Match-play demands of a Super Rugby team

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DECLARATION

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SUMMARY

Rugby union is a physically challenging intermittent sport, whose multi-faceted nature provides players with a range of playing positions, each with various physical traits, roles and responsibilities. In addition, following professionalisation, the match-play demands of the game have continued to evolve. There is currently limited literature on the contemporary match-play demands of rugby union, particularly temporal patterns as a match progresses, and peak periods of play. This study aimed to provide an accurate in-depth investigation of position-specific locomotive and contact demands during match-play, which will provide a basis for optimal preparation for competition, thereby potentially improving performance and reducing injury risk.

Thirty-four professional male rugby union players (20–32 years old) were assessed during match-play over two Super Rugby seasons (2014 and 2015). Players were grouped into Forwards (*n* = 83) and Backs (*n* = 124), as well as Tight Forwards (*n* = 33), Loose Forwards (*n* = 50), Inside Backs (*n* = 60), and Outside Backs (*n* = 64). GPS and video-based analysis provided locomotive (maximum speed, sprint count, total distance, walking distance, jogging distance, striding distance, and sprint distance) and contact (total contact involvements, rucks, tackles, carries, scrums, and mauls) match-play data that were described through three methods: Full Match Analysis, Temporal Pattern Analysis, and Peak Period Analysis. A mixed model repeated measures ANOVA was utilised to draw comparisons between positional groups.

Full Match Analysis saw the majority of locomotive demands to be greater for Backs than Forwards, and the majority of contact demands to be greater for Forwards than Backs. Further differences were seen for positional subgroups. Within-group Temporal Pattern Analysis of Forwards and backs suggest that both exhibit a slow-positive locomotive pacing strategy throughout each half. A similar pattern was identified for Forwards when measuring contact demands in the first half, and a flat-line pacing strategy in the second. However, the backs displayed a sporadic pattern. For the most part, the positional subgroups reflected the findings of each of their respective positional groups, Forwards and Backs, with some variation observed between forward positional subgroups. Analysis of peak periods suggest that Backs have more intense peak locomotive demands, where Forwards have more intense peak contact demands. The Forwards' and Backs' positional subgroups mirror these findings. Equations derived from Power Law are provided to indicate training drill intensity targets as a function of time, which would best reflect peak periods of match-play.

Various differences and similarities in locomotive and contact match-play demands exist between Forwards and Backs, and Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs. Performance staff should physically prepare players in a way that reflects these position-specific demands, with conditioning and recovery protocols tailored accordingly. Future research should aim to include multiple teams and further divide the positional groups into individual positions. With developments in technology, an acceleration metric would provide better context to the distances covered.

Keywords: match-play demands; physical preparation; video analysis; GPS; rugby union

OPSOMMING

Rugby is ‘n fisiek uitdagende sport met veelsydige vereistes wat spelers ‘n wye verskeidenheid posisies, rolle en verantwoordelikhede, elk met verskillende fisieke eienskappe, bied. Benewens die sport se fundamentele kompleksiteit, het professionalisering gelei tot verhoogde wedtrydsvereistes wat aanhoudend ontwikkel. Daar is tans beperkte literatuur beskikbaar aangaande die sport se huidige vereistes, veral met betrekking tot tyd-verwante spelpatrone vir 'n wedstryd soos dit vorder, asook teen piek spelperiodes. Hierdie studie het gepoog om ‘n akkurate omvattende ondersoek van posisie-spesifieke lokomotiewe- en kontakvereistes gedurende ‘n wedstryd te lewer. Hierdie resultate behoort die basis te vorm vir ‘n optimale seisoenvoorbereidingsprogram vir ‘n kompetisie, en kan sodoende spelers se atletiese werksverrigting verhoog en die beseringsrikiko verlaag.

Vier-en-dertig professionele manlike rugbyspelers (20-32 jaar oud) was geassesseer tydens ‘n reeks wedstryde wat strek oor twee Super Rugby seisoene (2014 en 2015). Die spelers was gegroepeer in ‘voorspelers’ (n = 83) en ‘agterspelers’ (n = 124), asook subgroepe vir ‘vastevoorspelers’ (n = 33), ‘losvoorspelers’ (n = 50), ‘binne-agterspelers’ (n = 60) en ‘buite-agterspelers’ (n = 64). GPS en video data-ontleding verskaf lokomotiewe data (maksimum spoed, naelloop-telling, totale reisafstand, stapafstand, drafafstand en naelloopafstand) en kontakdata (totale kontak voorvalle, losskrums, speler duike, baldrae, skrums en losgemale) wat beskryf was deur drie metodes: ‘n Volle wedstryd ontleding, tyd-patroon ontleding en piek spelperiode ontleding. ‘n Gemengde-model herhaalde mate ANOVA was gebruik om die verskillende posisies te vergelyk.

Volle wedstryd ontleding het getoon dat die ‘agterspeler’ groep se lokomotiewe vereistes hoër was as vir die ‘voorspeler’ groep, terwyl die kontak vereistes oor die algemeen hoër was vir die 'voorspelers' as vir die 'agterspelers'. 'n Ondersoek onder die subgroepe het meer verskille openbaar. Intragroep tyd-patroon ontleding toon dat beide groepe 'n lae, positief-toenemende pas strategie implementeer. 'n Soortgelyke patroon was waargeneem onder die 'voorspelers' se kontakvereistes in die eerste helfte van 'n wedstryd, wat dan afneem na 'n neutrale, plat pas strategie in die tweede helfte. Die 'agterspelers' toon 'n sporadiese patroon oor die hele wedstryd. Oor die algemeen stem die subgroepe se resultate ooreen met die oorhoofse groep, met klein afwykings onder die 'voorspeler' subgroepe. Piek spelperiode ontleding toon dat die 'agterspelers' meer intense lokomotiewevereistes het, terwyl die 'voorspelers' hoër kontakvereistes het. Die subgroepe bevestig hierdie resultaat. Vergelykings afgelei vanaf die kragwet word verskaf wat oefeningsintensiteit definieer as 'n funksie. Hierdie funksie verteenwoordig 'n goeie skatting van die piek spelperiodes van 'n wedstryd.

Daar is verskeie ooreenkomste en verskille tussen die 'voorspeler' en 'agterspeler' groepe, en die 'vastevoorspelers', 'losvoorspelers', 'binne-agterspelers' en 'buite-agterspeles' subgroepe, se lokomotiewe- en kontakvereistes tydens 'n wedstryd. Fisieke voorbereiding deur prestasiepersoneel vir spelers behoort die unieke vereistes vir elke posisie te reflekteer, met die kondisionering- en herstelprotokolle aangepas soos nodig. Toekomstige navorsing moet poog om meervoudige rugbyspanne en meer posisie subgroepe in te span. Met tegnologiese ontwikkeling sal 'n versnellingsmaatstaf meer konteks kan verskaf vir die afstande wat spelers dek.

Sleutelwoorde: wedstrydsvereistes; fiskieke voorbereiding; video-ontleding; GPS; rugby

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

%	:	Percentage
ANOVA	:	Analysis of Variance
B	:	Backs
cm	:	Centimetre (s)
F	:	Forwards
GPS	:	Global Positioning System
Hz	:	Hertz
IB	:	Inside Backs
IRB	:	International Rugby Board
IRFB	:	International Rugby Football Board
kg	:	Kilogram (s)
$km.h^{-1}$	:	Kilometres per hour
LF	:	Loose Forwards
LSD	:	Least Significant Difference
m	:	Meters
$m.min^{-1}$	:	Metres per minute
$m.s^{-1}$	:	Metres per second

min	:	Minute (s)
mm	:	Millimetre (s)
n	:	Number
OB	:	Outside Backs
RFU	:	Rugby Football Union
Rugby	:	Rugby union
s	:	Seconds
SANZAR	:	South African, New Zealand and Australian Rugby Unions
SD	:	Standard deviation
TF	:	Tight Forwards
TMA	:	Time-motion analysis
v	:	Versus
Vmax	:	Maximum velocity
WR	:	World Rugby

CHAPTER ONE

INTRODUCTION

A. PURPOSE OF THE STUDY

Rugby union's (rugby) multi-faceted nature provides potential players with a range of playing positions, each with various physical traits, roles and responsibilities (Jones et al., 2015; Lindsay et al., 2015; Duthie et al., 2003). It might be for this inclusivity that the sport sees men and women on all continents competing, forming one of the world's most popular sports. Although it is one of the oldest widely played contact team sports, rugby had a relatively late age of professionalisation (Malcolm et al., 2000). This is largely due to the founding union's strong belief in amateurism. A number of factors led to the eventual professionalisation of rugby in 1995, which resulted in increased resources and in turn, the rapid development of the game (Quarrie et al., 2007). Already a physically challenging intermittent sport, the demands of the contemporary game have evolved (Quarrie et al., 2007). In order to optimally prepare players for competition, regarding training prescription and recovery, these demands need to be quantified.

Two commonly used methods to quantify the external demands of rugby are global positioning system (GPS) and video-based analysis. GPS primarily provides locomotive data and, for the purpose of this study, video-based analysis was used to capture contact data. Once data is collected, there are various systems of analysis used to provide coaches and performance staff with valuable information that influences tactical decisions and physical preparation of players.

A conventional method is to report the entire match demands as totals. Although total match demands have their practical applications, it has been shown in rugby (Read et al., 2017) and similar contact sports that mean demands underestimate the peak periods of match-play (Gabbett et al., 2012). Therefore, it is critical to identify the demands during peak periods of play in order to give a better reflection of what is required of players. Another method is to analyse temporal patterns and investigate how measures change as the match progresses, indicating pacing strategies and the most likely areas of fatigue.

An accurate in-depth investigation of position-specific locomotive and contact characteristics during match-play should provide a basis for optimal preparation for competition, thereby potentially improving performance and reducing injury risk. In addition, analysis of temporal patterns should influence tactical decisions and strategies during match-play.

B. AIMS, HYPOTHESES AND OBJECTIVES

The current study aimed to quantify the locomotive (maximum velocity, total distance, walking distance, jogging distance, striding distance, sprint distance and sprint count) and contact characteristics (total contacts, carries, rucks, tackles, scrums and mauls) through various systems of analysis as guided by the aims. The systems of analysis included full match analysis, temporal pattern analysis, and peak period analysis. This analysis was according to positional groups (Forwards and Backs) and positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

B.1. FULL MATCH ANALYSIS

The first aim of the current study was to determine position-specific differences in locomotive and contact demands between Forwards and Backs, and positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs) of professional rugby players throughout an entire match, over a period of two Super Rugby seasons (2014 and 2015).

B.1.1. Hypothesis One

The majority of locomotive demands (maximum speed, sprint count, total distance, distance walking, distance jogging, distance striding, and distance sprinting) will be greater for Backs than Forwards.

Objective One: To compare the locomotive demands (maximum speed, sprint count, total distance, distance walking, distance jogging, distance striding, and distance sprinting) of Forwards and Backs throughout an entire match.

B.1.2. Hypothesis Two

The majority of contact demands (total contacts, carries, rucks, tackles, scrums, and mauls) will be greater for Forwards than Backs.

Objective Two: To compare the contact demands (total contacts, carries, rucks, tackles, scrums, and mauls) of Forwards and Backs throughout an entire match.

B.1.3. Hypothesis Three

The majority of locomotive demands (maximum speed, sprint count, total distance, distance walking, distance jogging, distance striding, and distance sprinting) will be greater for Outside Backs than Tight Forwards, Loose Forwards, and Inside Backs.

Objective Three: To compare the locomotive demands (maximum speed, sprint count, total distance, distance walking, distance jogging, distance striding, and distance sprinting) of Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs throughout an entire match.

B.1.4. Hypothesis Four: The majority of contact demands (total contacts, carries, rucks, tackles, scrums, and mauls) will be greater for Loose Forwards than Tight Forwards, Inside Backs, and Outside Backs.

Objective Four: To compare the contact demands (total contacts, carries, rucks, tackles, scrums, and mauls) of Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs throughout an entire match.

B.2. TEMPORAL PATTERN ANALYSIS

The second aim of the current study was to determine the position-specific within-group differences of Forwards, Backs, and positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs) during each eighth of a match in terms of total distance and contact involvements, over a period of Two Super Rugby seasons.

B.2.1. Hypothesis Five: Match periods one and five will have a further total distance and more contact involvements compared to all remaining match periods for Forwards and Backs.

Objective Five: To compare within-group, the total distance between the eight periods of match-play for Forwards and Backs.

Objective Six: To compare within-group, the total contact involvements between the eight periods of match-play for Forwards and Backs.

B.2.2 Hypothesis Six: Match periods one and five will have a further total distance and more contact involvements compared to all remaining match periods for all positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

Objective Seven: To compare within-group, the total distance between the eight periods of match-play for positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

Objective Eight: To compare within-group, the contact involvements between the eight periods of match-play for positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

B.3. PEAK PERIOD ANALYSIS

The third aim of the current study was to describe and determine the between- and within-group locomotive and contact differences in peak periods of play (rolling averages of most-intense 1–10 minutes) for Forwards and Backs, and positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs) throughout match-play, over a period of two Super Rugby seasons.

B.3.1. Hypothesis Seven: Backs will cover more relative distance than Forwards across all ten peak period durations, and Forwards will have more relative contact involvements than Backs across all ten peak period durations.

Objective Nine: To compare the relative distance between Forwards and Backs across all ten peak period durations.

Objective Ten: To compare the relative contact involvements between Forwards and Backs across all ten peak period durations.

Objective Eleven: To compare within-group, the relative distance between each peak period duration and its respective ensuing duration for Forwards and Backs.

Objective Twelve: To compare within-group, the relative contact involvements between each peak period duration and its respective ensuing duration for Forwards and Backs.

Objective Thirteen: To determine an equation to provide the peak relative distance as a function of time for Forwards and Backs.

Objective Fourteen: To determine an equation to provide the peak relative contact involvements as a function of time for Forwards and Backs.

B.3.2. Hypothesis Eight: Inside Backs and Outside Backs will cover more relative distance than Tight Forwards and Loose Forwards across all ten peak period durations, and Tight

Forwards and Loose Forwards will have more relative contact involvements than Inside Backs and Outside Backs across all ten peak period durations.

Objective Fifteen: To compare the relative distance between positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs) across all ten peak period durations.

Objective Sixteen: To compare the relative contact involvements between positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs) across all ten peak period durations.

Objective Seventeen: To compare within-group, the relative distance between each peak period duration and its respective ensuing duration for positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

Objective Eighteen: To compare within-group, the difference in relative contact involvements between each peak period duration and its respective ensuing duration for positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

Objective Nineteen: To determine an equation to provide the peak relative distance as a function of time for positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

Objective Twenty: To determine an equation to provide the peak relative contact involvements as a function of time for positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

C. VARIABLES

Table 1.1 List and definitions of study variables within context of the current study.

Variable	Definition
Maximum session speed	The fastest recorded speed at which a player travelled over a particular session, measured in kilometres per hour ($km.h^{-1}$).
Sprints	The total number (n) of times a player achieved a velocity faster than six metres per second (Refer to Table 3.3, speed zone 4).
Total distance	The total meterage (m) a player travelled.
Distance in speed zones	The total meterage (m) a player travelled within each of the four pre-set speed zones (Table 3.3).
Tackle	The total number (n) of tackles performed. Tackles and tackle attempts were counted where any player made contact with an opposing ball carrier in open play in a defensive manner with an attempt to bring them to ground.
Ruck	The total number (n) of attacking or defensive rucks a player was involved in. Ruck involvements were counted if a player made any contact with another player to either form or join a ruck.
Carries	The total number (n) an attacking player carried the ball into a tackle situation, where contact was made with a defending player.
Maul	The total number (n) of attacking or defensive mauls a player was involved in after "maul" had been called by the referee according to the World Rugby Laws of the Game
Scrum	When players from each team come together in scrum formation so that play can be started by throwing the ball into the scrum.
Total contact involvements	The sum of all video-derived variables (tackles, carries, rucks, mauls, scrums) as a single, totalled number (n).

D. ASSUMPTIONS

The following assumptions were made regarding the study: (a) that the players performed to the best of their abilities during matches, and (b) that the instruments used elicited valid and reliable responses at higher intensities.

E. SIGNIFICANCE OF THE STUDY

The demands required of rugby players during match-play are continually changing (Quarrie et al., 2007). Research is required in order to quantify the demands of the contemporary game. There is a dearth in current literature, where full match and temporal pattern analysis will add to the limited available literature for professional rugby. Peak period analysis will provide the first information of its kind for professional rugby.

Full match analysis quantifies the overall demands of players, providing a benchmark for training and game-replacement session prescription. Temporal pattern analysis might demonstrate an indication of the pacing strategies employed and the fatigue experienced throughout a match, which will identify position-specific demands as the match progresses. This information can be used to aid in the decision-making process for substitution times and position-specific areas of fatigue. Peak period analysis offers a deeper insight into match-play demands when compared to mean measures, which underestimate the maximum periods of play in rugby (Cunningham et al., 2018; Read et al., 2017). Quantifying the most-intense periods of match-play provides an indication of the intensities that drills should be completed at to best prepare for the peak periods of competition.

From a performance perspective, the information found can be practically applied. It will allow the coaching staff to better prepare players for the demands of the game through tailored training prescription and recovery, which will produce more resilient athletes that are potentially at a lower risk of injury and better prepared for performance.

F. OUTLINE OF THE DISSERTATION

The current study is broken down into five chapters, with this chapter considered the first. Chapter two gives a review of the literature and the significance of the study. The details of the methodology used for data capture and analysis is defined in chapter three. Chapter four presents the results. The results are then discussed in chapter five, which consists of the discussion, limitations, conclusion, practical applications and recommendations for future research.

CHAPTER TWO

THEORETICAL CONTEXT

A. INTRODUCTION

This chapter aims to firstly give a brief description of rugby and the professionalisation of the sport, which played a pivotal role in the development of Super Rugby. It follows into the known match-play demands required of players and the importance of players being able to meet them. The match-play demands vary according to playing position and their functional roles during match-play (Quarrie et al., 2013), which has resulted in various methods of grouping positions. Positions are often grouped into a generic split of forwards and backs, however, given the resources available to higher level teams, can be further divided into positional subgroups with training loads tailored accordingly. In order to tailor training loads, the training adaptation process needs to be understood. The current theory behind training adaptation is summarised with an emphasis on the need for a training stimulus that elicits optimal results.

The most common methods of collecting data on the demands at the elite level, through various forms of time-motion analysis (TMA), are explained. The movement characteristics relevant to the current study, provided through Global Positioning System (GPS), are covered as well as the contact characteristics, which are provided through video-based analysis. The different ways of interpreting and reporting these characteristics are discussed in detail, as well as the need for more intricate analysis to determine duration-specific intensities.

The methods used to analyse the data collected from TMA are discussed, as well as the practical applications thereof in preparation for competition. This is followed by descriptions of and current literature on the specific measures relevant to the current study.

The chapter concludes with the motivation for the study. Ultimately, the current study is aimed to investigate position-specific locomotive and contact characteristics during match-play. This information will aid in optimal player loading, through position-specific conditioning and recovery protocols.

B. DEVELOPMENT OF SUPER RUGBY

Rugby is a multi-faceted, invasion and evasion team sport, played in many countries across all continents by both men and women. As stipulated by World Rugby (WR, 2017), the 15-man format of the game comprises two teams of 15 players who compete against each other for two 40-minute halves (excluding time lost due to stoppages), with a break between that does not exceed 15 minutes during international matches. The rectangular playing field should not exceed 100 m between try lines and 70 m between touchlines, with a demarcated scoring area behind each try line (WR, 2017). Teams contest and gain possession, after which they can score points through tries, conversions, drop goals and penalty kicks. A try is scored through grounding the ball in the demarcated scoring area, while conversions, drop goals and penalty kicks are scored by kicking the ball over the crossbar and between the goalposts. The team who scores the most points is declared the winner. Rugby can be dated back well into the 19th century (Trueman, 2007), which has allowed for over a century of Law developments to form the contemporary game.

The Rugby Football Union (RFU) was the first governing body of rugby in England, the founding nation of rugby (Malcom et al., 2000). The RFU went on to form, along with other member unions, part of the International Rugby Board (IRB), who became the recognised lawmakers of the game (Trueman, 2007) and were replaced by World Rugby (WR) in 2014. One of the foremost catalysts in the development of the modern game was the professionalisation of the sport (Malcolm et al., 2000). For most of their history, the RFU and IRB were firm believers in the concept of amateurism. It was believed professionalism ran the risk of transforming play into work and thereby destroying the ‘essence’ of rugby. Critics claimed victory would be held above all else, leading to increasingly violent and dangerous play (Malcom et al., 2000). Additionally, it was believed rather than playing for the enjoyment of the game, players would become overly concerned with performing for spectators (Dunning & Sheard, 1976). In response, the RFU and International Rugby Football Board (IFRB, the predecessor of IRB) introduced anti-professionalism regulations which lead to a divide in rugby clubs, with one group branching off to form what became rugby league (Malcolm et al., 2000). As rugby grew in popularity, the pressure to professionalise the game increased. This was due to a number of underlying factors such as the gradual institutionalisation of indirect and direct payments to players, the development of an informal transfer 'market', increased sponsorship and marketing opportunities, the formalisation of player/club/governing body relationships, and the professionalisation of bureaucratic structures (Malcolm et al., 2000). All these factors accumulated and led to the official professionalisation of rugby in 1995 by the IFRB.

Following the professionalisation of rugby and the success of the 1995 Rugby World Cup, Southern Hemisphere rugby expanded. On the back of this expanse, the Super Rugby competition was officially inaugurated in 1996, although various Southern Hemisphere rugby competitions existed prior, such as the South Pacific Championship, the Super 6 and the Super 10. The Super 10 competition developed into Super Rugby, with the number of participating teams expanding to 12, 14, 15 and 18 (at the time of data collection for the current study) ("About Super Rugby", 2017). In 2018 the number of competing teams was reduced to 15 and is the current form of the competition. The competition was organised by the South African, New Zealand and Australian Rugby Unions (SANZAR), with participating teams located in each of these representative countries (Meiklejohn, 2010). As of 2016, Argentina has joined SANZAR to form SANZAAR, who has modified Super Rugby to include a team from both

Argentina and Japan. Super Rugby now acts as the premier rugby competition for the Southern Hemisphere and Japan.

Professionalisation ultimately changed the game of rugby. Since professionalisation in 1995, rugby has become more business-orientated. A major contributor to financial success for professional sports organisations are the fans. Fans provide direct revenue through gate-takings as well as indirect revenue from sponsorship, television rights and merchandise; therefore, viewer satisfaction is a primary goal (Garland et al., 2004). As a result of this, there have been a number of law changes in an attempt to enhance the sport's attractiveness to spectators as well as to remain competitive with other football codes (Duthie et al., 2003). Professionalisation also has indirectly led to changes within the team environment, with improvements in equipment technology, match analysis, player conditioning, and the appointment of specialist coaches and trainers (Quarrie et al., 2007). The aforementioned factors have resulted in the contemporary form of the game, which follows a faster pace with players that are heavier and taller (Quarrie et al., 2007).

Overall, it may be said that although the governing bodies of rugby have traditionally been in favour of amateurism, external pressures led to the professionalisation of the sport. Professionalisation indirectly led to the contemporary form of the game at the professional level, which is more intense with players that are better physically prepared (Quarrie et al., 2007).

C. MATCH-PLAY DEMANDS OF RUGBY

Rugby requires various tactical, technical, psychological, physical and physiological skills and abilities. Tactics can be described as "adaptation in action", where an attempt is made to secure objectives set by the strategy in the most effective way (Mouchet, 2005, p. 1). Ultimately, the objective of rugby is to win each match. Technical skills refer to the technique required to perform specific tasks, for instance passing the ball or performing a tackle. The psychology involved in athlete performance is often referred to informally as mental toughness (Jones, 2002). Mental toughness is defined by Jones (2002, p. 209) as "having the natural or developed psychological edge that enables the player to: generally, cope better than the opponents with the many demands (competition, training, lifestyle) that a sport places on a performer; specifically, be superior and more consistent than the opponents in remaining determined, focused, confident, and in control under pressure." The physical and physiological aspect refers to the anatomical structure and biochemical functions of an athlete, respectively. Players in peak physical and physiological condition would be better suited to perform the technical skills required of contact sports optimally and therefore better execute the strategy, also for longer periods of play (Gabbett, 2008; Argus et al., 2012; Johnston, 2015). The primary focus of the research undertaken for the current study was to quantify the locomotive and contact characteristics of players through various systems of analysis, thereby gaining insight into the physical and physiological requirements of players. This information could be practically utilised in performance programmes, with a goal of improving these physical and physiological requirements of players.

