting the input of expert rugby league coaches when designing applied match-analysis studies to examine tactical performance.

- Emerging technologies such as local position measurement or automated video-based systems could be used to obtain precise player locations during rugby league match-play, and analyses of the dispersion and inter-related movements of players could yield further insights into tactical components of rugby league match-play. Integrating these types of analyses with real-time statistics could be beneficial for informing tactical strategies during match-play.

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APPENDICES

APPENDIX A: UNIVERSITY ETHICS APPROVAL

Dear Applicant

The UTS Human Research Ethics Committee reviewed your application titled, "Factors affecting performance in professional rugby league", and I am pleased to inform you that ethics approval is now granted. Any conditions of approval as stipulated in the Committee's comments will be noted on our files.

Your approval number is UTS HREC REF NO. 2012000260

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

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

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

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

Yours sincerely,
Professor Marion Haas
Chairperson
UTS Human Research Ethics Committee
C/- Research & Innovation Office
University of Technology, Sydney