As a contact sport of intermittent nature, bouts of low-intensity activity, such as walking and jogging, are interspersed with bouts of high- and even maximal-intensity activity, such as sprinting and tackling. For example, during match-play, Super Rugby players were shown to complete on average 81 metres per minute ($m.min^{-1}$) in various speed zones and averaged one tackle, ruck involvement or ball carry into contact every two minutes (Lindsay, 2015). These values are based on averages throughout a match. Research which identifies and describes periods of most-intense play has shown these periods to present even greater distances covered (Read et al., 2018, Cunningham et al., 2018) and higher numbers of activities performed (Reardon et al., 2017). The intermittent nature of rugby places great physical and physiological demands on the players. Being able to perform these demands optimally is critical to success, and players should, therefore, be prepared for performance. The ability to accurately quantify the match-play demands of rugby should provide a basis for optimal position-specific player loading in terms of training and recovery.

The match-play demands placed on players can be broadly categorised as being external or internal. External demands refer to all physical activity imposed on the player during match-play, for example, the distance covered, number of sprints completed and tackles attempted, among other variables. Internal demands describe how the player's body reacts to the combination of the external demands, as well as other individual factors, such as sleep, nutrition and stress. Internal demands can be measured through physiological and psychological variables, for example, heart rate and rate of perceived exertion (Aniceto, 2015). The current study focused on quantifying the external match-play demands.

As individual positions in rugby vary according to physical traits (Nicholas, 1997; Duthie et al., 2003), roles and responsibilities (Jones et al., 2015; Lindsay et al., 2015; Deutsch et al., 2006), the training and recovery should be tailored according to playing position and reflect the unique demands of each. A team comprises 15 individual playing positions and numbers: (1) loose-head prop; (2) hooker; (3) tight-head Prop; (4) left lock; (5) right lock; (6) blind-side flanker; (7) open-side flanker; (8) number eight; (9) scrum-half; (10) fly-half; (11) left wing; (12) inside centre; (13) outside centre; (14) right wing; and (15) fullback. However, it is impractical to physically prepare an entire squad, which often consists of 45 or more players, according to individual positions. The positions are often split into two generic groups: Forwards (positions 1–8) and Backs (positions 9–15). Forwards are typically physically larger than Backs; often taller and heavier, with greater levels of body fat and absolute strength (Lombard et al., 2015; Duthie et al., 2003). These physical attributes prove advantageous to their positional roles. Greater body mass has been correlated with greater force production when scrummaging (Quarie et al., 2000) and greater stature provides a higher overall lineout jump height, critical to lineout success. These two events are key roles played by Forwards when restarting play. In general-play Forwards engage in more contact situations (Quarrie et al., 2013), with van Rooyen and colleagues (2008) reporting Forwards to be involved in 68 percent (%) of the total collisions. The bigger and stronger nature of the Forwards is advantageous when attempting to dominate the large number of collisions. In contrast, Backs are typically leaner, shorter, faster, more explosive, and relative to their mass, have superior aerobic fitness (Duthie et al., 2003). These characteristics better suit their roles in match-play, which require fewer contact involvements, but a greater time spent running and sprinting (Cahill et al., 2013).

The generic split of Forwards and Backs is more practical for training purposes but still neglects to account for the variation in demands between positional subgroups within the two groups. Teams of a higher level often have access to more resources, which allows for further positional divisions when preparing for competition. In this case, a team can be divided into various subgroups according to similar positional roles. One way of categorising these subgroups, adapted from Jones et al. (2015) and Tee and Coopoo (2015), includes Tight Forwards (positions 1–5), Loose Forwards (positions 6–8), Inside Backs (positions 9, 10, 12 and 13), and Outside Backs (positions 11, 14 and 15).

The following paragraphs briefly describe the primary roles of each position. While some of the research might seem outdated, it is important to note that the core roles of each position, such as set-piece involvement and field position, remain relevant and are position-specific (Quarrie et al., 2013). However, functional roles, such as tackles and ball carries, are dynamic. It is the intensities of positional demands that have evolved, with more recent research detailed in Sections G and H. It should also be acknowledged that while involvement in core roles remain the same, the frequency of these involvements do change, for example a decrease in the number of set-pieces in international rugby between 2007 and 2013 (Kraak et al., 2017). This can lead to changes in functional roles, including an increase in the number of ball carries and tackles (Kraak et al., 2017).

Props and hookers form the foundation of scrums and line-outs (Bell et al., 1993), and are often in close-quarter contact with the opposition through rucks, mauls and collisions on attack and defence (Nicholas, 1997). Locks are typically the jumpers in the line-outs, requiring lower body power and jumping ability (Hazeldine & McNab, 1991). They are often the tallest of the Forwards and benefit from mass and power when supporting the scrum and in general play (Bell, 1980). Flankers and number eights are generally the most dynamic of the Forwards (Reilley et al., 1993), requiring speed, acceleration and endurance to gain and retain possession of the ball in free play (Quarrie et al., 1996; Hazeldine & McNab, 1991). High levels of strength and power are also required for their roles on defence, and their roles played in scrums, rucks and mauls.

The scrum-half's primary role is the distribution of the ball that is retained or gained by the Forwards, providing a critical link between Forwards and Backs (Quarrie et al., 1996). The need to continuously be in the correct position to distribute, along with the need to support ball carriers and provide cover in defence, places a great emphasis on endurance as one of the scrum half's main physical abilities. Scrum-halves also provide an attacking threat, requiring speed to accelerate away from set-pieces, rucks and mauls (Hazeldine & McNab, 1991).

The Inside Backs have slightly different roles. Centres have more field space to work with and play critical roles on attack and defence, requiring a blend of speed, strength and power (Hazeldine & McNab, 1991). The fly-half's role is a hybrid of the scrum-half and centres, providing a secondary distributor while still requiring the abilities required for attack and defence in space. The Outside Backs are specialist "finishers", often forming support runners and the last receiver on attack, where they are expected to beat opposition through pace or power, in order to score tries. Their pace is also vital in other areas, such as chasing and fielding kicks, as well as providing cover defence.

In summary, rugby is a physically demanding sport, where each player's roles and responsibilities are position-specific. Players can be grouped while preparing for competition in a generic split (Forwards and Backs) or further divided into subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs. The grouping system used is dependent on the resources available for each environment, where a balance needs to be found between the accuracy of tailoring preparation and the practicality of administering the sessions. In order to accurately prescribe loads, it is necessary to first be able to monitor the loads performed by players.

D. MONITORING THE MATCH-PLAY DEMANDS OF RUGBY

The act of monitoring external demands, where specific movement patterns and contact characteristics are quantified, is known as time-motion analysis. There are two primary methods of TMA: video-based systems and GPS, each with their limitations (Dobson & Kogh, 2007).

The most common method is analysis through the use of video-based systems. This involves video-recording a practice session or match and then evaluating the performance indicators of players using specialised analysis software (Duthie et al., 2003). Video-based systems easily allow for enumeration of certain activities, such as tackles performed, but become time-consuming and costly when attempting to quantify specific movement patterns, such as distances covered at various speeds (Roberts et al., 2008). The analysis is completed manually; therefore, there is room for human error through subjective measurements (Cunniffe et al., 2009). However, the human error can be minimised through regular quality control and reliability checking.

A modern method used to quantify the demands involves tracking players via GPS technology, which is expected to increase in popularity as such systems become more common (Dobson & Kogh, 2007). These systems work using the principles of nuclear magnetic resonance, a method discovered by physicist Isidor Rabi. Developments in nuclear magnetic resonance resulted in the creation of the atomic clock, an accurate timepiece that forms the basis of satellite navigation (Rigden, 2000). The atomic clock allows for the precise calculation of the length of time a radio signal takes to travel from satellites orbiting earth to a GPS receiver on earth. The distance between the receiver and each satellite can be derived using this measurement of time. If at least four satellites are used in conjunction with one receiver, the location of the receiver can be accurately determined through triangulation (Larsson, 2003). The displacement over a given epoch can be derived using the precise location of the receiver, and analysis software used to calculate sport-specific variables. Sport-specific GPS units and software provide an objective, non-invasive alternative method for quantifying movement demands, without some of the limitations of video-based systems.

According to published scientific literature in the English language, the first attempt to validate a commercially available GPS device for human locomotion occurred in 1997 (Schutz et al., 1997). Since then the technology has been used for research in various football codes, including Australian football league, soccer, rugby union and rugby league (Cummins et al., 2013). Coutts and Duffield (2010), testing 20 elite Australian Rules Football players, suggested GPS devices have an acceptable level of accuracy and reliability for total distances and peak speeds during high-intensity, intermittent exercise, but may not provide reliable measures for higher intensity activities. However, Coutt and Duffield’s (2010) study was published in 2010, and the GPS devices used recorded at a frequency of 1 Hertz (Hz) (i.e. 1 sample per second). The low sampling frequency would explain the inaccuracy at very high intensities as the sample rate was low. Aughey (2011) suggested the validity and reliability of GPS devices increase with an increase in the sample rate, where devices with sample rates of 1 Hz, 5 Hz and 10 Hz were compared. Varley et al. (2012) confirmed that an increase in sample rate resulted in an increase in accuracy. Scott and colleagues' (2016) conclusions support that of Aughey (2011) and Varley and colleagues (2012) with sample rates of 1 Hz through to 10 Hz. However, an increase to 15 Hz had no additional benefit. Aughey (2011) concluded GPS devices have been validated for applications in team sports, but some doubts continue to exist with short high-speed movements. However, Barr and colleagues (2017) assessed the ability of 5 Hz (interpolated into 15Hz) GPS devices to monitor common movements seen in Canadian football and suggested that GPS devices are valid and reliable for assessing sprint demands in team sports. It was concluded modern GPS units may provide an acceptable tool for the measurement of constant speed, acceleration, and deceleration during straight-line running and have sufficient sensitivity for detecting changes in performance in team sport (Varley et al., 2012). Scott and colleagues (2016) came to a similar conclusion as Aughey (2011) and Varley and colleagues (2012), and stated the limitations presented by 1 Hz and 5 Hz seem to be overcome when utilising variables commonly recorded during team sport movements.

Sport-specific GPS units have developed over the years from a sample rate of 1 Hz to the current commercially available units, some of which record at frequencies of 20 Hz or higher. Recent developments have resulted in some units containing in-built microsensors, which might contain accelerometers, gyroscopes and magnetometers responsible for determining more specific variables such as the severity of impacts. Wundersitz and colleagues (2015) wanted to determine if an accelerometer could accurately measure physical-collision peak impact accelerations when 25 semi-elite rugby players were involved in contacts with a tackle bag, bump pad, and tackle drill. After analysing the 625 data sets, the researchers advocate the use of microsensors to measure contact movements in team sports. Gastin and colleagues (2013) made use of a combination of video and athlete tracking technology to assess 173 tackles made and 179 tackles received of professional Australian Football League players. The researchers suggested accelerometer data be ecologically valid when assessing impact forces in contact invasion sports (Gastin et al., 2013).

Each unit is held in place on a player by a padded neoprene harness supplied by the manufacturer. Most major manufacturers position the unit between the scapulae near the upper thoracic spine. Although this area is the least intrusive and most practical, it is limited when attempting to measure the force involved in contacts and impacts. Different areas of the body often come into contact with the opposition during match-play, in particular during a tackle situation. Fuller and colleagues (2008) found the body region of the ball carrier struck in a tackle to be distributed as head and neck (1.6%), upper limb (71.2%), trunk (12.9%) and lower limb (14.3%). A direct impact of a particular force to the upper body might produce a greater reading on the accelerometer when compared to an impact of a similar magnitude to the lower body, where the force might be dissipated before being measured. However, the positioning does provide a stable base for the GPS unit, which results in more consistent data.

To conclude, there are two primary methods for quantifying the external demands of rugby: video-based systems and GPS. Video-based systems are effective in providing a count of contact events, while GPS is effective in describing the movement characteristics of players.

E. THE IMPORTANCE OF APPLYING AN OPTIMAL LOAD

In order to appreciate the value of correctly prescribing training loads, the training adaptation process needs to be understood. Figure 2.1 illustrates an adapted version of Selye's (1946) general adaptation syndrome, which has been modified to illustrate a response to training (Bompa & Haff, 2009). This is broken down into four main phases: I—fatigue, II—recovery, III—supercompensation and IV—involution.

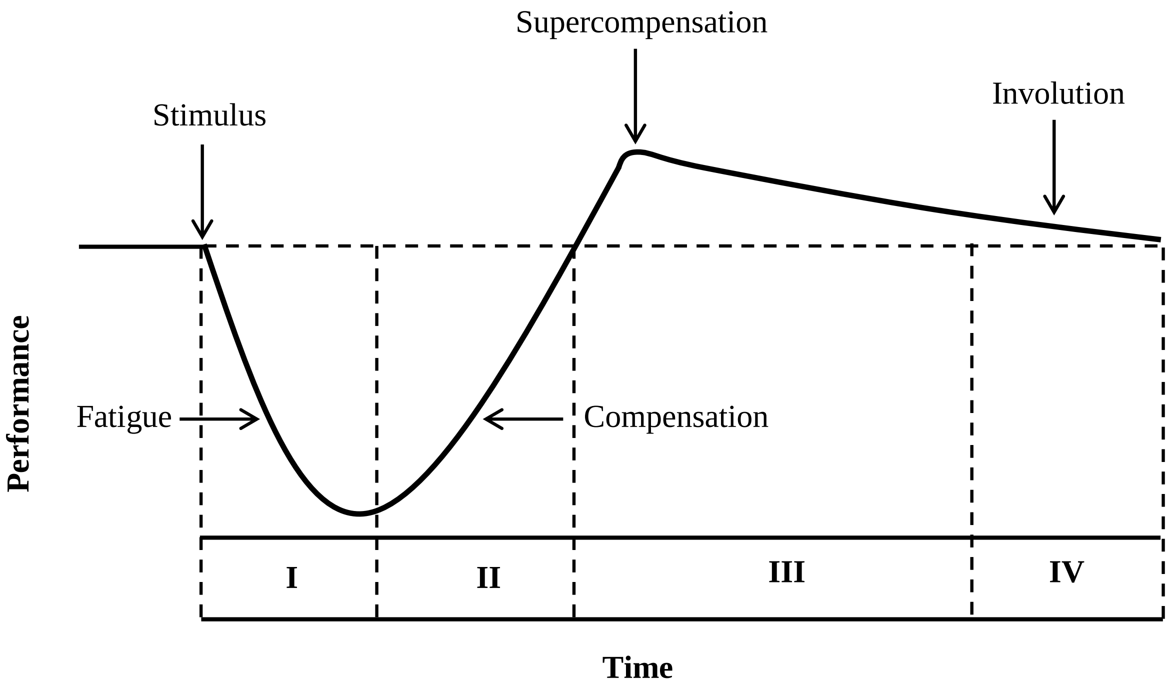

Figure 2.1. Performance at the various phases of adaptation after a training stimulus. Adapted from Bompa & Haff (2009).

If the stimulus in Figure 2.1 is considered a single training session in isolation, the different phases can be explained by the work of Bompa and Haff (2009). Before applying the stimulus, a player will be at their current baseline physical and physiological condition. Phase I begins by introducing a stimulus in the form of a training session. The decline in performance that follows represents the resultant fatigue as the session progresses. This exercise-induced fatigue occurs via central and peripheral mechanisms. Although dependant on the stimulus, the fatigue generally remains for one to two hours. Phase II, known as compensation, commences once the training stimulus has been terminated and performance starts to improve. Rest and recovery occur during this phase and typically lasts 24–48 hours until initial baseline performance levels are reattained. After retaining baseline performance levels, Phase III begins. This phase is characterised by supercompensation of performance through the adaptations that occurred as a result of the training stimulus, with the duration usually lasting 36–72 hours. The last phase, Phase IV, represents involution. If another training stimulus is not applied to the athlete during the supercompensation window, performance will decline and return to initial baseline levels within 3–7 days.

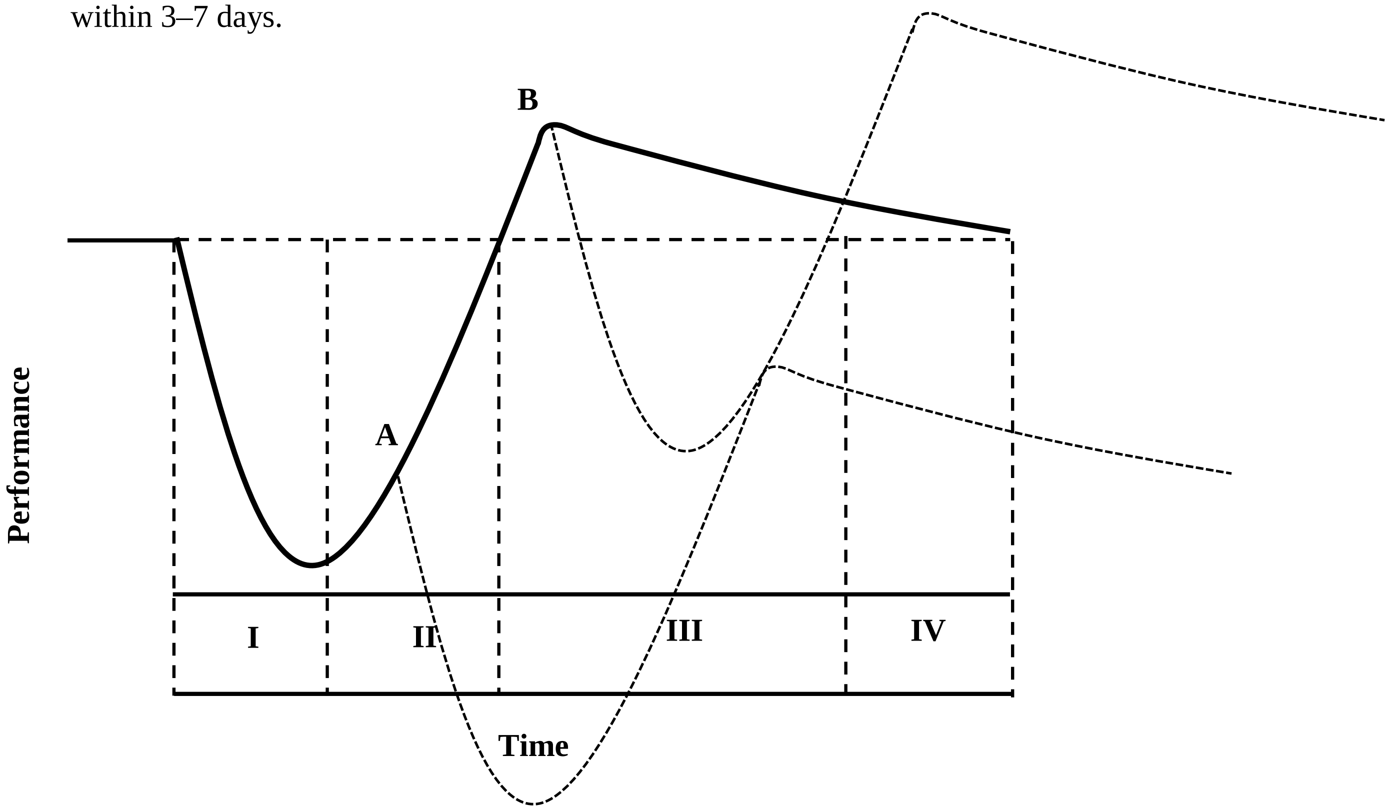

Figure 2.2. Performance at the various phases of adaptation after a training session, for premature (A) and optimal (B) timing of a second training stimulus. Adapted from Bompa & Haff (2009).

Figure 2.2 shows the importance of the timing of a second training stimulus that succeeds the initial stimulus. 'A' (Figure 2.2) demonstrates a prematurely applied successive stimulus, which would result in a reduction in performance (Halson et al., 2002) as the player has not been allowed enough time to sufficiently recover. 'B' (Figure 2.2) demonstrates the optimal timing of a second training stimulus where the player has fully recovered, and the stimulus is applied at the peak of their supercompensation phase. A second stimulus applied anywhere after B (Figure 2.2) will lead to a suboptimal response, where involution would lead to minimal or even no change from the player's original baseline condition.

Although the timing is critical to the outcome of periodisation, other factors come into play when prescribing training loads. Bompa and Haff (2009) further explained that when considering the correct stimulus for fatigue, three principles should be deliberated: overload, specificity and interference. The principle of overload states that when the body is put under higher stress than which it usually encounters, it will adapt, as shown by the supercompensation phase in Figure 2.1. When this overload is repeated gradually and regularly, with the correct relationship between stress and recovery, the body will adapt to tolerate the applied stress (Figure 2.2 B). However, if the training volume or intensity is too low, detraining might occur (Izquierdo et al., 2007). Specificity of training should also be taken into consideration. The principle of specificity states that the body which is stressed will adapt to the stimulus imposed in a very specific manner (Baechle & Earle, 2008). The principle of interference states that some forms of training might interfere with others and compromise the desired adaptations (Fyfe et al., 2014).

To summarise, rugby has a number of positions with various roles and responsibilities, as mentioned previously, and therefore players should train for their position-specific demands while minimising unnecessary training interference. The principles of overload, specificity and interference demonstrate the necessity of applying the correct stimulus at the right time in order to attain the desired adaptation.

F. UTILISING EXTERNAL LOAD DATA TO PREPARE FOR COMPETITION

The goal of rugby is to win each match. To increase the odds of success, from a physical preparation perspective, there are often two areas of focus: physical performance and player availability. Players with superior physical attributes are associated with higher levels of competition (Argus et al., 2012; Olds, 2001) and it can, therefore, be surmised that possessing superior attributes might lead to better performance. Lower injury rates result in higher player availability, which positively influences the success of a team (Hägglund et al., 2013). These two focus areas can be improved by developing one underlying theme: robustness. Robustness of a system is defined by the Oxford dictionary as “the ability to withstand or overcome adverse conditions or rigorous testing” (Simpson & Weiner, 1989, para. 2). The player’s body is considered the system. The adverse conditions or rigorous testing is considered the demands required to compete in an optimal manner to ensure success and avoid injury.

Research taking into account various training stimuli and their relationship to injury have often found a similar “J-shape” relationship, visualised in Figure 2.3. It is well documented that a change in training load that is too high, relative to an athlete’s current capacity, will increase the likelihood of injury (Malone et al., 2017; Blanch & Gabbett, 2016). A more novel finding is that when a change in training stimulus relative to an athlete’s current capacity over a given period is too low, there is not only a risk of inferior performance, as a result of detraining, but an increased likelihood of injury. Blanch and Gabbett (2016) demonstrated this relationship in a series of studies involving three different sports (cricket, rugby league and Australian rules football) (Figure 2.3). Malone and colleagues (2017) examined the relationship between chronic training loads, number of exposures to maximal velocity, the distance covered at maximal velocity, percentage of maximal velocity in training and match-play and subsequent injury risk in 37 Gaelic footballers. Results from the study show that players who were under- and overexposed to maximal velocity efforts have an increased risk of injury. In order to develop robust athletes, it is important to identify the demands of competition. This will provide a basis of what specific stimuli are required by athletes to compete optimally, and it is then the coaching staff's task to progress them safely to a point where they can withstand these demands of competition.

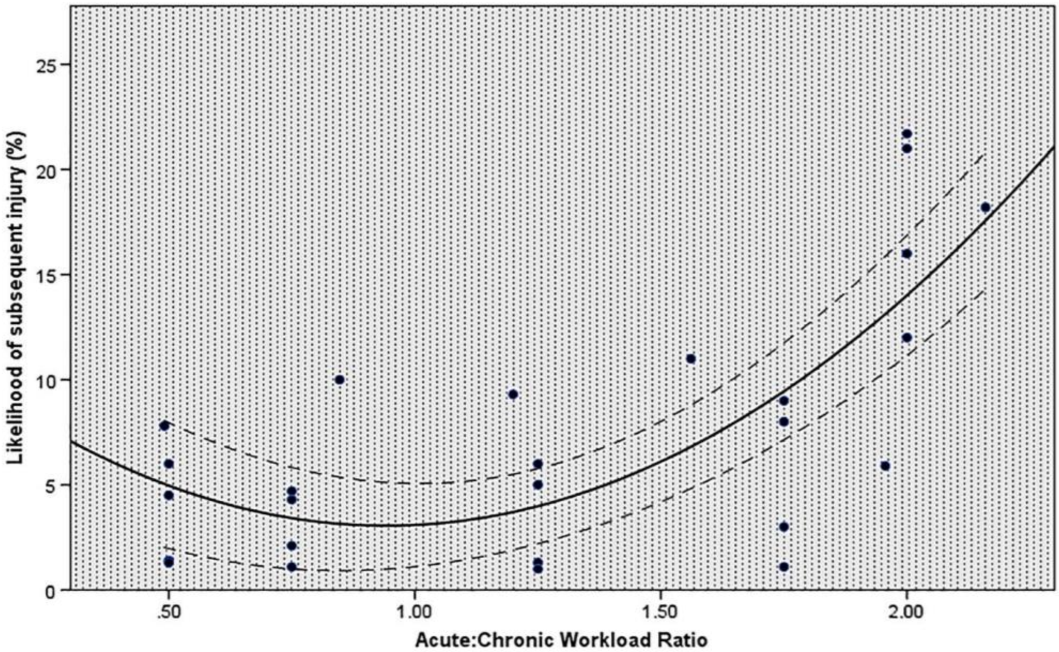

Figure 2.3. The relationship between change in training load and likelihood of subsequent injury. Acute:Chronic Workload Ratio is defined by Blanch and Gabbett (2016) as a comparison of the acute load (ie, the training that had been performed in the current week) with the chronic load (ie, the training that had been performed as a rolling average over the previous 4 weeks). Reproduced, with permission form Blanch and Gabbett (2016).

As discussed in previous sections, it is beneficial to apply a training stimulus that will produce optimal results and develop robust athletes. Currently, available technology (GPS and video-based analysis) provides a starting point to capture data that describes the external loads of competition. As data is gathered, it becomes essential to interpret and present the data in such a way that it can be applied in a practical setting. Three methods of interpretation, each providing practical information, are used for the current study: full match**,** temporal pattern and peak period analysis.

F.1. FULL MATCH ANALYSIS

Full match analysis describes the total demands required of a player who has completed the entire duration of the match. Limited literature has described the demands of a full rugby match, with most setting a cut-off time, generally around 60 minutes, and reporting values for this time played (Jones et al., 2015; Tee and Coopoo, 2015). While this cut-off does not provide an absolute measure of the entire match, positional group comparisons can be drawn. Full match analysis is useful in a practical setting, enabling decisions around the volume of specific training. These practical applications include: providing requirements for match replacement sessions, a relative marker off which to base training sessions and drills, decisions around load "top-ups" post-game for those who do not complete the full match, and benchmark goals for injured players returning to play, amongst others.

F.2. TEMPORAL PATTERN ANALYSIS

Temporal pattern analysis involves reporting a variable for various stages of a match. These stages are often split into eight equal periods, equating roughly 10 minutes each, as performed by Jones and colleagues (2015). Splitting the match into equal periods allows comparison of variables in different stages of a match and the identification of fluctuations in player performance. These fluctuations can be analysed to determine the effects of fatigue and pacing strategies throughout a match. In team sport, Waldron and Highton (2014) defined pacing as the distribution of energy resources that optimise match-running performance, and fatigue as a uni-directional construct that relates to the eventual reduction in physical performance compared with baseline values. It is suggested that team sport players regulate their efforts during match-play through macro-, meso- and micro-pacing strategies (Waldron & Highton, 2014). The macro-pacing strategy refers to the planned use of energy stores over an entire match, which is modulated through meso- (between halves) and micro-strategies (on a continual basis). In rugby league players (n = 52), differences were found between whole-game players and interchanged players. Interchanged players covered greater low-speed distances and total distances per quartile of a match than whole-game players. Different pacing strategies also existed between winning and losing teams (Black & Gabbett, 2014). Common pacing strategies previously found in rugby union include 'slow-positive' (higher intensity start and lower intensity finish) and 'flat' (no change throughout the match) strategies, where a 'slow-positive' strategy has been suggested to optimise running performance in all team sports (Waldron & Highton, 2014). Tee and colleagues (2017) showed different pacing strategies between positional groups in 46 professional rugby players. Forwards displayed a 'slow-positive' pacing strategy, while Backs had a 'flat' strategy. Identifying pacing strategies and periods of fatigue should contribute to the decision-making process for substitution times and enhance position-specific conditioning.

F.3. PEAK PERIOD ANALYSIS

Peak period analysis involves splitting match-play data into shorter (e.g. one minute) periods. These periods are then used to calculate the 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10-minute moving rolling-averages for the most-intense periods of match-play. Moving average durations were chosen for the purpose of this study, as fixed duration analysis has been shown to underestimate the peak periods of play (Varley et al., 2012). The Power Law is used to provide a prediction of the peak intensities of each variable as a function of time. This method has been utilised in other contact (Delaney et al., 2017a; Delaney et al., 2015) and non-contact sports (Delaney et al., 2017b). Delaney and colleagues (2017a) investigated the duration-specific running intensities of 40 Australian Football players during 30 games. Similarly, Delaney and colleagues (2015) assessed 32 rugby league players across a single season. This method was also applied to a non-contact sport, soccer, where 24 players were studied over 40 professional matches (Delaney et al., 2017b). All three of the aforementioned studies identified the peak intensities of 1–10 minute durations of play in their respective sports, where the study on rugby league went on to predict the peak running values as a function of time using power law. Although research has been undertaken in various sports, there is limited literature focussing on professional rugby (Cunningham et al., 2018; Read et al., 2018; Delany et al., 2017c). Peak period analysis provides a tool where training session intensities can be prescribed and monitored to reflect the peak periods of competition. Delaney and colleagues (2017a) suggest if a player is unable to cope with the peak match-play demands in a training context, the player may benefit from isolated training practices to improve work capacity in the specific area.

F.4. SUMMARY

In order to work towards the goal of winning in rugby, coaches should strive to improve individual performance and reduce injury risk through the development of robust athletes. The collection of external load data can aid in this development by utilising different methods of interpretation: full match, temporal pattern and peak period analysis.

G. EXTERNAL LOAD DATA: GPS-DERIVED METRICS

GPS tracking systems provide a large number of variables for analysis. The following section will discuss the GPS variables, and current literature, which provide insight into the known movement demands of players relevant to the current study. The GPS variables and definitions thereof that are applicable to the current study include:

- **Maximum Speed:** the fastest recorded speed ($km \cdot h^{-1}$) at which a player travelled over a given epoch.
- **Total Distance:** the total meters (m) a player travelled over a given epoch.
- **Distance in Speed Zones:** the total meters (m) a player travelled over a given epoch within one of the four pre-set speed zone (Table 2.1.).
- **Sprint Count:** the total number (n) of times a player achieved a velocity faster than 21.6 $km \cdot h^{-1}$ (Table 2.1., speed zone 4) over a given epoch.

Table 2.1. Speed zone classification system.

Zone	$m \cdot s^{-1}$	$km \cdot h^{-1}$	Speed Classification	Broad Classification
1	0–2	0.0–7.2	Walking	Low-intensity running
2	2–4	7.2–14.4	Jogging	
3	4–6	14.4–21.6	Striding	High-intensity running
4	> 6	> 21.6	Sprinting	

When categorising the speed zones, studies have made use of both relative (Venter et al., 2011; Cahill et al., 2013) and absolute methods (Jones et al., 2015; McLellan et al., 2013). Relative methods involve categorising an individual’s speed zones based on their own maximum speed, where zones will vary between individuals. Absolute methods base speed zones on set speed thresholds, where all individuals will have the same speed zones. A study by Gabbett (2015) compared the two and found that relative zones increase the high-speed running performed by slower players and decreases the high-speed running performed by faster players. Gabbett (2015) concluded that absolute and relative speed zones each have their strengths and weaknesses, with both methods being recommended from a practical perspective. For reasons further discussed in chapter three, the current study will focus on absolute speed zones. These zones are classified as walking, jogging, striding and sprinting, similarly used in previous studies (Tee et al., 2015; Jones et al., 2015).

G.1. FULL MATCH ANALYSIS

G.1.1. MAXIMUM SPEED

Rugby players achieve varying maximum speeds during match-play when grouped by positional groups and positional subgroups (Tee and Coopoo, 2015; Cahill et al., 2013; McLellan et al., 2013; Suárez-Arrones et al., 2012). In determining maximum speeds during match-play, Tee and Coopoo (2015) analysed 19 professional rugby players (age: 26 ± 2 years) over 24 matches during the 2013 rugby season (102 GPS data files), while Cahill and colleagues (2013) analysed 98 professional Premiership players (age: 27.5 ± 4.2 years) over 44 matches during the 2010 and 2011 seasons (276 GPS data files). McLellan and colleagues (2013) had a smaller sample of five Super Rugby players playing in 11 matches, which provided 55 GPS data files. Similarly, Suárez-Arrones and colleagues (2012) assessed nine national Spanish players (age: 25.9 ± 4.0 years) over 3 matches (42 GPS data files). Although the level of competition and number of GPS data files differ, the research is unanimous in the finding that Forwards (24.6–27.4 $km \cdot h^{-1}$) achieve slower maximum speeds than Backs (28.2–32.0 $km \cdot h^{-1}$).

Of the above-discussed research, only two studies assessed positional subgroups (Tee and Coopoo, 2015; Cahill et al., 2013). Tee and Coopoo (2015) found no differences between the Tight Forwards (25.6 ± 4.7 $km \cdot h^{-1}$), Scrum Half (28.8 ± 2.5 $km \cdot h^{-1}$) and Inside Backs (28.8 ± 3.2 $km \cdot h^{-1}$) for maximum speed achieved during match-play. The Loose Forwards (28.8 ± 4.3 $km \cdot h^{-1}$) reached faster speeds than the Tight Forwards, and the Outside Backs (33.8 ± 3.2 $km \cdot h^{-1}$) faster speeds than all other positional subgroups (Tee and Coopoo, 2015). Cahill and colleagues (2013) supported the finding that Outside Backs achieved the fastest (31.7 $km \cdot h^{-1}$)

speeds and that Loose Forwards (24.5 km·h^{-}) achieved faster speeds than Tight Forwards (Front Row (24.5 km·h^{-1}) and Second Row (25.0 km·h^{-1})). Scrum Half (29.0 km·h^{-1}) and Inside Backs (29.8 km·h^{-1}) reached faster speeds than Loose Forwards. These differences can potentially be explained by different strategies and tactics applied by teams from each competition, with one competing in the Southern Hemisphere and the other in the Northern Hemisphere. Different tactics and strategies might provide players with varying opportunity to achieve maximum speed during games.

G.1.2. TOTAL DISTANCE

The total distance covered by Forwards (4709–5853 m) in match-play is 11–28 percent lower than that of Backs (6005–6545 m) (McLellan et al., 2013; Cahill et al., 2013, Suárez-Arrones et al., 2012). Lindsay and colleagues (2015), who assessed 37 Super Rugby players (age: 26.6 ± 3.7 years; 81 GPS data files), had similar finding when considering relative distance throughout a match for Forwards and Backs (77 ± 21 v 85 ± 10 m·min^{-1}). Although McLaren and colleagues (2016) did not statistically analyse between-group differences of their 28 English Championship players (age: 27± 4years; 82 GPS data files), Forwards and Backs were reported to cover 5400 m and 5960 m of total distance throughout a match.

The trend of current research where Forwards cover less distance than Backs during match-play is disputed by Tee and Coopoo (2015), who found no difference between Forwards and Backs (69 ± 8 v 69 ± 9 m·min^{-1}) for relative distance covered. Tee and Coopoo's (2015) data for Forwards comprised 23 Tight Forwards and 30 Loose Forwards. This difference in positional subgroup sample size could skew the data of the Forwards, as the Front Row is generally the lowest running group (further detailed below). However, the Tight Forwards (70 ± 7 $m \cdot min^{-1}$) and Loose Forwards (68 ± 8 $m \cdot min^{-1}$) assessed exhibited no difference. A possible explanation is that the team assessed applied attacking and defensive structures which required their Tight Forwards to be more dynamic around the field of play during matches.

Current literature is conflicted when comparing positional subgroups. No difference was found between Inside Backs (86 ± 11 $m \cdot min^{-1}$) and Outside Backs (83 ± 8 $m \cdot min^{-1}$) when comparing relative distance, but both had higher intensities than the Front Row (71 ± 11 $m \cdot min^{-1}$), Second Row (77 ± 7 $m \cdot min^{-1}$) and Loose Forwards (86 ± 31 $m \cdot min^{-1}$) subgroups (Lindsay et al., 2015). Jones and colleagues (2015) found the Scrum-Halves (5693 ± 823 m), Inside Backs (5907 ± 709 m) and Outside Backs (6272 ± 1065 m) to cover more distance than Tight Forwards (4757 ± 885 m), and only Outside Backs to cover more distance than Loose Forwards (5244 ± 866 m). Tee and Coopoo (2015) reported that all subgroups covered similar total distances, except the Scrum-Half, which covered more total distance than any of the other subgroups. This finding was supported by Cahill and colleagues (2013), who found the scrum-half to cover the most distance, but Tight Forwards to cover less distance than Loose Forwards and the rest of the Backs.

Similarly to the Forwards and Backs, the discrepancies can be explained by teams operating in different environments. Different competitions, playing environments and coach-driven game-plans are all factors that might affect the strategy that drives the players' requirements on field. Furthermore, these factors might guide player recruitment. For example, for a team to best execute their attacking strategy, they might require a large ball carrier in their Outside Back group. Although this will increase their strike capacity, it has the potential to reduce the average distance covered by the Outside Backs as a group.

G.1.3 DISTANCE IN SPEED ZONES

The distance covered at various speeds is categorised according to speed thresholds, which form predetermined zones, and is reported in metres. The majority of past studies in rugby have categorised speed zones according to absolute values in four to six zones (Jones et al., 2015; Lindsay et al., 2015; Cummins et al., 2013). One method used (Jones et al., 2015, Suárez-Arrones et al., 2012) categorises the speed zones as: walking (0–6.0 km·h^{-1}), jogging (6.1–12.0 km·h^{-1}), cruising (12.1–14.0 km·h^{-1}), striding (14.1–18.0 km·h^{-1}), high-intensity running (18.0–20.0 km·h^{-1}) and sprinting (> 20.0 km·h^{-1}). McLellan and colleagues (2013) used a similar method, with only the high-intensity (18.0–22.0 km·h^{-1}) and sprint (> 22.1 km·h^{-1}) zones differing. Tee and Coopoo (2015) followed a simplified approach, splitting the zones into four: walking (0–7.2 km·h^{-1}), jogging (7.2–14.4 km·h^{-1}), striding (14.4–21.6 km·h^{-1}) and sprinting (> 21.6 km·h^{-1}). Lindsay and colleagues (2015) grouped zones according to distances covered while travelling at speeds greater than 7, 16, 20 and 25 km·h^{-1}.

Another method is to group the zones according to relative speeds based on the percentage of one's maximum speed. This was implemented by Cahill et al. (2013) to form standing and walking (< 20% (maximum velocity (Vmax)), jogging (20–50% Vmax), striding (51–80% Vmax), sprinting (81–95% Vmax), and maximum sprint (96–100% Vmax). While speed zone thresholds in literature differ slightly, they generally all represent distance covered standing/walking, jogging, cruising/striding and higher-intensity running.

When comparing Forwards and Backs over an entire match, Suárez-Arrones and colleagues (2012) found no difference in the distance covered while standing and walking, jogging, cruising and striding. However, the Forwards covered less distance than the Backs during high-intensity running and sprinting (Suárez-Arrones et al., 2012), which was supported by McLellan and colleagues (2013) for both absolute and relative values. Similar findings (Lindsay et al., 2015) suggested that there is no difference between Forwards and Backs for the distance covered while moving faster than 7 $km{\cdot}h^{-1}$, but the Backs cover more distance at speeds faster than 16, 20 and 25 $km{\cdot}h^{-1}$. Work by Tee and Coopoo (2015) supports the notion that Backs cover more distance sprinting, but found Forwards to cover more distance walking and jogging, with no difference seen while striding. The current body of research has slightly different speed zones categories, but are in agreement that Backs tend to cover more distance in the higher-intensity zones. While most research is synonymous in finding no difference in lower-intensity zones, Tee and Coopoo's (2015) opposing findings might be explained by a more dynamic Forward group, as previously discussed.

An outlying study with contradictory findings concluded that Backs cover more distance walking than Forwards, but no difference while jogging, striding or sprinting (Cahill et al., 2013). These differences are likely due to the use of a relative speed zone classification system, where relative zones increase the high-speed running performed by slower players and decreases the high-speed running performed by faster players (Gabbett, 2015), thereby balancing out the higher intensity zones.

Current research comparing the distance covered in speed zones by positional subgroups is conflicted (Jones et al., 2015; Lindsay et al., 2015; Tee and Coopoo, 2015; Cahill et al., 2013;

Suárez-Arrones et al., 2012). Suárez-Arrones and colleagues (2012) had a limited sample for positional subgroups, and therefore only compared front rowers to Loose Forwards and scrum halves to centres. Front Rowers covered more distance cruising and less distance during high-intensity running and sprinting than Loose Forwards. Centres covered more distance sprinting than Scrum-halves, with no difference observed for any other speed zones. Jones and colleagues (2015) found Outside Backs to cover more distance walking than Tight Forwards, Loose Forwards and Inside Backs; with Scrum Halves covering more than Loose Forwards. No difference was observed between any of the positional subgroups while jogging. Outside Backs covered less distance while cruising than Tight Forwards and Scrum-halves. When striding, Scrum Halves covered more distance than Tight Forwards and Outside Backs, and Inside Backs covered more than Tight Forwards. High-intensity running saw all Backs to cover more distance than the Tight Forwards, and the Inside Backs to cover more than Loose Forwards. All positional subgroups covered more sprint distance than Tight Forwards, and Inside and Outside Backs covered more than the remaining subgroups.

Tee and Coopoo (2015) considered the distance covered walking, jogging, striding and sprinting. Loose Forwards walked less distance than Inside and Outside Backs. Outside Backs covered less distance jogging than Tight Forwards, Loose Forwards and Scrum-halves. Scrum-halves covered more distance striding than all other positional subgroups, aside from the Loose Forwards. When sprinting, the Tight Forwards covered less distance than all other positional subgroups.

When comparing positional subgroups over certain speeds, rather than between set speeds, differences were observed (Lindsay et al., 2015). Distance at speeds faster than 7 $km \cdot h^{-1}$ saw the Inside Backs to cover the most distance. For speeds faster than 16, 20 and 25 $km \cdot h^{-1}$ Loose Forwards covered more distance than the Front Row and Locks, and Inside and Outside Backs covered more distance than all forward groups. Outside Backs covered notably more metres above 25 $km \cdot h^{-1}$ than the Inside Backs.

Assessing distances covered using relative speed zones saw no difference between positional subgroups when sprinting at maximum capacity (Cahill et al., 2013). Distinctive characteristics noted included the Loose Forwards covering more distance, and at higher speeds than the Front Row. The Outside Backs covered almost double the sprint metres when compared to the Inside Backs.

Although the existing research on distances travelled by positional subgroups varies, generally the findings are conflicted at the lower-intensity zones. However, the Backs, particularly the Outside Backs, are commonly found to cover more high-intensity metres. The current study aims to add to the existing body of research in the hopes of clarifying the distances covered by positional subgroups.

G.1.4 SPRINT COUNT

The sprint count is an enumeration of high-speed efforts, providing a count of the number of times a player achieves a speed above a set threshold. While the set sprint thresholds might differ slightly, it is well established that Forwards complete fewer sprints throughout match-play when compared to Backs (Tee & Coopoo, 2015; McLellan et al., 2013; Suárez-Arrones et al., 2012). With the threshold set at 21.6 km·h^{-1}, Forwards (1 every 14 min) complete fewer sprints than Backs (1 every 7 min) (Tee & Coopoo, 2015). McLellan and colleagues (2013) were synonymous in finding Forwards to complete fewer sprints than Backs throughout match-play (13 ± 6 v 2 ± 3), with a threshold of 22.1 km·h^{-1}. These findings are supported by Suárez-Arrones and colleagues (2012) at a threshold of 20 km·h^{-1}, where Backs completed more sprints than Forwards (26 ± 10 v 11 ± 5). The higher number of sprints observed by Suárez-Arrones and colleagues (2012) is likely due to the author's using the lowest speed of the studies for their sprint threshold. It must be noted that both McLellan and colleagues (2013) and Suárez-Arrones and colleagues (2012) had sample sizes of five and nine, where individual differences will have a greater influence on sprints observed.

There is limited literature which compares the sprint count of positional subgroups, with most studies focusing on distance sprinting (Jones et al., 2015; Tee & Coopoo, 2015). Tee and Coopoo (2015) assessed sprint counts for Tight Forwards (1 every 33 ± 33 min), Loose Forwards (1 every 10 ± 17 min), Scrum-halves (1 every 7 ± 14 min), Inside Backs (1 every 9 ± 11 min) and Outside Backs (1 every 6 ± 14 min). The only difference noted as Loose Forwards and Outside Backs sprinted more often than the Tight Forwards. One might expect to see further differences, but the results are possibly obscured by the large standard deviations observed by Tee and Coopoo (2015). This is likely due to the sporadic nature of sprints in match-play, rather than the size of the data set (102 files). It can be surmised that sprinting during match-play is often as a result of being presented with the opportunity to sprint, rather than the physical ability of a player. The current study will provide further data on the sprint frequency of positional groups and provide valuable insight into the sprint requirements of positional subgroups during match-play.

G.2. TEMPORAL PATTERN ANALYSIS

G.2.1. RELATIVE DISTANCE

Contrary to full match analysis, limited literature exists with regards to temporal pattern analysis in rugby. To the author's knowledge, only two studies have used GPS to investigate the demands of rugby through Temporal Analysis (Tee et al., 2017; Jones et al., 2015). Tee and colleagues (2017) assessed nineteen professional rugby players (age: 26 ± 2 years) from a professional South African team and documented 105 GPS data files. The study by Jones and colleagues (2015) examined 33 professional rugby players (age: 25 ± 4 years), who competed in European leagues, that provided 141 GPS data files.

When assessing the mean of an entire team, no difference was found between the first (67.6 ± 8.0 $m.min^{-1}$) and second halves (64.7 ± 10.2 $m.min^{-1}$) (Jones et al., 2015). Although no difference was observed between halves, there was a decline throughout each half, particularly between the first 10 minutes and the remaining periods (Jones et al., 2015). This indicates a slow-positive pacing strategy throughout each half for the team as a whole.

Conversely, when analysed by positional groups, Tee and colleagues (2017) found both the Forwards (74 ± 11 v 65 ± 8 $m.min^{-1}$) and Backs (70 ± 8 v 63 ± 5 $m.min^{-1}$) covered more relative distance in the first half when compared to the second. As both positional groups contradicted the whole team findings of Jones and colleagues (2015), it is not likely that the positional grouping is the reason for the inconsistency in their results. Tee and colleagues (2017) found both Forwards and Backs to exhibit a flat pacing strategy when assessing relative distance in 10 minute periods of match-play, where they maintained relative distance throughout the match except for a large drop-off exhibited by the Backs in the final quarter of the second half (Tee et al., 2017). The final quarter of the second half was the only 10 minute period where a difference was seen between the Forwards and Backs (Tee et al., 2017).

Another study made up of 29 video data files from English Premiership players investigated temporal pattern analysis in rugby through video-based TMA (Roberts et al., 2008). Without considering positional groups, no difference was observed between the first and second halves, which are consistent with the finding of Jones and colleagues (2015). In addition, Roberts and colleagues considered 10 minute periods of play and concluded that the intensity of the 0–10 minute period of match-play was higher than that of the 50–60 and 70–80 minute periods.

To the author's knowledge, no current literature exists around temporal pattern analysis of relative distance for positional subgroups. Results of the current study will assist in filling the current dearth in literature.

G.3. PEAK PERIOD ANALYSIS

G.3.1. RELATIVE DISTANCE

To the researcher's knowledge, only three studies have assessed the peak periods of play through moving average durations in rugby (Cunningham et al., 2018; Read et al., 2018; Delany et al., 2017c). Cunningham and colleagues (2018) investigated durations of play from one to five minutes using elite level rugby players (Forwards: age: 24 ± 4 years; Backs: age: 23 ± 4 years). Backs (60 seconds (s) = 177.4 ± 21.1; 120 s = 140.1 ± 16.3; 180 s = 123.4 ± 15.4; 240 s = 114.2 ± 14.4; 300 s = 107.5 ± 13.3 $m.min^{-1}$) covered greater distances across all epoch lengths when compared to Forwards (60 s = 139.0 ± 21.1; 120 s = 140.1 ± 16.3; 180 s = 123.4 ± 15.4; 240 s = 114.2 ± 14.4; 300 s = 107.5 ± 13.3 $m.min^{-1}$). Read and colleagues (2018) investigated the relative distance covered during peak periods of match-play for English academy players (age: 17.7 ± 0.6 years). The time durations used included 15 and 30 second (s), 1, 2, 2.5, 3, 4, 5 and 10 minute periods. The authors' findings support that of Cunningham and colleagues (2018), where (1) the running intensity for consecutive durations decreased as the time increased and (2) the running intensity of Forwards was lower than that of Backs across all durations. This indicates that the trends seen over peak periods of play for Forwards and Backs at the professional level are paralleled at academy level.

Delaney and colleagues (2017c) assessed positional subgroups of 67 international players (age: 27.3 ± 3.1 years; 560 GPS data files) and reported that the Tight Forwards covered less distance than all other positional subgroups when evaluating moving average durations of one to ten minutes. Cunningham and colleagues (2018) categorised their positional subgroups similarly to that of Delaney and colleagues (2017c), with the only difference being that the Tight

Forwards were split into the Front Row and Second Row. The Front Row was found to cover less distance than Second Row, Loose Forwards, Half Backs, Centres, and Outside Backs over all durations (Cunningham et al., 2018). It can be surmised that the lower relative distances for Tight Forwards reported by Delaney and colleagues (2017c) is more likely due to the influence of the Front Row on the group's average. Read and colleagues (2018) compared positional subgroups within the Forwards and Backs and found the running intensity to be lower for the Front Row than that of the Second Row and Loose Forwards at all durations, and Scrum Halves had higher intensities than the Inside Backs and Outside Backs for all time periods except 15 and 30 s (Read et al., 2018).

Although limited, literature in other contact sports, such as Australian Rules Football (Delaney et al., 2017a) and Rugby League (Delaney et al., 2015) suggests that differences exist between positional groups. To the author's knowledge, no study has attempted to use Power Law to predict peak running intensities of professional rugby, as previously completed with professional soccer players (Delany et al., 2017b). The current study will aim to contribute to the limited body of research and offer the first information of its kind in the form of an equation, derived through Power Law, which can be used to set running intensity training targets that will replicate the position-specific peak periods of match-play.

G.4. SUMMARY

As summarised in Tables 2.2–2.4, full match analysis has been well documented in professional men’s rugby, while limited research exists for temporal and peak period analysis.

When assessing an entire match, Backs tend to cover more distance than Forwards, particularly in high-speed zones. Additionally, differences are seen when further dividing positions into positional subgroups.

Temporal pattern analysis has shown Forwards to have a slow-positive pacing strategy and backs either a slow-positive or flat pacing strategy. Currently, no literature exists around temporal pattern analysis and positional subgroups.

Peak running intensities for Backs are higher than that of Forwards overall rolling average durations, with the Front Row and Tight Forwards often exhibiting the lowest intensities of the positional subgroups. No literature currently exists around using Power Law to estimate the peak running demands of match-play as a function of time in rugby.

Table 2.2 Studies that used GPS for the quantification of locomotive variables in senior men's Rugby Union match-play through full match analysis (since 2010).

Study	Sample	Positional Grouping	Findings
McLaren et al., 2016	English Championship players 82 GPS files	F & B	Although not statistically analysed, Backs tend to cover more total distance than Forwards, particularly at very high-speed running.
Lindsay et al., 2015	Super Rugby players 104 GPS files	F & B FR: 1, 2 & 3 SR: 4 & 5 LF: 6, 7, 8 IB: 9, 10, 12 & 13 OB: 11, 14 & 15	Both Inside and Outside Backs covered more total relative distance when compared to all Forward positions. Loose Forwards covered more distance than Front Rowers and Locks at speeds above 16, 20 and 25 $km{\cdot}h^{-1}$. No difference in distance was found between any positional subgroups while between speeds 7–16 $km{\cdot}h^{-1}$.
Jones et al., 2015	Professional players	TF: 1, 2, 3, 4 & 5 LF: 6, 7 & 8 HB: 9 & 10 IB: 12 & 13 OB: 11, 14 & 15	Inside Backs and Outside Backs have the greatest high speed running demands and Outside Backs cover more total distance than the Forwards.
Tee & Coopoo, 2015	Super Rugby players 102 GPS files	F & B TF: 1, 2, 3, 4 & 5 LF: 6, 7 & 8 SH: 9 IB: 10, 12 & 13 OB: 11, 14 & 15	No difference in Forwards and Backs for relative distance covered, however, backs reached higher maximum speeds. Outside Backs attained the fastest maximum speeds of the positional subgroups. Tight Forwards covered the most distance in low-intensity zones and scrum-halves the most in high-intensity zones. Loose Forwards and Inside Backs had similar movement patterns.
Cahill et al., 2013	English Premiership players 276 GPS files	F & B FR: 1, 2 & 3 SR: 4 & 5 LF: 6, 7, 8 SH: 9 IB: 10, 12 & 13	Forwards had a lower maximum speed, total distance and walking distance than Backs. No difference was found in the jogging, striding, sprinting distance. Scrum Halves completed the most total distance and the Front Row the least. Outside Backs attained the highest maximum speeds and covered the most distance walking and sprinting. The Loose Forwards covered more distance, and at higher speeds, than the remaining Forwards.

		OB: 11, 14 & 15	
McLellan et al., 2013	Super Rugby players 55 GPS files	F & B	Backs achieved faster maximum speeds, completed more sprints, and covered more total distance and distance sprinting than Forwards.
Suárez-Arrones et al., 2012	Elite Spanish players 14 GPS files	F & B	Backs covered greater total distance than Forwards. Backs completed a greater number of sprints and achieved faster maximum speeds when compared to Forwards. Additionally, the Backs covered more distance during high-speed running and sprinting.

Note: *FR = Front Row; SR= Second Row; LF = Loose Forwards; HB = Halfbacks; SH = Scrum Half; IB = Inside Backs; OB = Outside Backs; F = Forwards; B = Backs.*

Table 2.3 Studies that used TMA for the quantification of relative distance in senior men's Rugby Union match-play through temporal analysis.

Study	Sample	Positional Grouping	Findings
Tee et al., 2017	Professional players 46 GPS files	F&B	Forwards and Backs maintained movement intensity when assessing relative distance alone, and showed a flat pacing strategy. A drop in intensity was seen by the Backs in the final quarter of the second half.
Jones et al., 2015	Professional players 141 GPS files	Team	Low- and high-intensity movement declined throughout each half, indicating a slow-positive pacing strategy
Roberts et al., 2008	English Premiership players 29 Video files	Team	Relative distance was lower towards the end of the match when compared to the first 10-minute period, indicating a slow-positive pacing strategy.

Note: *F = Forwards; B = Backs; Team = Entire Team.*

Table 2.4 Studies that used GPS for the quantification of relative distance in senior men's Rugby Union match-play through peak period analysis.

Study	Sample	Positional Grouping	Findings
Cunningham et al., 2018	International players 708 GPS files	F & B FR: 1, 2 & 3 SR: 4 & 5 LF: 6, 7, 8 HB: 9 & 10 IB: 12 & 13 OB: 11, 14 & 15	Backs covered greater total distances overall peak epoch lengths (1–5 min). Front Row covered the least of the subgroups for all epoch lengths.
Read et al., 2018	English academy player 472 GPS files	F & B FR: 1, 2 & 3 SR: 4 & 5 LF: 6, 7, 8 SH: 9 IB: 10, 12 & 13 OB: 11, 14 & 15	Peak running intensity for Forwards was lower than that of Backs for all moving average durations (15 and 30 s, 1, 2, 2.5, 3, 4, 5 and 10 min). Second and Loose Forwards had higher peak running intensities than the Front Row at all durations. Scrum Halves had higher peak running intensities than Inside and Outside Backs for all durations except 15 and 30 s.
Delany et al., 2017c	International players 570 GPS files	TF: 1, 2, 3, 4 & 5 LF: 6, 7 & 8 HB: 9 & 10 OB: 11, 12, 13, 14 & 15	Peak running intensities for Backs and Loose Forwards were higher across all moving average durations (1–10 min) than Tight Forwards.

Note: *FR = Front Row; SR= Second Row; LF = Loose Forwards; HB = Halfbacks; SH = Scrum Half; IB = Inside Backs; OB = Outside Backs; F = Forwards; B = Backs.*

H. EXTERNAL LOAD DATA: VIDEO-DERIVED METRICS

Video-based tracking systems traditionally provide an enumeration of specific events of interest. The following section will discuss the video-derived variables, and current literature, which provide insight into the known contact involvements of players relevant to the current study. The video-based variables and definitions (World Rugby definitions of the relevant contact variables are defined in Chapter Three, Table 3.3) thereof that are applicable to the current study include:

- **Total Contact Involvements:** the sum of all other video-derived variables (tackles, carries, rucks, mauls, and scrums), as a single, totalled number (n).
- **Tackles:** The total number (n) of tackles performed. Tackles and tackle attempts were counted where any player made contact with an opposing ball carrier in open play in a defensive manner with an attempt to bring them to ground.
- **Carries:** the total number (n) an attacking player carried the ball into a tackle situation, where contact was made with a defending player.
- **Rucks:** the total number (n) of attacking or defensive rucks in which a player was involved. Ruck involvements were counted if a player made any contact with another player to either form or join a ruck.
- **Mauls:** the total number (n) of attacking or defensive mauls a player was involved in after “maul” had been called by the referee.
- **Scrums:** the total number (n) of attacking or defensive scrums a player was involved in after “set” was called by the referee.

H.1. FULL MATCH ANALYSIS

H.1.1. TOTAL CONTACT INVOLVEMENTS

Although individual contact involvements are well researched (Campbell et al., 2018; Lindsay et al., 2015; Eaton & George, 2006), there is limited literature on the total contact events in which professional rugby players are involved.

Two studies reported on total contact involvements for positional groups (Lindsay et al., 2015; Jones et al., 2015). Lindsay and colleagues (2015) observed 37 Super 15 players over five games (*n* = 104) and based their 'total impact' count on a total of all tackles or tackle assists, a ball carry resulting in contact with the opposition and any ruck involvements, which was presented relatively per minute. The total contact involvements were higher for Forwards (0.56 ± 0.23 contacts.min^{-1}) than that of Backs (0.36 ± 0.17 contacts.min^{-1}). Jones and colleagues (2015) assessed twenty-eight European Cup players (age: 25.1 ± 3.1 years) over four games (*n* = 57). The total contact involvements included a frequency of tackles, hit-ups, and player contacts at the breakdown area reported as a total over a match. Similarly to Lindsay and colleagues (2015), Forwards (25 ± 9 contacts) were found to engage in more total contacts than Backs (15 ± 7 contacts) (Jones et al., 2015). A study by Quarrie and colleagues (2013) attempted to evaluate the actions and movements of 763 international players over 90 matches (*n* = 3700). Although the authors did not directly compare total contact involvements, their extensive description of single contact events lead them to the conclusion that Forwards are much more heavily involved in contact events than Backs (Quarrie et al., 2013).

Lindsay and colleagues (2015) analysed positional subgroups, which indicated that the Front Row (0.51 ± 0.11 contacts.min^{-1}), Second Row (0.54 ± 0.01 contacts.min^{-1}) and Loose Forwards (0.64 ± 0.36 contacts.min^{-1}) are involved in more contacts per game than the Inside Backs (0.39 ± 0.20 contacts.min^{-1}) and Outside Backs (0.31 ± 0.09 contacts.min^{-1}), with no differences between the Forward and Back positional subgroups (Lindsay et al., 2015). These differences are likely due to positional roles and responsibilities and, as a result, the greater propensity for specific types of contact involvements (Campbell et al., 2018; Lindsay et al., 2015; Jones et al., 2014), which are discussed in the following sections.

H.1.2. TACKLES

Current literature is conflicted when comparing tackle involvements of Forwards and Backs (Lindsay et al., 2015; Jones et al., 2015; Deutsch et al., 2006). Lindsay and colleagues (2015) found Forwards to attempt more tackles than Backs (0.15 ± 0.08 v 0.11 ± 0.11 min^{-1}). In contrast, Jones and colleagues (2015) found no difference between the Forwards and Backs (Forwards: 5 ± 3 v Backs: 4 ± 3). This was supported by Deutsch and colleagues (2006), who investigated 29 Super 12 players over 8 matches (n = 29) and concluded that Forwards (23.1 ± 14.0) are not involved in more tackles than Backs (23.4 ± 10.2). The dissimilarity in research is likely due to methodological differences. Lindsay and colleagues (2015) totalled tackles as any defensive tackle involvement, counting both tackles made and tackle assists. Jones and colleagues (2015) stated that a frequency of tackles was recorded, with no mention of tackle assists. Deutsch and colleagues (2006) recorded both offensive and defensive tackle involvements, where both tackling and being tackled counted towards the total tackle count.

Further differences exist when assessing positional subgroups. Campbell and colleagues (2018) assessed 32 Premier Grade club rugby players (age: 24 ± 4 years) over 14 matches

(294 video data files) and found all positional subgroups to attempt more tackles than the Outside Backs (1.5 ± 1.0). Furthermore, Loose Forwards (7.2 ± 3.2) were involved in more tackles than the Centres (5.7 ± 2.6), and the Centres more than the Halves (4.5 ± 2.4). No additional differences were seen for the Front Row (5.6 ± 3.0) and Second Row (6.0 ± 2.9) (Campbell et al., 2018). Similar findings by Lindsay and colleagues (2015) indicated that the Outside Backs (0.07 ± 0.07) were involved in the least amount of tackles per minute, with the Loose Forwards (0.17 ± 0.09) involved in the most. No other differences were seen for the Front Row (0.14 ± 0.07), Second Row (0.16 ± 0.09) and Inside Backs (0.14 ± 0.12). The only difference found by Eaton and George (2006), who evaluated 35 professional rugby players (age: 20–34 years) over six Premiership matches, was that the Loose Forwards (13 ± 6) participate more tackles than the Outside Backs (6 ± 3), which was confirmed by Deutsch and colleagues (2006) (29 v 16.5, assessing both tackling and being tackled in combination). In addition, Deutsch and colleagues (2006) found both the Loose Forwards (29) and Inside Backs (28) to attempt more tackles than the Front Row (19).

It is a common trend of current research that the Loose Forwards engage in the most tackles and the Outside Backs the least (Campbell et al., 2018; Lindsay et al., 2015; Eaton and George, 2006). However, the differences seen in the remaining subgroups is conflicted. The current study aims to contribute to this area in the hopes of better clarifying the tackle involvements of positional subgroups.

H.1.3. BALL CARRIES

There are inconsistent results in current literature when assessing carries into contact for Forwards and Backs (Lindsay et al., 2015; Jones et al., 2015). Findings indicate that either the Backs have more carries than the Forwards (0.11 ± 0.06 v 0.08 ± 0.05 per min) (Lindsay et al., 2015) or that no difference exists (Forwards: 5 ± 2 v 5 ± 3) (Jones et al., 2015). Both studies had similar methodology and definitions of carries into contact. It is, therefore, more likely that the differences observed are due to the different competitions in which each team participated (Super 15 and European Cup) and the resultant tactics and strategies employed by each team.

Lindsay and colleagues (2015) investigated positional subgroups and found all positional subgroups to complete more carries than the Front Row (0.06 ± 0.05 per min). In addition, Inside Backs (0.11 ± 0.07 per min) and Outside Backs (0.12 ± 0.06 per min) were found to complete more carries than the Second Row (0.10 ± 0.02 per min) and Loose Forwards (0.09 ± 0.06 per min) (Lindsay et al., 2015). Similar studies focusing on describing contact involvements in rugby often omit positional subgroups (Jones et al., 2015) or carries (Campbell et al., 2018; Deutsch et al., 2006; Eaton and George, 2006), and it is, therefore, challenging to draw direct comparisons with literature.

H.1.4. RUCKS

Current research is in synonymous in the finding that Forwards participate in more rucks than Backs (Lindsay et al., 2015; Jones et al., 2015; Deutsch et al., 2006). While assessing relative ruck involvements, Lindsay and colleagues (2015) concluded that Forwards complete 0.33 ± 0.25 rucks per minute, while Backs engage in 0.13 ± 0.09. Similar findings saw Forwards to be involved in 15 ± 6 contacts at the breakdown and Backs 6 ± 4 (Jones et al., 2014). Deutsch and colleagues (2006) supported the finding that Forwards participate in more rucks than Backs. These findings reflect the role of the Forwards, who are often required to retain and maintain possession at the breakdown, providing an attacking platform for the Backs.

When evaluating ruck involvements for positional subgroups, Lindsay and colleagues (2015) found the Front Row (0.32 ± 0.09), Second Row (0.28 ± 0.06) and Loose Forwards (0.37 ± 0.42) to be involved in more rucks per minute than the Inside Backs (0.15 ± 0.11) and Outside Backs (0.11 ± 0.03). Campbell and colleagues' (2018) findings support that of Lindsay and colleagues (2015), where no difference was seen in the number of ruck involvements per match for the Front Row (10.9 ± 4.5), Second Row (15.0 ± 6.4) and Loose Forwards (12.9 ± 4.2).

When assessing rucks and mauls together, work by Eaton and George (2006) supported the notion that all Forward positional subgroups are involved in more rucks than Back positional subgroups, with no difference seen within each group. A similar study supported these findings (Deutsch et al., 2006), however, the author's concluded that the Front Row engage in more rucks and mauls than the Loose Forwards. The authors' contended that the Front Row is more involved in the setting of the offensive platform at the breakdown, while the Loose Forwards play a pseudo-back-line role. However, the findings of Deutsch and colleagues (2006) are outlying when compared to other literature. The study was completed over the 1996 and 1997 Super Rugby seasons. It is known that the physical demands of rugby have changed over time (Quarrie et al., 2007), and while the core positional roles remain the same, the specific strategies and tactics around positional involvements might have evolved. This is demonstrated by Kraak and Colleagues (2017), where law changes and an increase in ball-in-play time has resulted in changes in functional roles of players, such as more ball carries and tackles.

H.1.5 MAULS

The number of maul involvements is highly specific to positional roles, with mauling almost entirely falling under the Forwards' role. In this regard, many studies have not included mauls in when describing the game demands (Lindsay et al., 2015; Jones et al., 2015) or a comparison of Backs and Back positional subgroups (Campbell et al., 2018). Campbell and colleagues (2018) assessed the total mauls throughout a match for Forward positional subgroups and found no difference between the Front Row (3.1 ± 2.7), Second Row (3.3 ± 3.0) and Loose Forwards (2.9 ± 2.6).

As previously mentioned, other researchers (Deutsch et al., 2006; Eaton & George, 2006) assessed rucks and mauls in combination. Deutsch and colleagues (2006) found Forwards to participate in more rucks and mauls than Backs, with the Front Row involved in more than all other positional subgroups and Loose Forwards more than the Inside and Outside Backs. Eaton and George (2006) found all Forward positional subgroups engage in more combined rucks and mauls than all Back positional subgroups. However, these results are likely a skewed representation of mauls due to the higher number of rucks relative to mauls per game (Campbell et al., 2018), and therefore might not give a true reflection of maul involvements.

Although purely descriptive, with no comparisons stated, the significance of the sample size of work by Quarrie and colleagues (2013) makes the findings of their study worth mentioning. They reported on counts of mauls per match for all starting players: props (1.2 ± 1.9), hooker (1.9 ± 1.7), locks (1.8 ± 2.1), flankers (1.6 ± 1.8), number 8 (1.7 ± 1.8), scrum-half (0.15 ± 0.43), fly-half (0.17 ± 0.47), midfielders (0.29 ± 0.60), wingers (0.24 ± 0.49), and fullback (0.22 ± 0.71). These results support the statement that although there is a chance the Backs might be involved in a maul, the chances are negligible. It also indicates that there is a possibility that differences might be seen between the Forward positional subgroups.

H.1.6 SCRUMS

Similarly to maul involvements, as a result of the positional demands, it is no surprise that Forwards (13 ± 5) participate in more scrums than Backs (0 ± 0) (Jones et al., 2015). The scrum forms one of the set-pieces of rugby, where all Forward positional subgroups are involved and, as expected, no difference exists between positional subgroups (Campbell et al., 2018; Deutsch et al., 2006; Eaton & George, 2006). The Front Row, Locks and Loose Forwards have been reported to complete 21.7 ± 5.5, 21.4 ± 7.2, and 23.4 ± 3.9 scrums per match, respectively (Campbell et al., 2018). Eaton and George (2006) found Props (29 ± 6), Hookers (29 ± 6), Locks (29 ± 6) and Loose Forwards (27 ± 7) engage in a comparable amount of scrums per match. The frequencies reported by Jones and colleagues (2014) are noticeably lower than other studies. Although not stated by the authors, a possible explanation is that scrums that were reset were tallied as a single event, rather than multiple events which represent each scrum engagement.

H.2. TEMPORAL PATTERN ANALYSIS

H.2.1. RELATIVE CONTACT INVOLVEMENTS

To the author's knowledge, there is currently no literature detailing the contact involvements quantified through temporal pattern analysis. As changes in movement demands have been documented when comparing halves (Tee et al., 2017) and comparing temporal periods within each half (Jones et al., 2015), it can be surmised that there might be differences in contact involvements as the match progresses. The current study aims to address this gap in literature and provide position-specific information on contact involvements during match-play through temporal pattern analysis.

H.3. PEAK PERIOD ANALYSIS

H.3.1 RELATIVE CONTACT INVOLVEMENTS

Similarly to temporal pattern analysis, the author is unaware of any current literature aiming to quantify the contact involvements during peak periods of play in a manner analogous to the current study. However, two studies have provided information that might provide applicable information (Pollard et al., 2018; Reardon et al., 2017).

A study by Pollard and colleagues (2018) assessed 22 international players (age: 27.0 ± 2.9 years) over 8 matches, providing 88 data files. The authors focused on a mean collision frequency while the ball was in play. It was concluded that the Forwards engage in more collisions than Backs for plays lasting 30–60 seconds (1.1 ± 0.2 v 0.5 ± 0.1), 61–90 seconds (1.2 ± 0.2 v 0.7 ± 0.2), and plays greater than 90 seconds (1.1 ± 0.2 v 0.6 ± 0.1).While ball in play time might not directly mimic peak periods throughout an entire match, it gives an indication of the collision involvements while removing "dead time." Another similar study by Reardon and colleagues (2017) identified the longest period of play and the corresponding collisions per minute for 39 professional rugby players (age: 27.2 ± 3.9 years). The longest period of play during matches was found to be 152–161 seconds and the relative contact involvements per minute were higher for the Tight Forwards (0.62–0.84) and Loose Forwards (0.75–1.01) when compared to the Inside Backs (0.17–0.40) and Outside Backs (0.27–0.56).

While the aforementioned studies provide insight into the positional differences during more intense periods of match-play, they do not provide contact information over duration-specific peak periods of play. The current study offers novel information by detailing these duration-specific peak periods of play and providing an equation to estimate the collisions required in training to replicate the peak periods of match-play.

H.4. SUMMARY

Table 2.5 provides a summary of the video-derived metrics. Current literature tends to agree that Forwards engage in more total contact events than Backs and that Forwards are involved in more rucks, scrums and mauls. However, there is inconsistency in whether a difference exists for the number of tackles and carries in which players are involved. Additionally, differences in the various video-derived metrics for positional subgroups are evident. There is currently a dearth in literature for temporal pattern and peak period analysis when assessing contact involvements derived from video. The current study aims to contribute to this area, providing novel information on the contact demands involved in rugby union match-play.

Table 2.5 Studies using video-based analysis for the quantification of contact variables in professional Rugby Union match-play (since 2006).

Study	Sample	Positional Grouping	Significant Findings
Campbell et al., 2018	Premier grade club players. 146 Data files.	FR: 1, 2 & 3 SR: 4 & 5 LF: 6, 7, 8 HB: 9 & 10 MF: 12 & 13 OB: 11, 14 & 15	Tackles: All subgroups > OB. LF > MF > H. Rucks: FR, SR, LF > H, MF, OB. SR > FR. Mauls: No difference between FR, SR, LF. Scrums: No difference between FR, SR, LF.
Lindsay et al., 2015	Super Rugby players. 104 Data files.	F & B FR: 1, 2 & 3 SR: 4 & 5 LF: 6, 7, 8 IB: 9, 10, 12 & 13 OB: 11, 14 & 15	Total Impacts: Forwards > Backs. FR, SR, LF > IB, OB. Tackles: Forwards > Backs. LF > FR, SR, IB > OB. Ball carries: Backs > Forwards. IB, OB > SR, LF > FR. Rucks: Forwards > Backs. FR, SR, LF > IB, OB.
Jones et al., 2015	European Cup players. 57 Data files.	F & B	Total Impacts: F > B. Tackles and Carries: F = B. Rucks and Scrums: F > B.
Deutsch et al., 2006	Super Rugby players. 29 Data files.	F & B FR: 1, 3, 4 & 5 LF: 2, 6, 7 & 8 IB: 10, 12 & 13 OB: 11, 14 & 15	Tackles: F = B. LF, IB > FR. LF > OB. Rucks / Mauls: F > B. FR > all subgroups. LF > IB & OB. Scrums: FR = BR.
Eaton & George, 2006	English Premiership players. 90 Video Files.	P: 1 & 3 H: 2 SR: 4 & 5 LF: 6, 7 & 8; SH: 9 IB: 10, 12 & 13 OB: 11, 14, 15	Tackles: LF > OB. Combined Rucks and Mauls: P, H, SR, LF > SH, IB, OB. Scrums: No difference between P, H, SR & LF.

Note: *FR = Front Row; SR= Second Row; LF = Loose Forwards; HB = Halfbacks; MF = Midfield; IB = Inside Backs; OB = Outside Backs; F = Forwards; B = Backs; P = Prop; H = Hooker; SH = Scrumhalf.*

I. SUMMARY

Rugby's multi-faceted nature provides potential players with a range of playing positions, each with various physical traits, roles and responsibilities (Jones et al., 2015; Lindsay et al., 2015; Duthie et al., 2003). Given these differences, players are often grouped when preparing for competition in positional groups (Forwards and Backs) and positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

Quantifying the positional demands of players during match-play is a requisite for prescribing optimal training loads. There are two primary methods for quantifying the external demands of rugby: video-based systems and GPS. Video-based systems are effective in providing a count of contact events, while GPS is effective in describing the movement characteristics of players.

Once quantified, information gained on position-specific demands of match-play can be used to best implement the principles of overload, specificity and interference to apply the correct training stimulus and attain the desired resultant adaptation. Over time, the adaptation should develop robust athletes with improved potential for performance and reduced injury risk. Better insight into this development can be attained by utilising different methods of interpretation for external load data: full match, temporal pattern and peak period analysis.

When assessing an entire match, Backs tend to cover more distance than Forwards, particularly in high-speed zones. Additionally, differences are seen when further dividing positions into positional subgroups. Temporal pattern analysis has shown Forwards to have a slow-positive

pacing strategy and backs either a slow-positive or flat pacing strategy. Currently, no literature exists around temporal pattern analysis and positional subgroups. Peak running intensities for Backs are higher than that of Forwards overall rolling average durations, with the Front Row and Tight Forwards often exhibiting the lowest intensities of the positional subgroups. No literature currently exists around using Power Law to estimate the peak running demands of match-play as a function of time in rugby.

Current literature tends to agree that Forwards are involved in more total contact events than Backs and that Forwards are involved in more rucks, scrums and mauls. However, there is inconsistency in whether a difference exists for the number of tackles and carries in which players engage. Additionally, differences in the various video-derived metrics for positional subgroups are evident.

There is currently a dearth in literature for temporal pattern and peak period analysis when assessing contact involvements derived from video. The current study aims to contribute to this area, providing novel information on the contact demands involved in rugby match-play.

CHAPTER THREE

METHODOLOGY

A. INTRODUCTION

A dearth in current literature calls for an in-depth analysis of rugby match-play locomotive and contact characteristics. This chapter provides a breakdown of the manner in which the study was carried out and provides the necessary particulars for it to be replicated. It starts by giving a broad overview of the study design. The participants' details, as well as the inclusion and exclusion criteria for sample selection, are described. Mention is given to the relevant ethical aspects of the study. The study outline is covered with a focus on the place of study, sessions monitored and data sources. After that, the data sources are elaborated on through the Tests and Measurements section, which describes the equipment used and procedures followed throughout the study. Outcome variables derived from the data are then listed and defined. Lastly, the methods of statistical analysis used to provide informative insight to the data are described. This chapter ends with a summary of the methodology of the study.

B. STUDY DESIGN

The current study followed a descriptive design with no intervention, where player locomotive and contact characteristics were quantified during Super Rugby match-play. The group was monitored through GPS and video-based analysis over a period of two competitive seasons (2014: 20 weeks and 2015: 19 weeks) of Super Rugby. GPS data were collected by the team's strength and conditioning coach and broadcasted video recordings, available in the public domain, were obtained. Data were grouped by positional demands and then analysed in response to the study objectives. As shown in Figure 3.1., only 45% (n = 207) of the data sets were used. The limited data is primarily due to the exclusion of players that did not complete a full match, as varying substitution times might have skewed the data as a result of fatigue in later stages of match-play.

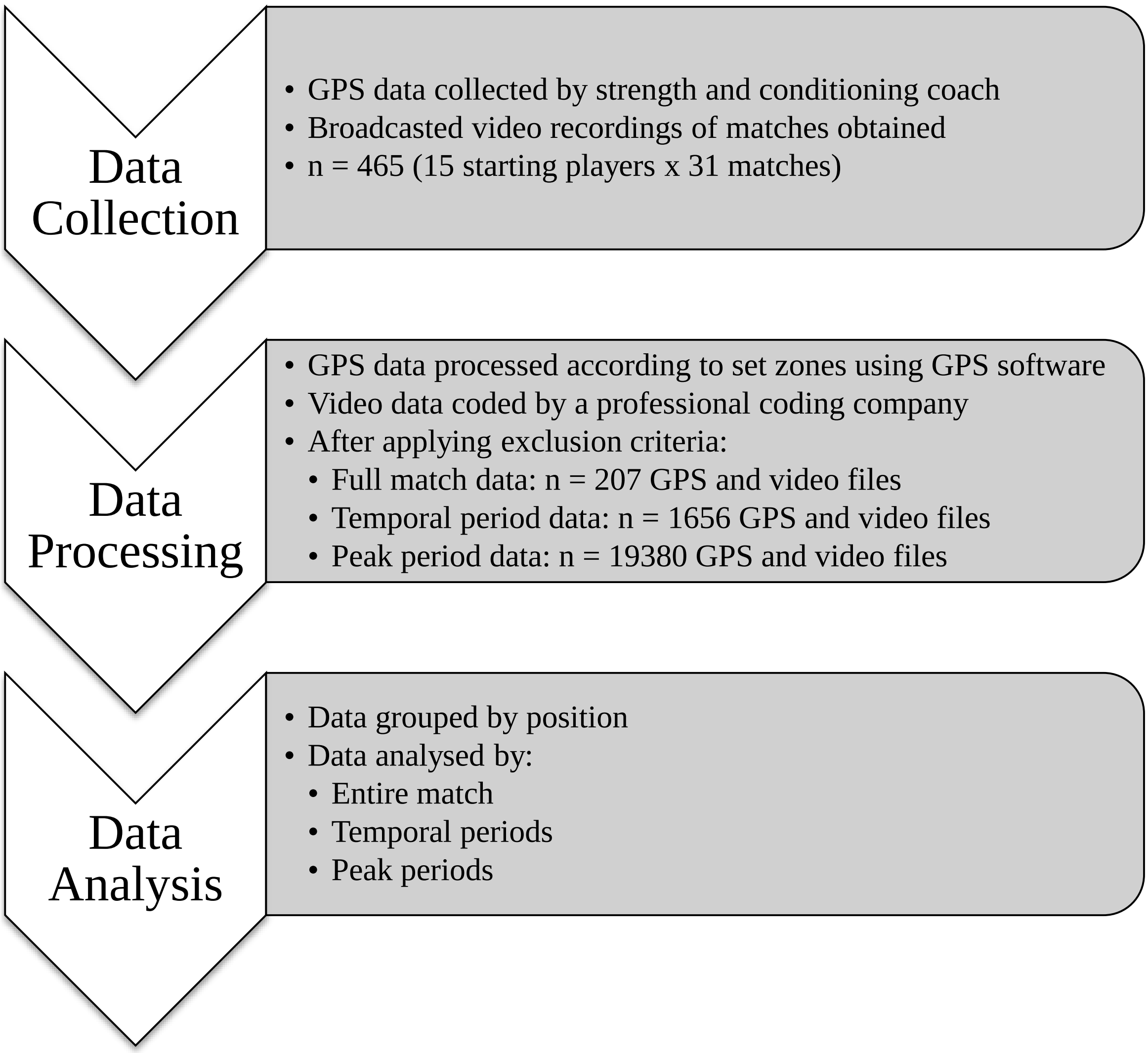

Figure 3.1. Schematic representation of the study design.

C. PARTICIPANTS

A sample of convenience was used and consisted of 34 professional male rugby players (24.4 ± 3.8 years of age; body mass 101.4 ± 13.2 kilograms (kg); stature 187 ± 8 centimetres (cm)), aged 20 to 32 years, upon commencement of the study. These players were included in a Super Rugby squad for the 2014 season, 2015 season, or both seasons. The head strength and conditioning coach of the team was contacted by the researcher, who then organised a meeting with the required team staff members. The meeting included the primary researcher, the head strength and conditioning coach of the team, the team manager and one of the team's coaches. When the staff members approved the proposed study, signed informed consent was given by the head of strength and conditioning to grant access to the organisation's data.

C.1. POSITIONAL GROUPS

Rugby consists of 15 individual playing positions, which differ in physical traits (Duthie et al., 2003; Nicholas, 1997), roles and responsibilities (Jones et al., 2015; Lindsay et al., 2015; Deutsch et al., 2007). For the current study, players were split into Forwards and Backs, as well as more specific positional groups according to similar demands of playing positions. These groups were similar to those used by Jones et al. (2015) and Tee and Coopoo (2015), as to allow for comparisons with literature, but slightly modified to allow for easier practical application:

1. *Forwards and Backs*

   Forwards: loose-head prop, hooker, tight-head prop, left lock, right lock, blindside flanker, openside flanker and number eight.

Backs: scrum-half, fly-half, left wing, inside centre, outside centre, right wing and fullback.

2. *Tight Forwards, Loose Forwards, Inside Backs and Outside Backs*

   Tight Forwards: loose-head prop, hooker and tight-head prop, left lock and right lock.

   Loose Forwards: blind-side flanker, open-side flanker and number eight.

   Inside Backs: scrum-half, fly-half, inside centre and outside centre.

   Outside Backs: left wing, right wing and fullback.

C.2. INCLUSION AND EXCLUSION CRITERIA

Players were included in the study if they were men between the ages of 20 and 33 years of age, who were involved in Super Rugby match-play during the 2014 season, 2015 season, or both Super Rugby seasons.

A player's data for a specific match were excluded if:

a) they did not complete the entire 80-minute duration of the match for any reason (replacement, substitution or penalty cards)
b) they changed position during the match and moved to a different positional group
c) they failed to wear the GPS device
d) the GPS device failed to form a connection with the satellites
e) the GPS device lost signal after forming the initial satellite connection
f) the video data was unobtainable due to broadcasting technical difficulties

D. ETHICAL ASPECTS

The study protocol was approved by the Departmental Ethics Committee (DESC) and the Research Committee for Humanities at Stellenbosch University (reference number HS1043/2014) (Appendix A).

The study layout was verbally explained to the key coaching staff, and they were therefore aware of what the study entailed and what was required of them. Signed informed consent was emailed to the team's head of strength and conditioning, which was signed and returned upon meeting. Participation through the use of wearing the GPS device was voluntary, and all players were able to withdraw their data from the study at any time, where a reason for withdrawal was not necessary. All data were treated with strict confidentiality and remained anonymous when reported in the study. Coaches had access to the raw data through a password-protected personal computer as per usually applied practices by the strength and conditioning coach of the team. Any additional information provided by the primary researcher to the coaching staff (upon consent) was used to monitor players and for player load management and did not affect team selection. Data were stored on the primary researcher's password-protected personal computer, as well as an online back-up through password-protected cloud-based software, of which only the researcher had access. The researcher acted professionally and treated players and staff with respect at all times. All data used for analysis was safely and securely stored after completion of the study. Due to the non-invasive nature of the data gathering techniques that are already commonly used in the modern game, there were no physical risks as a result of the research.

E. STUDY OUTLINE

The study monitored Super Rugby players' external loads over two periods during two competitive seasons. Data were gathered over a total period of 39 weeks, providing data for 31 matches. The coaching staff selected the starting XV players of each week. Those that met the inclusion and exclusion criteria were monitored through GPS and video recording during match play. Data were collected and categorised into data sets according to set positional groups and analysed according to various periods of play.

E.1. PLACE OF STUDY

Monitoring of the players took place in various venues depending on the stage of the competition. The majority of the data capturing occurred at Newlands Stadium in Cape Town. However, when away games were played the match venues varied depending on the opposition that was played. Opposition venues comprised the home ground stadiums of the local or foreign Super Rugby teams that the team under study competed against. These included: AMI Stadium in Christchurch, GIO Stadium in Canberra, Suncorp Stadium in Brisbane, Free State Stadium in Bloemfontein, Loftus Versfeld in Pretoria, Kings Park Stadium in Durban, Emirates Airline Park in Johannesburg, Westpac Stadium in Wellington, Allianz Stadium in Sydney and nib Stadium in Perth.

E.2. MATCHES AND TRAINING SESSIONS

Matches were played on the Friday, Saturday or Sunday of each match week. Each match consisted of two scheduled 40-minute halves with a 12-minute break between halves. Fourteen matches were recorded over a 20 week period of the first season and 16 matches over a 19 week period of the second season. Additional weeks with no matches were as a result of byes and the midseason break for the international tests. During the week the team trained in a gymnasium and participated in field-based training sessions in an attempt to maximise match performance, with slight variations depending on what day the match was to be played.

Table 3.1. **Example week showing the team's weekly field-based training sessions and their duration in minutes, on a standard Saturday match turnaround.**

Session	M	T	W	T	F	S	S
Team	60	60	45	Off	Captain's Practice	Match	Off
Split	30	45	Off	Off			Off

"Team": team trains together

"Split": team trains in two separate groups (Forwards and Backs)

E.3. DATA SOURCES

GPS data

GPS data of the team's starting XV were recorded for the entire duration of match-play in order to quantify the locomotive characteristics. This resulted in 465 match-play data files.

Video data

Video recordings of the entire duration of all matches and professional video codes were obtained in order to quantify the contact demands. This resulted in 465 video data files.

The GPS and video data sets were narrowed down to 208 full match data files after applying the exclusion criteria (i.e. did not complete the entire duration of the match for any reason, changed position during the match and moved to a different positional group, failed to wear the GPS device, the GPS device failed to form a connection with the satellites, the GPS device lost signal after forming the initial satellite connection, or the video data was unobtainable due to broadcasting technical difficulties). These files were further split into 1664 and 19743 data files for temporal period and peak period analysis respectively.

F. TESTS AND MEASUREMENTS

Anthropometrical data were obtained in order to determine the descriptive characteristics of the study sample. GPS and video data acted as a measurement of the external loads placed on players, quantifying locomotive and contact characteristics, respectively. Independent variables included positional groups and the time periods used for analysis. Dependent variables comprised locomotive and contact match-play characteristics.

F.1. ANTHROPOMETRICAL MEASUREMENTS

Anthropometrical measurements included stature and body-mass, both of which were provided by the team's strength and conditioning coach. The strength and conditioning coach is a qualified Biokineticist who regularly administers these measurements. The height and mass measurement guidelines stipulated by the International Society for the Advancement of Kinanthropometry (ISAK) were followed.

F.2. GPS DATA

GPS data were collected using tracking devices (SPI HPU; GPSports Systems, Canberra, Australia; mass: 67g; Size: 74 x 42 x 16 mm). According to the manufacturer's specifications (GPSports Systems), each tracking device had a 5 Hz true GPS sampling rate, which was interpolated into 15 Hz, and housed various microsensors. The microsensors included a built-in 100 Hz triaxial accelerometer and magnetometer, with the manufacturer omitting a gyroscope which was included in earlier models. The device used in the current study has been deemed valid and reliable for use in team sports (Barr et al., 2017; Johnston et al., 2012). The validity and reliability of distances at lower intensities are commonly accepted (Barr et al., 2017, Johnston et al., 2012). However, higher intensity movement is controversial, with some cautioning the use above 20 $km.h^{-1}$ (Johnston et al., 2012) and others supporting it (Barr et al., 2017). Each GPS unit was held in place, between the scapulae in the upper thoracic spine region, by a padded neoprene harness provided by the manufacturer, as shown in Figure 3.1. Various sizes were available to ensure a comfortable fit for the players.

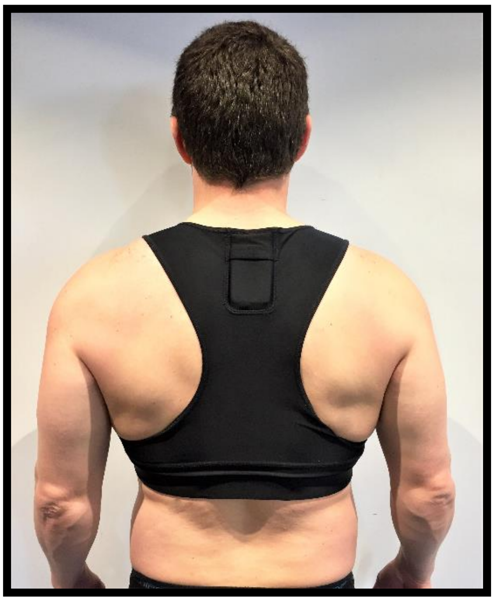

Figure 3.2 A neoprene GPS harness similar to those worn by the athletes in the study. (Photograph by Shaun Owen).

Players had been familiarised with the use of the GPS devices during a full week of training sessions before the first recorded game. Devices were assigned to players before each match and worn for the entire duration of the warm-up and match-play. The same device was assigned to the same player for the duration of the study. Several minutes prior to use, the devices were switched on and satellite connection was established. Roughly 15 minutes after matches the devices were switched off. Time and location data were registered and temporarily stored on the device itself. After the data were recorded, the devices were placed in a docking station where the data were transferred via infra-red. The data were then transferred from the docking station to the strength and conditioning coach's personal computer. It was then copied to the primary researcher's personal computer where it was split to reflect the session times and then analysed with the software provided by the manufacturer (Team AMS software, Version R1 2016.7, GPSports, Canberra, Australia) to give locomotive variables. Any data that had poor satellite connection were excluded. All pre-game, half-time, and post-game data were removed so that only match time was included in the analysis.

F.2.1 SPEED ZONE CLASSIFICATION

Movement speeds were classified into four zones representing walking, jogging, striding and sprinting, similarly used in previous studies (Jones et al., 2015; Tee et al., 2015). Absolute values were used as opposed to relative values (zones based on percentages of a player's maximum speed) as this could provide a more practical and accurate representation of the movement characteristics of each positional group. The reason for this is three-fold. Firstly, the validity of GPS at very high speeds is questionable (Johnston et al., 2012; Coutts and Duffield, 2010), and this is what the zones would be based off. Secondly, the faster the maximum speed an athlete can achieve does not correlate with an improved aerobic running performance at submaximal speeds (Meckel et al., 2009). Therefore, it could be erroneous to assume that a faster player will have a greater capacity to work at specific relative submaximal speeds when compared to a slower player and vice versa. Thirdly, the effort required of athletes in match-play is independent of the athlete themselves, where failing to meet absolute thresholds might hinder team performance.

Zone 1 indicates the lowest speed category, with zones incrementally increasing in speed until zone 4, which describes the maximum movement effort and intensity. The zones are listed in Table 3.1 and describe the typical locomotive activity profiles of intermittent team sports (Dywer & Gabbett, 2012). McLean (1992) defined passive rest as activities that signify very little to no movement and active recovery as low-intensity activities such as walking or jogging, where high-intensity activity such as striding and sprinting are defined as work. As a result, the zones can be classified into two broader zones of rest and active recovery (low-intensity running: zones 1 and 2) and work (high-intensity running: zones 3 and 4). The total distance accumulated, the distance in each of the four speed zones, as well as the frequency of zone 4 entries (sprint count) were recorded.

Table 3.2 Speed zone classification system.

Zone	$m \cdot s^{-1}$	$km \cdot h^{-1}$	Speed Classification	Broad Classification
1	0–2	0.0–7.2	Walking	Low-intensity running
2	2–4	7.2–14.4	Jogging	
3	4–6	14.4–21.6	Striding	High-intensity running
4	> 6	> 21.6	Sprinting	

F.3. VIDEO DATA

Video footage of match-play, as broadcasted, was analysed by a professional video coding company (OPTA Sportsdata Company; Sportscode software) post-game to identify contact events for each player, including a tackle, carry, ruck, maul and scrum involvement count. Any operation definition that differed from that of the current study's definition was adjusted to meet the requirements of the study definition. These times were then adjusted using Microsoft Excel (Microsoft Corporation, USA) to reflect the Coordinated Universal Time (UTC) of each event and synced with GPS data. The description of the variables related to the video data is provided in the next section (video-derived variables and Table 3.2.). No current research addresses the reliability of the specific software used in rugby, however, inter-reliability of the software has been demonstrated in another team sport (Liu et al., 2013). In addition, inter-reliability and intra-reliability of similar computerised notational system has been demonstrated in rugby (Painczyk et al., 2018)

G. OUTCOME VARIABLES

G.1. GPS-DERIVED VARIABLES

Maximum Speed: the fastest recorded speed at which a player travelled over a particular session, measured in kilometres per hour.

Total distance: the total meterage (m) a player travelled.

Distance in speed zones: the total meterage (m) a player travelled within each of the four pre-set speed zones (Table 3.1).

Sprints: the total number (n) of times a player achieved a velocity faster than 21.6 kilometres per hour (Table 3.1, speed zone 4).

G.2. VIDEO-DERIVED VARIABLES

Total contact involvements: the sum of all video-derived variables (tackles, carries, rucks, mauls, scrums) as a single, totalled number.

Tackles: The total number (n) of tackles performed. Tackles and tackle attempts were counted where any player made contact with an opposing ball carrier in open play in a defensive manner with an attempt to bring them to ground.

Rucks: the total number (n) of attacking or defensive rucks in which a player was involved. Ruck involvements were counted if a player made any contact with another player to either form or join a ruck.

Carries: the total number (n) an attacking player carried the ball into a tackle situation, where contact was made with a defending player.

Mauls: the total number (n) of attacking or defensive mauls a player was involved in after “maul” had been called by the referee.

Scrums: the total number (n) of attacking or defensive scrums a player was involved in after “set” was called by the referee.

Table 3.3 World Rugby definitions of terms relevant to the video-based variables. (WR, 2017)

Term	World Rugby Definition
Tackle	When the ball carrier is held by one or more opponents and is brought to ground.
Ruck	A phase of play where one or more players from each team, who are on their feet, in physical contact, close around the ball on the ground. Open play has ended.
Maul	A maul begins when a player carrying the ball is held by one or more opponents, and one or more of the ball carrier's teammates bind on the ball carrier. A maul, therefore, consists, when it begins, of at least three players, all on their feet; the ball carrier and one player from each team. All the players involved must be caught in or bound to the maul and must be on their feet and moving towards a goal line. Open play has ended.
Scrum	When players from each team come together in scrum formation so that play can be started by throwing the ball into the scrum.

G.3. METHODS OF INTERPRETATION

The GPS and video-based variables were interpreted through three different methods in an attempt to provide detailed information about the different aspects of match-play, for the aforementioned positional groups and subgroups. These three interpretation methods comprised full match, temporal pattern and peak periods analysis.

Full match: total values that represent the entire duration of a match.

Temporal patterns: values were reported as variable per minute for various stages of a match. These stages are split into eight equal periods, equating roughly 10 minutes each.

Peak periods: match data were split into one minute periods, which were then used to calculate the 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10-minute rolling-averages for the most-intense periods of match-play. Power Law analysis was used to provide a prediction of the mean and peak locomotive and contact event intensities as a function of time, similarly used by Delaney and colleagues (2017b). The Power Law is given by the equation $y = cx^n$, where c and n are constants, and x and y represent two variables with a dependent relationship. A slope n and intercept c^e can be derived from a straight line produced by plotting log (x) and log (y) (Katz & Katz, 1994). Linear regression was used to determine values for n and c for each variable, and the exponential of c was calculated. This provided a predictive equation, $i = ct^n$ of each variables intensity (i) as a function of time (t).

H. STATISTICAL ANALYSIS

Positional information is described using descriptive statistics (mean ± standard deviation (SD)) and compared through independent t-Tests, and mixed model repeated measures ANOVA, followed by Fisher's Least Significant Difference (LSD) for post hoc testing. Participants were grouped according to playing position, broadly classified as Forwards and Backs and more specifically as Tight Forwards, Loose Forwards, Inside Backs and Outside Backs. Each grouping was analysed through three methods of interpretation: Full Match, temporal pattern and peak period analysis.

Given the normality of the data, parametric tests were conducted for statistical analysis. A mixed model repeated measures ANOVA was used to compare data, followed by Fisher's Least Significant Difference (LSD) for post hoc testing. The level of significance was set at

95% ($P \leq 0.05$), with a lettering system ($^{A,\ a\text{–}e}$) utilised to denote significant differences in figures and tables. STATISTICA was used for statistical analysis of the data (DELL INC version 13.0.159.8).

I. SUMMARY

This descriptive study attempted to quantify the position-specific locomotive and contact match-play characteristics of a Super Rugby team over two in-season periods. Locomotive demands were monitored using GPS, while video-based analysis provided a count of contact events. The characteristics were interpreted according to full match, temporal patterns and peak period analysis.

CHAPTER FOUR

RESULTS

A. INTRODUCTION

The study investigated the position-specific locomotive and contact characteristics of professional rugby players during match-play, throughout two Super Rugby seasons (2014 and 2015). This chapter starts with the descriptive statistics and then presents the results for each method of interpretation: full match, temporal pattern, and peak period analysis. Each method of interpretation contains data categorised, firstly, by positional groups: Forwards and Backs, and secondly, by positional subgroups: Tight Forwards, Loose Forwards, Inside Backs and Outside Backs. This chapter then concludes with a summary of the results.

The average duration of the matches included in the current study was 92 minutes and 34 seconds, which will be used in Chapter 5 to draw comparisons with similar research.

B. PARTICIPANTS

A total of 34 professional male rugby players were included through a sample of convenience. Table 4.1 details the anthropometrical characteristics of the players, including age, height and mass upon commencement of the study. Table 4.2 presents a breakdown of the individual playing positions, the positional groups and positional subgroups, as well as the 207 GPS and video data files analysed for each playing position. Forwards made up 83 (40%) of the total files and Backs 124 (60%). The positional subgroups of Tight Forwards, Loose Forwards, Inside Backs and Outside Backs each contributed 33 (16%), 50 (24%), 60 (29%) and 64 (31%) files respectively.

Table 4.1 Anthropometrical characteristics of participants (Mean ± SD).

Participant Categories	Age (years)	Height (cm)	Mass (kg)
Entire sample	24.2 ± 3.4	186 ± 9	98.9 ± 13.2
Forwards (F)	25.3 ± 2.9	192 ± 7	111.1 ± 6.5
Backs (B)	23.4 ± 3.5[A]	182 ± 7[A]	90.7 ± 9.9[A]
Tight Forwards (TF)	25.2 ± 2.8	196 ± 7	114.1 ± 4.9
Loose Forwards (LF)	25.4 ± 3.0	190 ± 5[a]	109.1 ± 6.7[a]
Inside Backs (IB)	24.9 ± 3.4	183 ± 7[ab]	93.2 ± 8.0[ab]
Outside Backs (OB)	22.0 ± 3.1[abc]	182 ± 8[ab]	88.3 ± 10.9[abc]

Note: [A], [a], [b], [c] denotes a significant difference to Forwards, Tight Forwards, Loose Forwards, and Inside Backs, respectively, $P < 0.05$.

Table 4.2 Individual positions and groups detailing the number of GPS and video files contributed per position.

Position	Position Name	GPS and Video Files
1	Loose-head prop	1
2	Hooker	3
3	Tight-head prop	3
4	Left lock	6
5	Right lock	20
6	Blind-side flanker	18
7	Open-side flanker	10
8	Number eight	22
9	Scrum-half	5
10	Fly-half	8
11	Left wing	21
12	Inside centre	20
13	Outside centre	27
14	Right wing	19
15	Fullback	24

Note: Positional groups: Forwards and Backs .
Positional subgroups: Tight Forwards , Loose Forwards , Inside Backs , and Outside Backs .

C. FULL MATCH ANALYSIS

C.1. FORWARDS AND BACKS

C1.1. SPRINT VARIABLES

Figure 4.1 illustrates the differences in sprint variables between Forwards and Backs. Backs obtained significantly faster maximum speeds (30.1 ± 2.9 v 25.5 ± 2.9 $km.h^{-1}$, *P* < 0.01) and a higher number of sprints (7.7 ± 9.1 v 18.3 ± 9.9, *P* < 0.01) than Forwards.

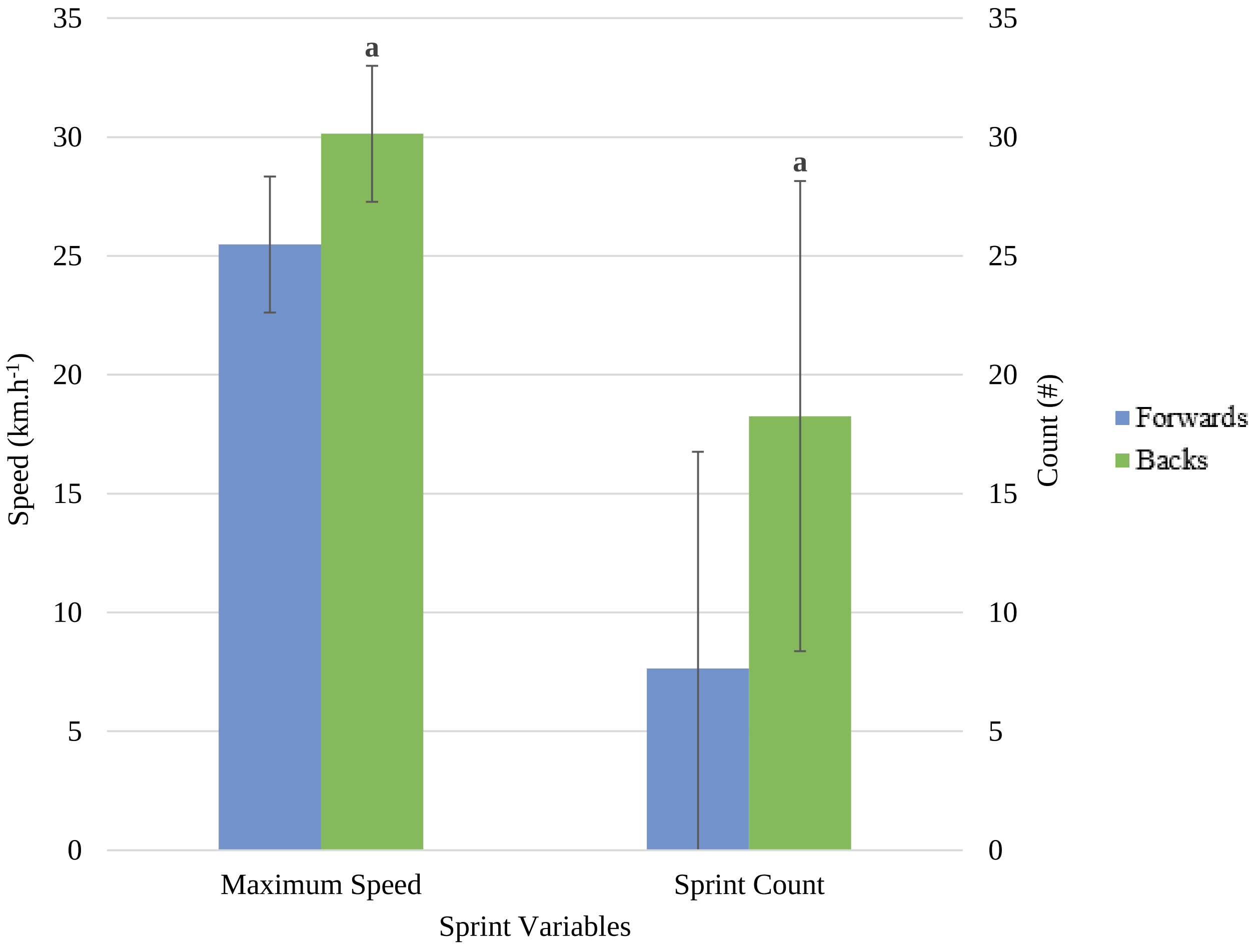

Figure 4.5 Differences in sprint variables between Forwards and Backs.
[a] Significantly different to Forwards, P < 0.01.

C.1.2. DISTANCE VARIABLES

Forwards and Backs are compared in Figure 4.2 for all distance variables, including: total distance, distance in Zone 1 (walking: 0–2 m·s^{-1}), distance in zone 2 (jogging: 2–4 m·s^{-1}), distance in Zone 3 (striding: 4–6 m·s^{-1}) and distance in Zone 4 (sprinting: > 6 m·s^{-1}). The Backs covered significantly more distance than the Forwards across all distance variables (Total Distance: 6164 ± 619 v 5365 ± 504 m, $P < 0.01$; Walking: 3245 ± 355 v 2789 ± 220 m, $P < 0.01$; Striding: 815 ± 261 v 655 ± 304 m, $P = 0.01$; Sprinting: 273 ± 147 v 78 ± 93 m, $P < 0.01$), except when Jogging (1821 ± 333 v 1842 ± 324 m, $P = 0.63$).

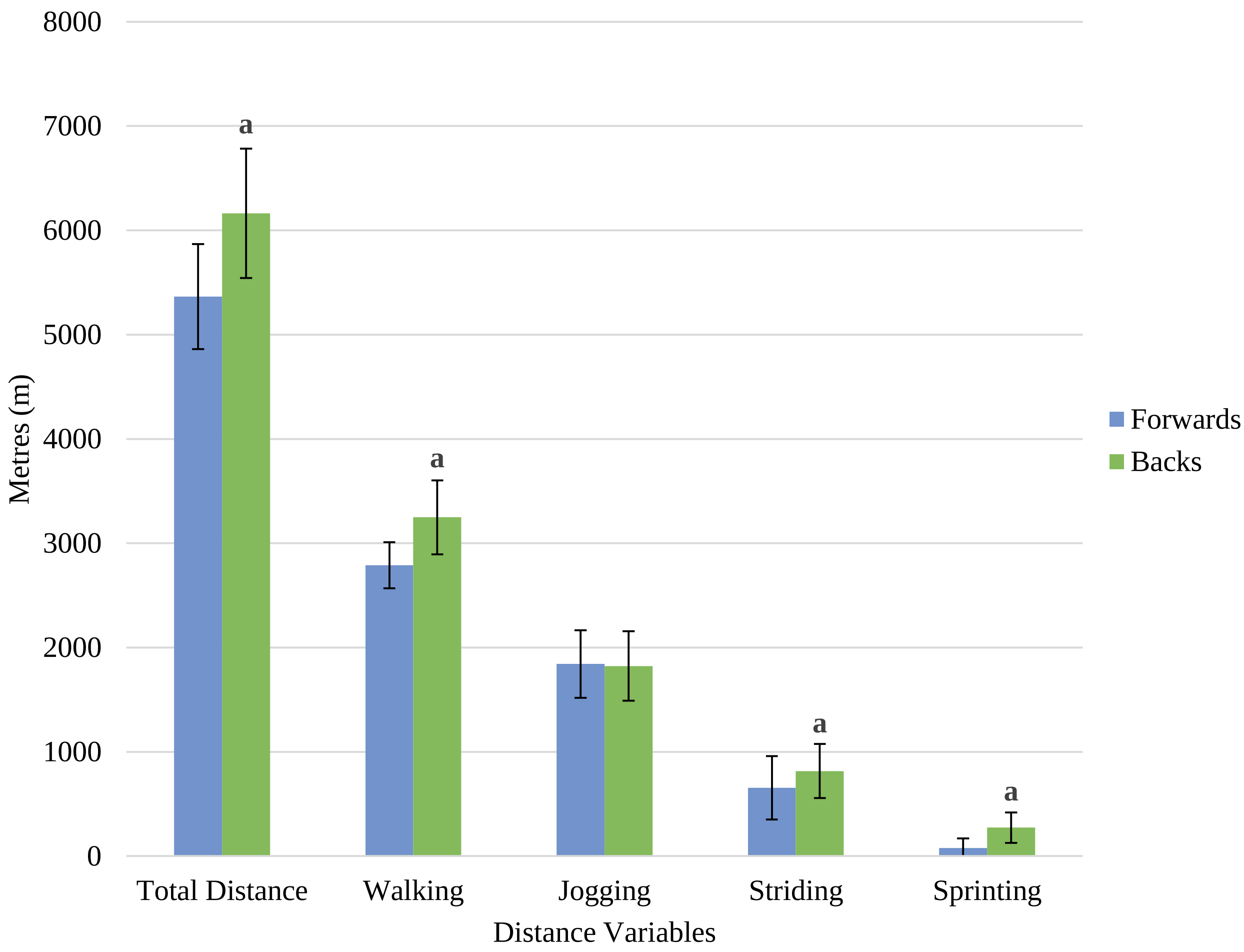

Figure 4.6 Differences in distance variables between Forwards and Backs.
[a] Significantly different to Forwards, P < 0.01.

C.1.3. CONTACT VARIABLES

The contact variables for Forwards and Backs, as well as the number of scrum and maul involvements for Forwards, are illustrated in Figure 4.3. Forwards engaged in significantly more total contacts than Backs (65 ± 10 v 21 ± 7, $P < 0.01$). When isolating the variables that make up the total contact count, Forwards had significantly more tackle (11 ± 5 v 6 ± 4, $P < 0.01$) and ruck (23 ± 7 v 9 ± 4, $P < 0.01$) involvements than Backs, with no difference in the number of carries (7 ± 4 v 6 ± 3, $P = 0.44$). Forwards were involved in 17.3 ± 4.1 scrums per match and 6.2 ± 3.2 mauls.

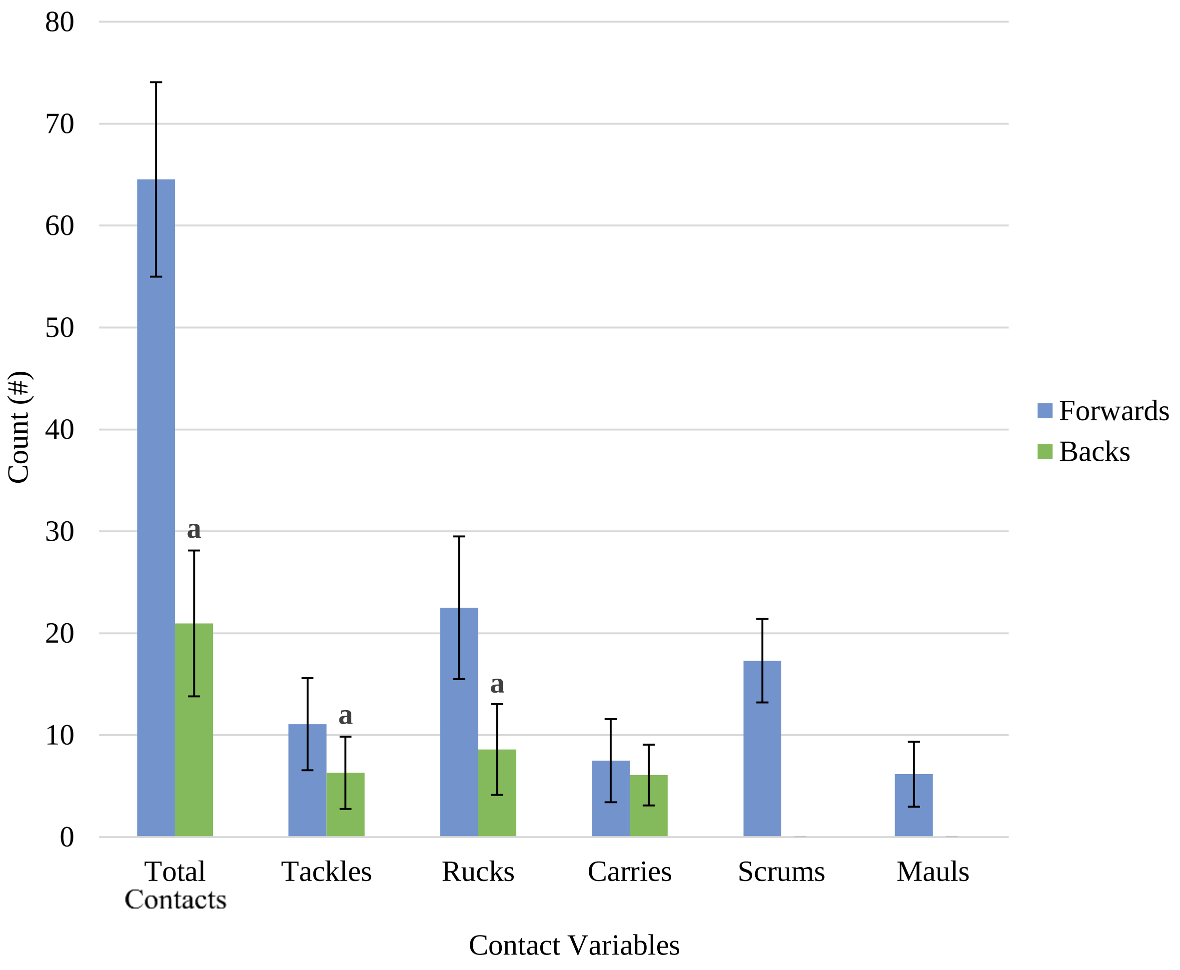

Figure 4.7 Differences in the total contacts, tackles, rucks, carries, scrums, and mauls between Forwards and Backs. [a] Significantly different to Forwards, P < 0.00.

C.2. POSITIONAL SUBGROUPS

C.2.1. SPRINT VARIABLES

Figure 4.4 details the sprint variables for the positional subgroups. The maximum speed for Tight Forwards (24.0 ± 2.9 $km.h^{-1}$), Loose Forwards (26.5 ± 2.5 $km.h^{-1}$), Inside Backs (29.1 ± 2.8 $km.h^{-1}$) and Outside Backs (31.2 ± 2.6 $km.h^{-1}$) are illustrated. Tight Forwards achieved significantly slower maximum speeds than all other positional subgroups (LF: $P = 0.05$; IB: $P = 0.01$; OB: P < 0.01). No difference was observed between Inside Backs and Loose Forwards ($P = 0.1$) or Outside Backs ($P = 0.08$). However, Inside Backs achieved faster maximum speeds than Tight Forwards ($P = 0.01$), while Outside Backs achieved faster maximum speeds than both Tight Forwards ($P < 0.01$) and Loose Forwards ($P = 0.02$).

Tight Forwards (2.9 ± 3.2) completed fewer sprints than all other positional subgroups (LF: 10.8 ± 10.3, $P = 0.04$; IB: 16.2 ± 10.2 $P = 0.01$; OB: 20.2 ± 9.3 $P = 0.01$). No difference was found between Loose Forwards and Inside Backs ($P = 0.17$), or Inside Backs and Outside Backs ($P = 0.12$). Additionally, Outside Backs completed more sprints Loose Forwards ($P = 0.03$).

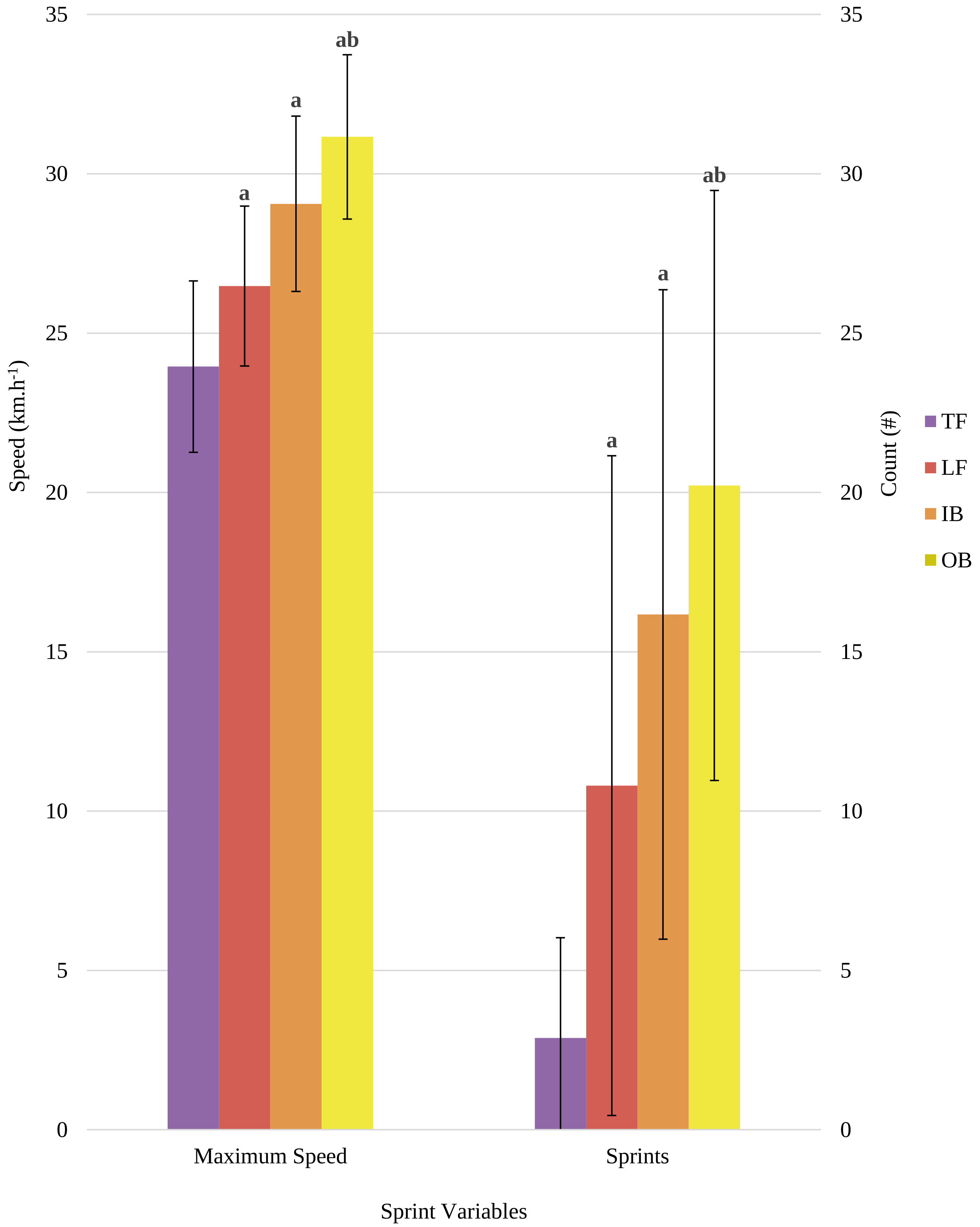

Figure 8.4 Differences in sprint variables between Tight Forwards (TF), Loose Forwards (LF), Inside Backs (IB) and Outside Backs (OB). [a] Significantly different to Tight Forwards; [b] significantly different to Loose Forwards; [c] significantly different to Inside Backs. $P <= 0.05$.

C.2.2. DISTANCE VARIABLES

As shown in Figure 4.5, a comparison of the positional subgroups for the various distance variables indicates that no statistical difference was found when comparing Tight Forwards and Loose Forwards (5348 ± 481 v 5376 ± 523 m, $P = 0.63$), or Inside Backs and Outside Backs (6233 ± 607 v 6099 ± 629 m, $P = 0.09$) for total distance covered. Both Inside Backs and Outside Backs covered more distance than Tight Forwards ($P = 0.01$; $P = 0.03$) and Loose Forwards ($P = 0.01$; $P = 0.05$).

Similarly to the total distance covered, no difference was found between Tight Forwards and Loose Forwards (2809 ± 201 v 2776 ± 234 m, $P = 0.73$), or Inside Backs and Outside Backs (3245 ± 370 v 3250 ± 344 m, $P = 0.46$) when comparing the distance covered walking. Both Inside Backs and Outside Backs covered more distance walking than Tight Forwards ($P = 0.04$; $P = 0.02$) or Loose Forwards ($P = 0.04$; $P = 0.02$).

When comparing the distance covered jogging, Inside Backs totalled significantly more than Outside Backs (1914 ± 330 v 1735 ± 315 m, $P = 0.03$). No other differences were observed for the distance covered jogging (TF: 2042 ± 338; LF: 1711 ± 238; $P > 0.05$).

Tight Forwards (471 ± 203) covered less distance striding than all other subgroups (LF: 776 ± 300, $P = 0.02$; IB: 848 ± 289, $P = 0.01$; OB: 785 ± 229, $P = 0.03$). No difference was found between the remaining positional subgroups ($P > 0.05$).

Outside Backs (OB: 321 ± 141) covered more distance sprinting than all other positional subgroups (TF: 26 ± 28, $P < 0.01$; LF: 111 ± 105, $P = 0.01$; IB: 221 ± 136, $P = 0.04$). No difference was found between Tight Forwards and Loose Forwards ($P = 0.08$), or Loose Forwards and Inside Backs ($P = 0.09$). However, Inside Backs covered significantly more distance sprinting than Tight Forwards ($P = 0.01$).

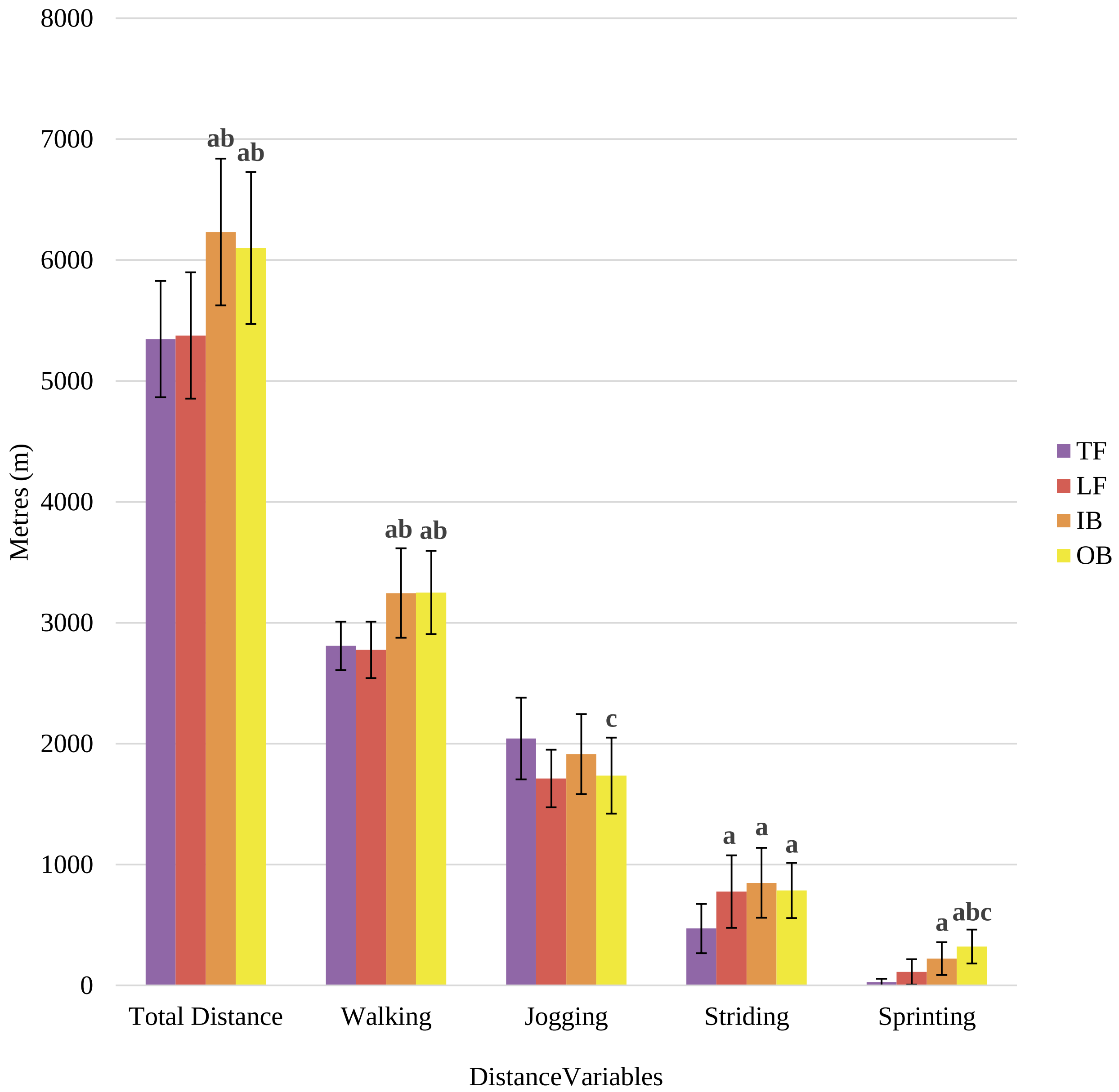

Figure 4.5 Differences in distance variables between Tight Forwards (TF), Loose Forwards (LF), Inside Backs (IB) and Outside Backs (OB). [a] Significantly different to Tight Forwards; [b] significantly different to Loose Forwards; [c] significantly different to Inside Backs. P <= 0.05.

C.2.3. CONTACT VARIABLES

The contact variables for the positional subgroups are presented in Figure 4.6. Outside Backs (17.6 ± 5.0) participated in significantly fewer total contacts than all other positional subgroups (TF: 62.6 ± 8.3, $P < 0.01$, LF: 65.8 ± 10.2, $P < 0.01$, IB: 24.5 ± 7.3, $P = 0.05$). No significant difference was found between Tight Forwards and Loose Forwards ($P = 0.2$), while Inside Backs were involved in fewer total contacts than Tight Forwards (P < 0.01) and Loose Forwards ($P < 0.01$).

Outside Backs (4.2 ± 2.0) engaged in fewer tackle situations than all other positional subgroups (TF: 10.0 ± 4.4, $P = 0.01$, LF: 11.8 ± 4.5, $P < 0.01$, IB: 8.5 ± 3.5, $P = 0.02$). No differences were found between Tight Forwards and Loose Forwards ($P = 0.31$) or Inside Backs ($P = 0.1$), but Inside Backs were involved in fewer tackles than Loose Forwards ($P = 0.04$).

Rucks saw Tight Forwards (22.8 ± 5.8) and Loose Forwards (22.3 ± 7.8) to both have more involvements than Inside Backs (9.5 ± 5.1, TF: $P = 0.01$, LF: $P < 0.01$) and Outside Backs (7.8 ± 3.6, TF: $P < 0.01$, LF: $P < 0.01$). No difference was found between Tight Forwards and Loose Forwards ($P = 0.28$) or Inside Backs and Outside Backs ($P = 0.37$).

Loose Forwards (9.1 ± 3.8) carried the ball into contact more than Tight Forwards (5.0 ± 3.2, $P = 0.03$) and Outside Backs (5.6 ± 2.6, $P = 0.04$), with no difference observed when compared to Inside Backs (6.6 ± 3.3, $P = 0.13$). No differences were found between any other positional subgroups ($P > 0.1$).

No difference was observed between Tight Forwards and Loose Forwards (17.2 ± 3.5 v 17.3 ± 4.5, P = 0.89) for scrum involvements, with Inside Backs and Outside Backs not involved due to their positional roles. Similarly, Inside Backs and Outside Backs were not involved in mauls; however, Tight Forwards participated more often than Loose Forwards (7.6 ± 3.1 v 5.2 ± 2.9, P = 0.02).

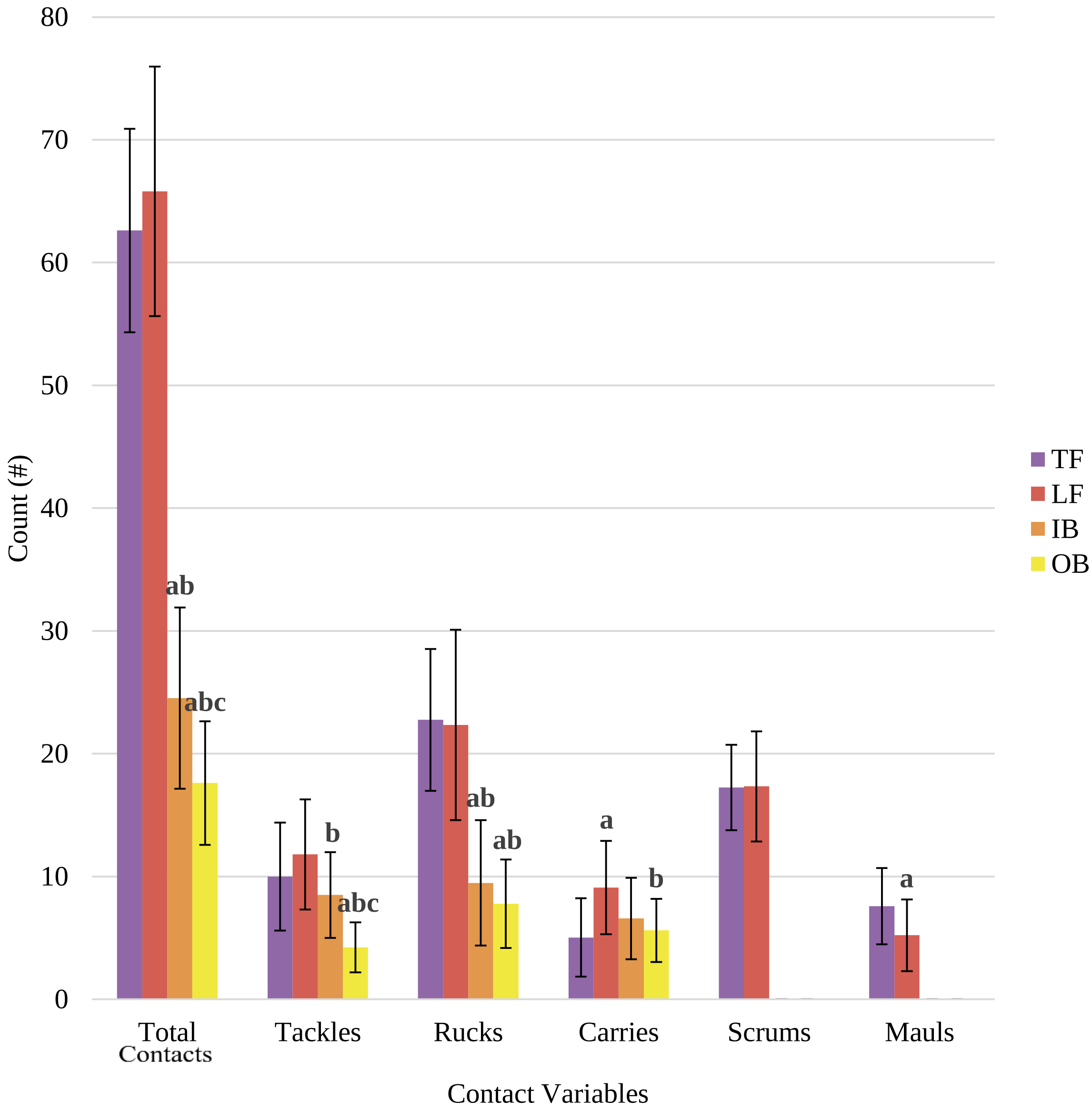

Figure 4.6 Differences in contact variables between Tight Forwards (TF), Loose Forwards (LF), Inside Backs (IB) and Outside Backs (OB). [a] Significantly different to Tight Forwards; [b] significantly different to Loose Forwards; [c] significantly different to Inside Backs. P < 0.05.

D. TEMPORAL PATTERN ANALYSIS

D.1. FORWARDS AND BACKS

D.1.1. TOTAL DISTANCE

Figure 4.6 details the within-group differences in total distance covered for Forwards and Backs over each of the eight periods of match-play, where each time-period represented an eighth of the match in sequence. Match periods one (Forwards: 768 ± 151 m; Backs: 871 ± 152 m) and five (Forwards: 756 ± 137 m; Backs: 850 ± 157 m) saw significantly more distance covered than all other periods for both Forwards and Backs ($P < 0.05$). Match period four had less distance covered than period two for the Backs (697 ± 115 v 778 ± 128 m, $P = 0.01$). No within-group differences were found for any of the remaining periods ($P > 0.05$).

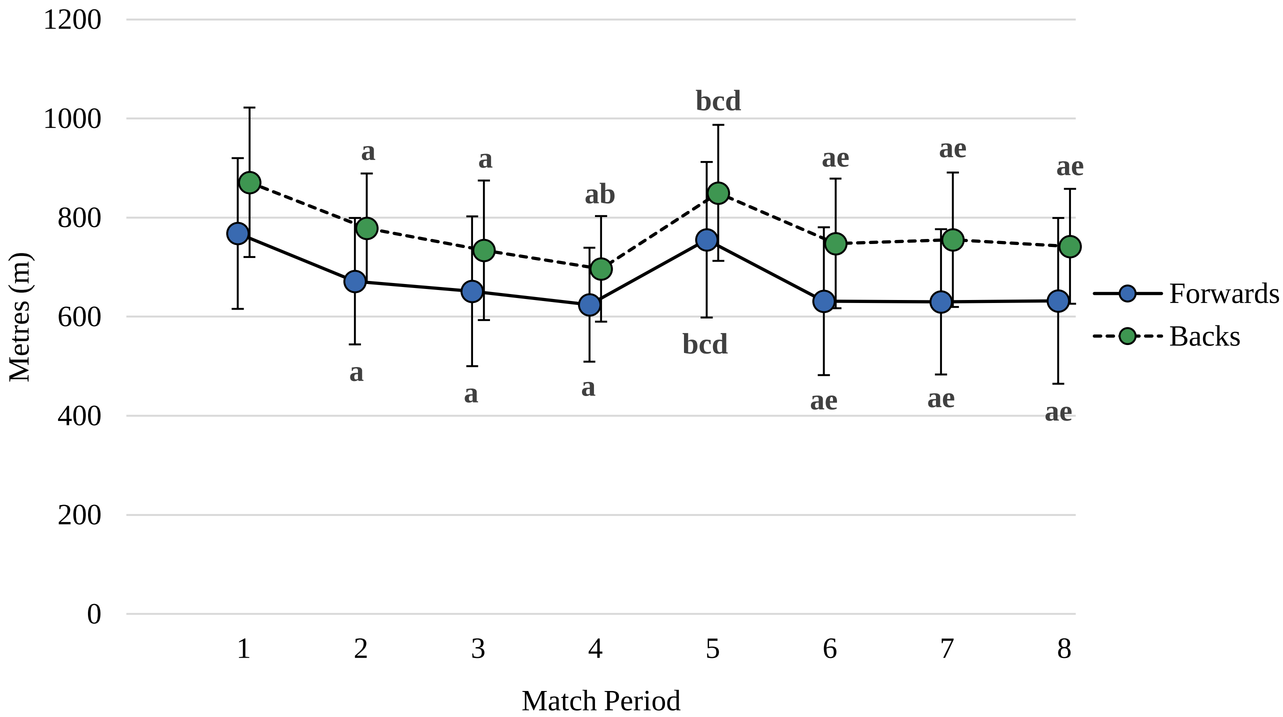

Figure 4.7 Within-group difference in total metres covered for Forwards and Backs over each of the eight periods of match-play. [a], [b], [c], [d], [e] significantly different to Match Period 1, 2, 3, 4 and 5, respectively. $P < 0.05$.

D.1.2. TOTAL CONTACTS

The within-group differences in total contact involvements for Forwards and Backs over each of the eight periods of match-play are illustrated in Figure 4.7. Forwards were involved in significantly more contacts in match period one (9.0 ± 2.8) than periods three (7.3 ± 2.3, *P* < 0.01), four (7.5 ± 2.3, *P* < 0.01), six (7.9 ± 2.5, *P* = 0.02) and seven (7.8 ± 2.3, *P* = 0.01). Match period three also saw the Forwards having fewer contact involvements than period two (8.4 ± 2.6, *P* = 0.02), five (8.2 ± 2.6, *P* = 0.05) and eight (8.2 ± 2.7, *P* = 0.05). No within-group differences were observed for the Backs across any of the eight match periods (*P* > 0.05).

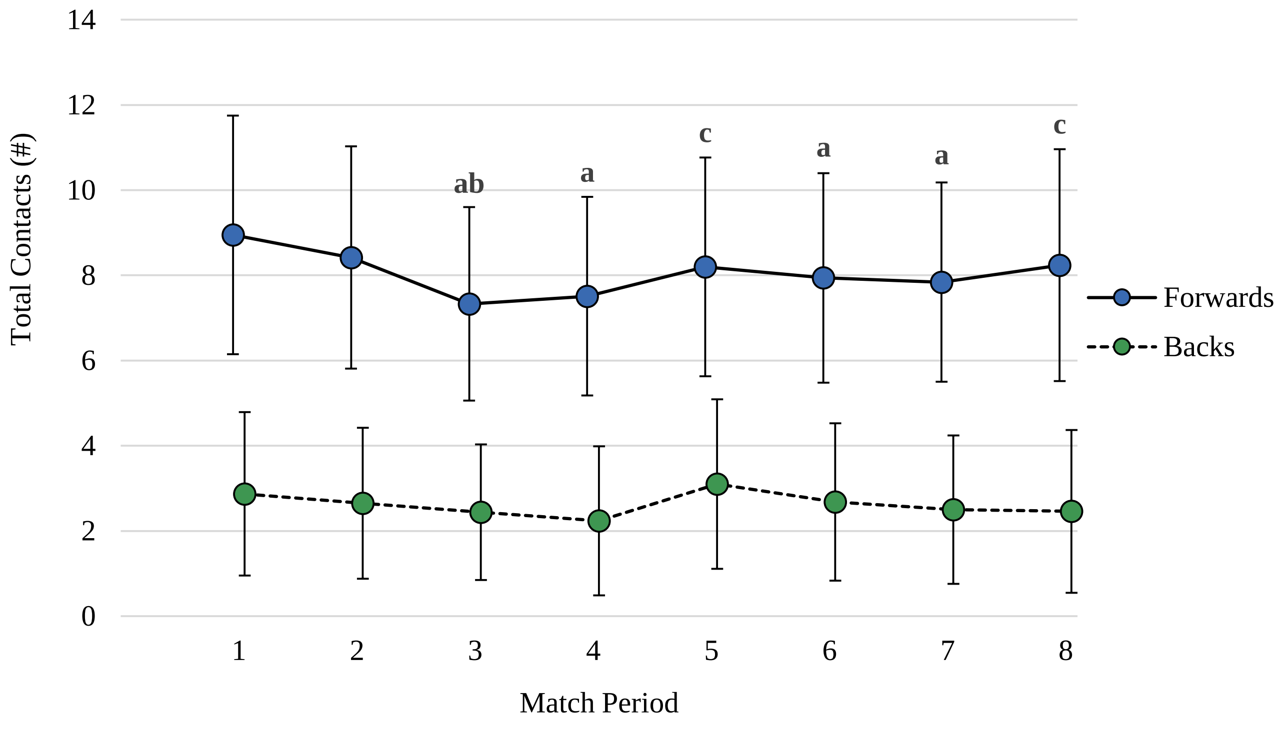

Figure 4.8 Within-group difference in total contact involvements for Forwards and Backs over each of the eight periods of match-play. [a] Significantly different to Match Period 1; [b] Significantly different to Match Period 2; [c] Significantly different to Match Period 3. P <= 0.05.

D.2. POSITIONAL SUBGROUPS

D.2.1. TOTAL DISTANCE

When comparing within-group differences in the total distance over the eight match periods for the positional subgroups, similar results were found for Tight Forwards and Loose Forwards, and Inside Backs and Outside Backs (Table 4.3). Match periods one and five saw significantly further distances travelled when compared to all other periods for all positional subgroups ($P < 0.05$) with no difference observed between periods one and five ($P > 0.05$). Additionally, Inside Backs and Outside Backs covered less distance in period four when compared to period two ($P < 0.05$). No other within-group differences were observed between periods for all positional subgroups ($P > 0.05$).

D.2.2. TOTAL CONTACTS

Table 4.4 details the within-group differences in total contact involvements for all positional subgroups over each of the eight periods of match-play. Match period one had significantly more contact involvements than periods three, four, six and eight for Tight Forwards ($P < 0.05$). The only other difference for Tight Forwards was that period two had more contact involvements than period three ($P = 0.03$). Match period one saw Loose Forwards to cover more distance than periods three, four and seven ($P < 0.05$). More distance was covered in period eight than periods three and four ($P < 0.05$), and more in period five than three ($P < 0.05$). No other within-group differences were observed for Loose Forwards ($P > 0.05$). No within-group differences were observed for Inside Backs or Outside Backs across any of the eight match periods ($P > 0.05$).

Table 4.3 Within-group difference in Total Metres covered for Positional Subgroups over each of the eight periods of match-play.

Positional Subgroup	Period of Match-Play							
	1	2	3	4	5	6	7	8
Tight Forward	758 ± 143	683 ± 115 [a]	644 ± 134 [a]	625 ± 104 [a]	758 ± 153 [bcd]	629 ± 128 [ae]	617 ± 128 [ae]	624 ± 109 [ae]
Loose Forward	775 ± 159	664 ± 108 [a]	657 ± 147 [a]	624 ± 110 [a]	754 ± 127 [bcd]	633 ± 134 [ae]	639 ± 141 [ae]	637 ± 121 [ae]
Inside Back	880 ± 144	786 ± 117 [a]	755 ± 158 [a]	711 ± 114 [ab]	863 ± 167 [bcd]	752 ± 150 [ae]	766 ± 157 [ae]	744 ± 154 [ae]
Outside Back	863 ± 160	771 ± 137 [a]	715 ± 143 [a]	683 ± 115 [ab]	837 ± 148 [bcd]	744 ± 150 [ae]	745 ± 138 [ae]	740 ± 180 [ae]

Note: [a], [b], [c], [d], [e] *denotes a significant difference to Match Period 1, 2, 3, 4 and 5, respectively, $P < 0.05$.*

Table 4.4 Within-group difference in Total Contacts for Positional Subgroups over each of the eight periods of match-play.

Positional Subgroup	Period of Match-Play							
	1	2	3	4	5	6	7	8
Tight Forward	8.9 ± 2.4	8.6 ± 2.8	7.1 ± 2.2 [ab]	7.5 ± 2.1 [a]	7.7 ± 2.7	7.3 ± 2.3 [a]	7.7 ± 2.1	7.7 ± 2.2 [a]
Loose Forward	9.0 ± 3.1	8.3 ± 2.5	7.5 ± 2.3 [a]	7.5 ± 2.5 [a]	8.6 ± 2.4 [c]	8.4 ± 2.5	7.9 ± 2.5 [a]	8.7 ± 3.0 [cd]
Inside Back	3.2 ± 2.0	3.1 ± 1.9	2.7 ± 1.6	2.8 ± 1.9	3.6 ± 2.0	3.2 ± 1.9	3.1 ± 1.9	2.9 ± 2.1
Outside Back	2.7 ± 1.8	2.2 ± 1.5	2.2 ± 1.6	1.8 ± 1.5	2.7 ± 1.9	2.2 ± 1.7	2.0 ± 1.5	2.1 ± 1.7

Note: [a], [b], [c], [d] *denotes a significant difference to Match Period 1, 2, 3, and 4, respectively, $P < 0.05$.*

E. PEAK PERIODS

E.1. FORWARDS AND BACKS

E.1.1. RELATIVE DISTANCE

Forwards moved at a significantly slower relative distance than the Backs during peak periods of play for all moving average durations (Figure 4.9). The moving average durations for minutes one to six were all different from their ensuing within-group duration for Forwards ($P < 0.05$). Backs showed within-group differences for minutes one to seven with their respective ensuing durations ($P < 0.05$). The curves in Figure 4.9 represent predicted values as a function of time using the Power Law. The equation of the line for Forwards and Backs were $y = 137.93x^{-0.26}$ and $y = 157.08x^{-0.271}$, respectively.

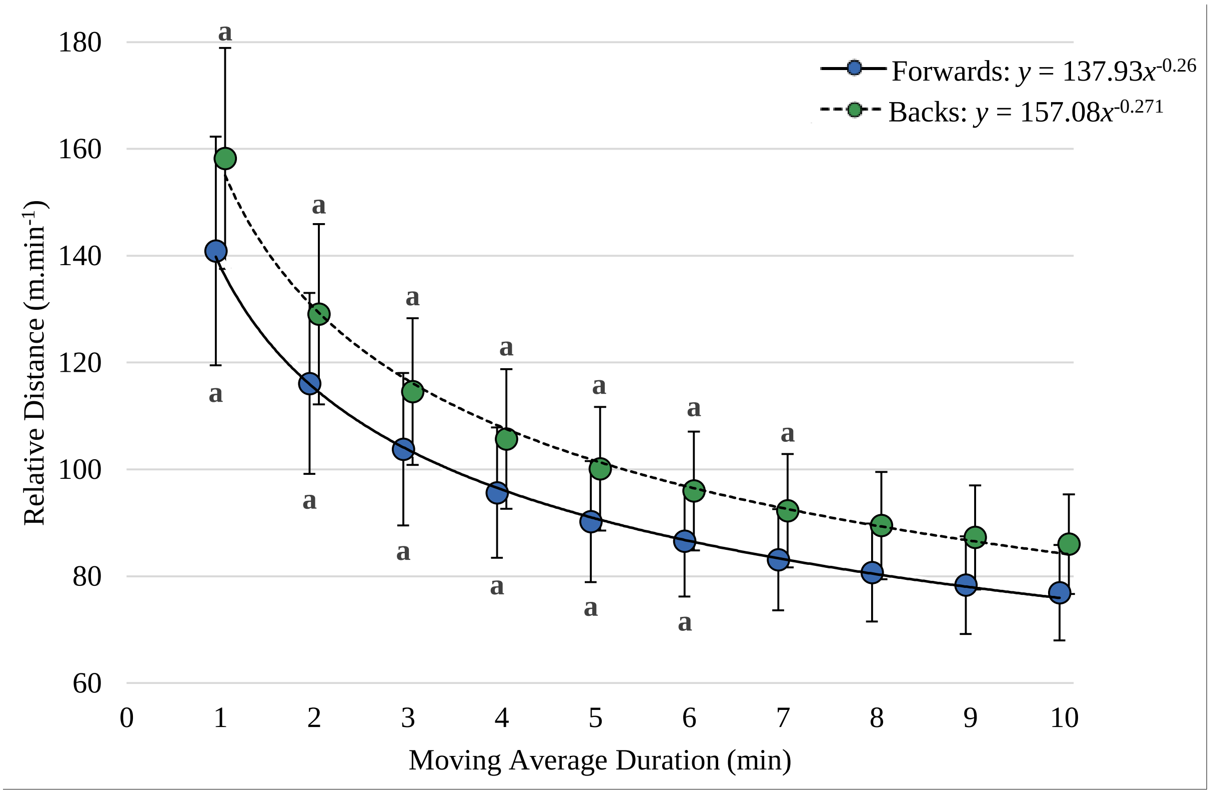

Figure 4.9 Between-group and within-group differences in relative distance for Forwards and Backs during peak periods of play. [a] Significantly different to ensuing moving average duration within each group. Between-group differences for all moving average durations were statistically significant. $P < 0.05$. Curves represent predicted values as a function of time.

E.1.2. RELATIVE CONTACTS

The between-group and within-group differences in relative contact involvements for Forwards and Backs during peak periods of play are shown in Figure 4.10. Forwards displayed significantly more relative contact involvements across all moving average durations when compared to Backs ($P < 0.05$). When isolating within-group differences, Forwards showed differences for durations one to six with their respective ensuing duration ($P < 0.05$). Durations one to five differed with their respective ensuing durations for Backs ($P < 0.05$). The equations of the Power Law curves are $y = 2.8701x^{-0.451}$ and $y = 1.9644x^{-0.626}$ for Forwards and Backs respectively.

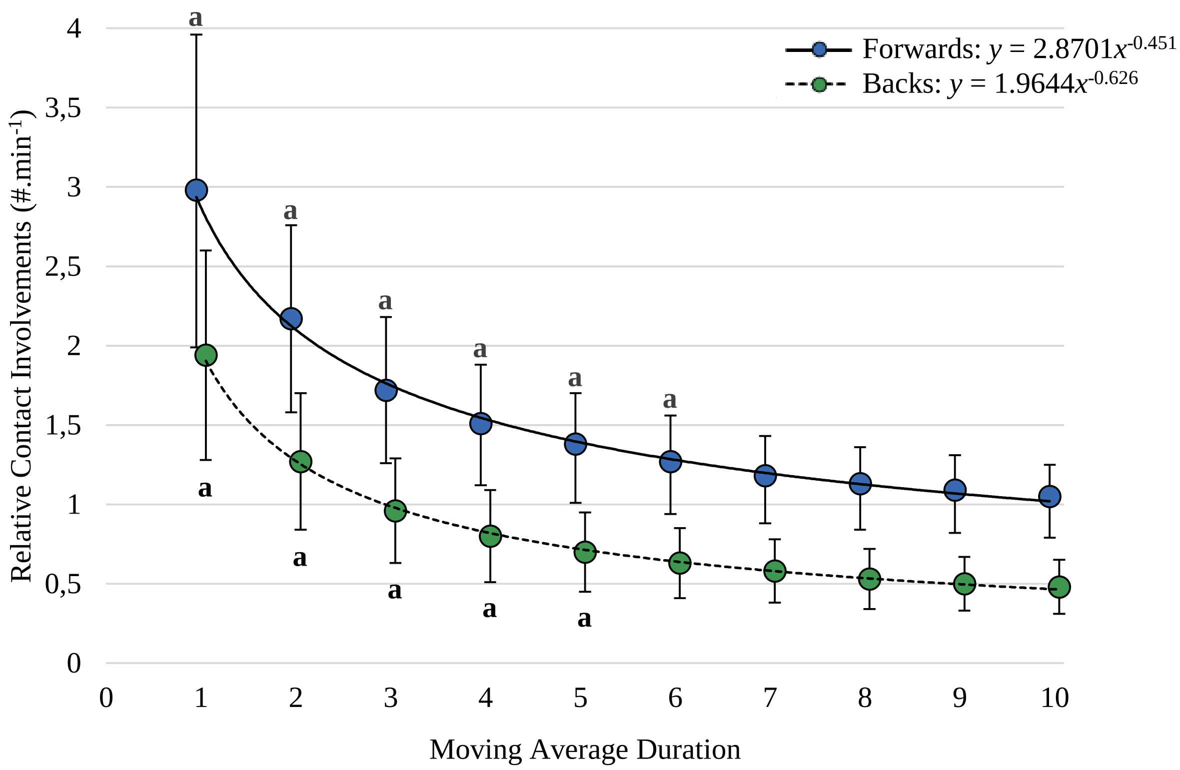

Figure 4.10 Between-group and within-group differences in relative contact involvements for Forwards and Backs during peak periods of play. [a] Significantly different to ensuing moving average duration within each group. Between-group differences for all moving average durations were statistically significant. $P < 0.05$. Curves represent predicted values as a function of time.

E.2. POSITIONAL SUBGROUPS

E.2.1 RELATIVE DISTANCE

Table 4.5 compares the between-group and within-group differences for positional subgroups, detailing peak relative distances during moving average durations one to ten. Within-group significant differences showed Tight Forwards to move at a higher intensity in durations one through four when comparing each duration to their respective ensuing duration ($P < 0.05$). Loose Forwards, Inside Backs and Outside Backs all saw differences for durations one through six ($P < 0.05$).

No between-group differences were observed between Tight Forwards and Loose Forwards, or Inside Backs and Outside Backs for all moving average durations ($P > 0.05$). However, both Tight Forwards and Loose Forwards moved at a lower intensity than Inside Backs and Outside Backs for all moving average durations ($P < 0.05$).

Power Law provided an equation to estimate intensity values as a function of time: Tight Forwards: $y = 137.85x^{-0.252}$, Loose Forwards: $y = 141.05x^{-0.272}$, Inside Backs: $y = 152.86x^{-0.257}$, and Outside Backs: $y = 158.04x^{-0.276}$.

E.2.2. RELATIVE CONTACTS

Similarly to Table 4.5, the between-group and within-group differences of positional subgroups for relative contact involvements are shown in Table 4.6, with the peak moving average durations one to ten detailed. Tight Forwards, Loose Forwards and Inside Backs had more relative contact involvements when comparing durations one to five with their respective ensuing durations (*P* <= 0.05). Outside Backs had more relative contact involvements when comparing periods one to four with each duration's ensuing duration (P <= 0.05).

No between-group differences were found between Tight Forwards and Loose Forwards (*P* > 0.05). However, both were involved in more contacts per minute than Inside Backs and Outside Backs for all moving average durations (*P* <= 0.05). Inside Backs engaged in more contact situations than Outside Backs across all moving average durations (P <= 0.05).

Power Law provided an equation to estimate intensity values as a function of time: Tight Forwards: $y = 2.7568x^{-0.446}$, Loose Forwards: $y = 3.0432x^{-0.466}$, Inside Backs: $y = 1.9339x^{-0.572}$, and Outside Backs: $y = 1.9132x^{-0.668}$.

Table 4.5 Peak Relative Distance ($m.min^{-1}$) during peak moving average durations for Positional Subgroups (Mean ± SD).

Positional Subgroup	Moving Average Duration									
	1	2	3	4	5	6	7	8	9	10
Tight Forward	142 ± 17 [A]	115 ± 15 [A]	104 ± 12 [A]	97 ± 11 [A]	92 ± 10	88 ± 10	85 ± 9	82 ± 9	80 ± 9	78 ± 9
Loose Forward	140 ± 23 [A]	117 ± 18 [A]	104 ± 15 [A]	95 ± 13 [A]	90 ± 12 [A]	86 ± 11 [A]	82 ± 10	80 ± 9	78 ± 9	77 ± 9
Inside Back	157 ± 19 [Aab]	129 ± 16 [Aab]	114 ± 13 [Aab]	106 ± 12 [Aab]	100 ± 11 [Aab]	96 ± 10 [Aab]	93 ± 10 [ab]	90 ± 9 [ab]	88 ± 9 [ab]	87 ± 8 [ab]
Outside Back	159 ± 22 [Aab]	129 ± 18 [Aab]	115 ± 15 [Aab]	106 ± 14 [Aab]	100 ± 13 [Aab]	96 ± 12 [Aab]	92 ± 12 [ab]	89 ± 11 [ab]	87 ± 11 [ab]	86 ± 10 [ab]

Note: [A] *denotes a significant within-group difference to the ensuing moving average duration;* [a] *denotes a significant between-group difference to Tight Forwards at the matching moving average duration;* [b] *denotes a significant between-group difference to Loose Forwards at the matching moving average duration. P <= 0.05.*

Table 4.6 Peak Relative Contacts ($n.min^{-1}$) during peak moving average durations for Positional Subgroups (Mean ± SD).

Positional Subgroup	Period of Match-Play									
	1	2	3	4	5	6	7	8	9	10
Tight Forward	2.8 ± 0.7 [A]	2.1 ± 0.5 [A]	1.7 ± 0.4 [A]	1.5 ± 0.4 [A]	1.3 ± 0.3 [A]	1.2 ± 0.3	1.1 ± 0.3	1.1 ± 0.2	1.1 ± 0.2	1.0 ± 0.2
Loose Forward	3.1 ± 0.8 [A]	2.2 ± 0.6 [A]	1.8 ± 0.4 [A]	1.5 ± 0.4 [A]	1.4 ± 0.3 [A]	1.3 ± 0.3	1.2 ± 0.3	1.2 ± 0.2	1.1 ± 0.2	1.1 ± 0.2
Inside Back	2.0 ± 0.7 [Aab]	1.3 ± 0.4 [Aab]	1.0 ± 0.3 [Aab]	0.9 ± 0.3 [Aab]	0.8 ± 0.3 [Aab]	0.7 ± 0.2 [ab]	0.6 ± 0.2 [ab]	0.6 ± 0.2 [ab]	0.6 ± 0.2 [ab]	0.5 ± 0.2 [ab]
Outside Back	1.9 ± 0.7 [Aabc]	1.2 ± 0.4 [Aabc]	0.9 ± 0.3 [Aabc]	0.7 ± 0.3 [Aabc]	0.6 ± 0.2 [abc]	0.6 ± 0.2 [abc]	0.5 ± 0.2 [abc]	0.5 ± 0.2 [abc]	0.4 ± 0.2 [abc]	0.4 ± 0.1 [abc]

Note: [A] *denotes a significant within-group difference to the ensuing moving average duration;* [a] *denotes a significant between-group difference to Tight Forwards at the matching moving average duration;* [b] *denotes a significant between-group difference to Loose Forwards at the matching moving average duration;* [c] *denotes a significant between-group difference to Inside Backs at the matching moving average duration. P <= 0.05.*

F. SUMMARY

This chapter provided the descriptive characteristics of the participants as an entire group, positional groups and positional subgroups.

Full match analysis found Backs to cover more distance and at faster speeds than Forwards, while Forwards were involved in contact more often. Positional Subgroups saw differences in sprint, distance and contact variables. Notably, Tight Forwards moved at the slowest speeds and the Outside Backs the fastest. Tight and Loose Forwards, and Inside and Outside Backs covered similar total distances and engaged in equal total contacts, although differences were observed in the specific distance and contact variables.

Within-group differences were shown for Forwards and Backs when analysing Temporal Periods for total distance, with the first and quarter of each half being the most-intense of the match. Similar within-group findings were shown for total contacts for Forwards during various Temporal Periods of match-play; however, no differences were shown for Backs. When assessing positional subgroups, Tight Forwards and Loose Forwards had similar results, as did Inside Backs and Outside Backs, with the match periods one and five having the most-intense running demands of the match. The Tight Forwards and Loose Forwards generally had more contact in match period one, with the Tight Forwards displaying a drop off in contact intensity in the last match period and the Loose Forwards maintaining the intensity. No within-group differences in contact intensity were seen for Inside and Outside Backs.

Peak period analysis of within-group differences in running intensity saw Forwards having significantly higher intensities for moving average durations one to six, and Backs from durations one to seven when compared with each duration's ensuing duration. Higher contact intensities were observed for Forwards from durations one to six and durations one to five for Backs. Backs moved at a higher intensity than Forwards across all moving average durations, and Forwards had more contacts than Backs overall moving average durations.

Within-group differences in the relative distance during Peak Periods found the Tight Forwards to run at a higher intensity in moving average durations one through four when compared to each ensuing duration. Loose Forwards, Inside Backs and Outside Backs moved at higher intensities for moving average durations one to six. Tight Forwards and Loose Forwards covered significantly less distance than Inside Backs and Outside Backs overall moving average durations, with no difference seen between the Tight Forwards and Loose Forwards, and Inside Backs and Outside Backs.

Tight Forwards, Loose Forwards and Inside Backs had significantly higher contact intensities for durations one to five when compared with their respective ensuing durations, while Outside Backs were higher for durations one to four. Between-group differences saw no difference between Tight Forwards and Loose Forwards for all moving average durations, but both having higher contact intensities than the Inside Backs and Outside Backs. Additionally, the Inside Backs had higher contact intensities than Outside Backs across all moving average durations.

CHAPTER FIVE

DISCUSSION

A. INTRODUCTION

The current study investigated the position-specific locomotive and contact characteristics of professional rugby players during match-play, over a period of two Super Rugby seasons (2014 and 2015). The primary findings and discussion of the study will be prepared according to the three aims, which, in summary, entailed full match analysis, temporal pattern analysis, and peak period analysis. Under each sub-section, the discussion will be based on the corresponding hypotheses and stated research objectives. A conclusion based on the findings will follow. Mention will be given to the limitations of this study and potential opportunities for future research will be identified. Finally, recommendations will be given for the practical application of this study.

B. FULL MATCH ANALYSIS

The first aim of the current study was to determine position-specific differences in locomotive and contact demands between Forwards and Backs, and positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs) of professional rugby players throughout an entire match, over a period of two Super Rugby seasons.

For comparative purposes, similar research that has used relative metrics will be equated to 92 minutes and 34 seconds, which represents the average duration of the matches included in the current study.

Firstly, it was hypothesised that the majority of locomotive demands (maximum speed, sprint count, total distance, distance walking, distance jogging, distance striding, and distance sprinting) will be greater for Backs than Forwards. The hypothesis is accepted as differences were observed, where Backs achieved faster maximum speeds, completed more sprints, covered more total distance, and distance walking, striding and sprinting. Jogging distance was the only locomotive characteristic where no difference was observed.

The first objective of the study was to compare the locomotive demands (maximum speed, sprint count, total distance, distance walking, distance jogging, distance striding, and distance sprinting) of Forwards and Backs throughout an entire match.

Assessment of the sprint variables demonstrated that Backs (30.1 ± 2.9 km.h^{-1}) achieve faster maximum speeds than Forwards (25.5 ± 2.9 km.h^{-1}) (Figure 4.1). The findings of the current study are consistent with previous literature, which reported Forwards to achieve maximum speeds of 24.6–27.4 km.h^{-1} and Backs 28.2–32.0 km.h^{-1} (Tee and Coopoo, 2015; Cahill et al., 2013; McLellan et al., 2013; Suárez-Arrones et al., 2012).

The sprint count mirrors the findings of the maximum speeds achieved, where the Forwards (7.7 ± 9.1) had a lower number of sprints than the Backs (18.3 ± 9.9) (Figure 4.1). Tee and Coopoo (2015) analysed players from the same competition with an identical sprint threshold of 21.6 km.h^{-1} and reported the Forwards (1 every 14 min) to complete more sprints than Backs (1 every 7 min). Equating this to 92.6 minutes of play, it reflects 6.6 sprints for Forwards and 13.2 sprints for Backs over the duration of an entire match, which are similar to the findings of the current study. McLellan and colleagues (2013) set their speed threshold slightly faster at 22.1 km.h^{-1} and found Forwards (2 ± 3) to complete fewer sprints than Backs (13 ± 6). The slightly faster sprint threshold might explain the slightly lower sprint count observed for both Forwards and Backs compared to that of the current study. Inversely, a lower sprint threshold set at 20 km.h^{-1} saw more sprints for Forwards (11 ± 5) and Backs (26 ± 10), however, the Backs were still found to complete more sprints than the Forwards (Suárez-Arrones et al., 2012). Although the number of sprints achieved varies, likely due to inconsistent sprint thresholds, literature and the current study are unanimous in the finding that Forwards complete fewer sprints than Backs throughout a match. The finding that Backs reach faster maximum speeds and complete more sprints is likely due to the positional setup. Forwards are primarily closer to the ball, contesting possession, and Backs (particularly the Outside Backs) are out in wider channels, often chasing kicks, attempting to finish attacking plays and sprinting on cover defence. This allows the Backs more space and a greater opportunity to run at faster speeds throughout play.

Forwards were found to cover less total distance than Backs (5365 ± 504 v 6164 ± 619 m) throughout match-play. This is synonymous with most literature, where Forwards were found to cover 11–28 percent less distance (4709–5853 v 6005–6545 m) than Backs (McLellan et al., 2013; Cahill et al., 2013; Suárez-Arrones et al., 2012). A study using relative distance added to the body of literature supporting the notion that Backs cover more total distance than Forwards during match-play (equated to 7158 ± 1898 v 7843 ± 963 m) (Lindsay et al., 2015).

The current study's findings differ from that of Tee and Coopoo (2015), who reported no difference between the relative distance covered during match-play for Forwards (69 ± 8 $m.min^{-1}$) and Backs (69 ± 9 $m.min^{-1}$). If their data is equated to reflect 92.6 minutes of play, the Forwards would cover a total distance of 6387 ± 741 metres and the Backs 6387 ± 833 metres, which makes the Backs comparable with the current study's results but the Forwards to be notably further. Upon further scrutiny of Tee and Coopoo's (2015) work, no major methodological differences stand out, as 19 professional rugby players were assessed over 24 matches of the 2013 Super Rugby season. It is possible that the sample provided a skewed representation of the Forwards, with 23 Tight Forwards and 30 Loose Forwards, where Loose Forwards have been reported to operate at higher intensities than Tight Forwards (Cahill et al., 2013). However, no difference in relative distance was observed by Tee and Coopoo (2015) between the Tight Forwards and Loose Forwards. Therefore, it can be surmised that the team under study by Tee and Coopoo (2015) might have had strategies and tactics that required the Forwards, particularly the Tight Forwards, to operate at higher movement intensities than previously reported. Alternatively, as the breakdown of the Tight Forwards was not given by the authors, the sample could potentially be skewed with more Second Rowers than Front Rowers.

Analysis of speed zones in the current study investigated the distance covered walking, jogging, striding and sprinting for Forwards and Backs (Figure 4.2). Findings indicated that the Forwards cover less distance walking (2789 ± 220 m) than the Backs (3245 ± 355 m). This is in contrast to literature, which concluded that either the Forwards cover more distance walking (Lindsay et al., 2015; McLellan et al., 2013; Suárez-Arrones et al., 2012) or no difference exists between the Positional Groups (Tee & Coopoo, 2015). The current study found no difference in the distance covered jogging between Forwards (1842 ± 324 m) and Backs (1821 ± 333 m), which is in accordance with the majority of current research (Lindsay et al., 2015; McLellan et al., 2013; Suárez-Arrones et al., 2012). Backs (815 ± 261 m) were found to cover more distance striding than Forwards (655 ± 304 m) in the current study, which is supported by Lindsay and colleagues (2015). However, most studies have found no difference in the distance covered striding (Tee and Coopoo, 2015; McLellan et al., 2013; Suárez-Arrones et al., 2012). When assessing the sprint distance, the Backs were found to cover more distance sprinting (273 ± 147 m) than the Forwards (78 ± 93 m). These findings on sprint distance are synonymous with previous literature (Lindsay et al., 2015; Tee and Coopoo, 2015; McLellan et al., 2013; Suárez-Arrones et al., 2012).

Overall, the lower intensity movement zones (walking and jogging) have mixed results, where the higher intensity zones (striding and sprinting) tend to be greater for Backs. A likely explanation for this trend is due to the positional roles, where Forwards are often moving short distances from breakdown to breakdown, resulting in limited opportunity to reach faster speeds and a greater emphasis placed on contact involvements. Backs, in contrast, are positioned further away from the breakdown and less involved in contact situations, which requires more time striding to get into position and are provided with greater opportunities to sprint during open play.

Discrepancies in literature, particularly evident in the lower-intensity zones, are likely due to advances in technology, limited sample size (McLellan et al., 2013), team-specific strategies and tactics, and the style of play associated with Northern and Southern Hemisphere rugby.

The second hypothesis contended that the majority of contact demands (total contacts, carries, rucks, tackles, scrums, and mauls) will be higher for Forwards than Backs. Forwards were involved in more total contacts, tackles, rucks, scrums and mauls than Backs, with no difference seen for the number of Carries (Figure 4.3). Therefore, the hypothesis is accepted.

Relating to the aims of the current study, an objective was to compare the contact demands (total contacts, carries, rucks, tackles, scrums, and mauls) of Forwards and Backs throughout an entire match.

The current study found Forwards (65 ± 10) to engage in more Total Contacts than Backs (21 ± 7). Individual contact involvements have been thoroughly researched (Campbell et al., 2018; Quarrie et al., 2012; Eaton & George, 2006), however, limited literature exists around total contact involvements for professional rugby players. The first of three comparable studies found the Forwards (0.56 ± 0.23) to be involved in more contacts per minute than the Backs (0.36 ± 0.17) (Lindsay et al., 2015). If equating to 92.6 minutes of rugby, this would reflect 51.8 ± 21.3 and 33.3 ± 15.7 contact involvements per minute for Forwards and Backs, respectively. The total contact involvements found by Lindsay and colleagues (2015) is notably less than that of the current study. This is likely due to the exclusion of scrums and mauls from their total contact count, as the scrum count was 17 ± 4 and the maul count 6 ± 3 in the current study. The Backs' total contact involvements were markedly greater in the study by Jones and colleagues (2015) and as it was a similar sample size through the same competition, this difference is likely due to the team's individual strategies and tactics. The second study to assess total contact involvements had similar findings, with Forwards (25 ± 9) having a greater count than Backs (15 ± 7) (Jones et al., 2015). Again, scrums and mauls were excluded from the total contact count, explaining the lower result for the Forwards, while the Backs' result was comparable. The Forwards having greater collision rates than the Backs was further confirmed by Schoeman and colleagues (2017).

The Forwards attempted more tackles than the Backs (11 ± 5 v 6 ± 4) in the current study. This finding was supported by Lindsay and colleagues (2015), with relative measures converted to reflect 92.6 minutes of play and equating to a comparable 13.8 ± 7.4 and 10.2 ± 10.2 tackles per match. In contrast, Jones and colleagues (2015) found no difference in the tackle count between Forwards (5 ± 3) and Backs (4 ± 3). Jones and colleagues (2015) stated that tackles were recorded, with no mention of tackle attempts or assists, which might explain the lower numbers and disparity in results. Similarly to Jones and colleagues (2015), Deutsch and colleagues (2006) concluded that there is no difference in the tackle count between Forwards (23.1 ± 14.0) and Backs (23.4 ± 10.2). However, both offensive and defensive tackle involvements were recorded, which potentially explains the larger number of tackles seen and the conflicting results with that of the current study.

Results of the current study indicated that there is no difference in the number of carries between Forwards (7 ± 4) and Backs (6 ± 3). This finding is supported by Jones and colleagues (2014), who concluded that Forwards and Backs complete an equal amount of carries per match (5 ± 2 v 5 ± 3). In contrast, Lindsay and colleagues (2015) determined that Backs have a greater relative carry count in match-play than Forwards (0.11 ± 0.06 v 0.08 ± 0.05 per min). Equated to 92.6 minutes of match-play, this reflects 10.2 ± 5.6 carries for the Backs and 7.4 ± 4.6 for the Forwards. The methodology and definitions of carries of all three studies were similar, therefore, the differences observed are more likely due to the competitions in which each team partook. The current study and Jones and colleagues (2015) were both observing a team competing in Super Rugby (Southern Hemisphere), and that of Lindsay and colleagues (2015) was in the European Cup (Northern Hemisphere).

The current study saw the Forwards to participate in more rucks throughout a match than the Backs (23 ± 7 v 9 ± 4). This finding is synonymous with literature (Jones et al., 2015; Lindsay et al., 2015; Deutsch et al., 2006). The results are comparable, with Forwards previously having been reported as being involved in 15–30 and Backs 6–12 rucks per match (Jones et al., 2015; Lindsay et al., 2015).

As a result of the position-specific requirements for scrums and mauls, only Forwards will be discussed, where the current study found the Forwards to engage in 17.3 ± 4.1 scrums and 6.2 ± 3.2 mauls. The results are similar to those of Jones and colleagues (2015), who found the Forwards to be involved in 13 ± 5 Scrums. Other research focusses on positional subgroups, rather than the Forwards as a whole (Campbell et al., 2018; Deutsch et al., 2006; Eaton & George, 2006). There is limited literature on the Forwards' total maul involvements throughout a match. Campbell and colleagues (2018) assessed positional subgroups and reported Forward positional subgroups to participate in 2.9–3.3 mauls per match. The lower number of mauls reported by Campbell and colleagues (2018) is likely due to the level of competition (Premier Grade) and team-specific strategies and tactics.

The greater number of involvements of the Forwards for total contacts, tackles and rucks is logical, as the Forwards' positional roles require them to retain and maintain possession at the breakdown, providing an attacking platform for the Backs. Similarly, the Forwards' role in scrums and mauls are unique and contribute to their greater number of total contact involvements. The comparable amount of carries between Backs and Forwards reflects the shared attacking load of the team under study, and supports the notion that no difference exists (Jones et al., 2015).

With regards to the aim of determining position-specific differences in locomotive and contact demands between Forwards and Backs, and positional subgroups, it was hypothesised that the majority of locomotive demands (maximum speed, sprint count, total distance, distance walking, distance jogging, distance striding, and distance sprinting) will be greater for Outside Backs than Tight Forwards, Loose Forwards, and Inside Backs.

Various differences were observed between the positional subgroups across all locomotive characteristics (Figures 4.4 and 4.5), however, sprint distance was the only measure where Outside Backs had a significantly greater demand than all the remaining groups. As a result, the hypothesis is rejected.

In order to further describe full match demands, another objective of the current study was to compare the locomotive demands (maximum speed, sprint count, total distance, distance walking, distance jogging, distance striding, and distance sprinting) of Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs throughout an entire match.

Tight Forwards (24.0 ± 2.9 $km.h^{-1}$) had a slower maximum speed during match-play when compared to Loose Forwards (26.5 ± 2.5 $km.h^{-1}$), Inside Backs (29.1 ± 2.8 $km.h^{-1}$) and Outside Backs (32.5 ± 2.6 $km.h^{-1}$) in the current study. Additionally, the Outside Backs reached faster maximum speeds than the Loose Forwards. Literature is in agreement that, of the positional subgroups, the Tight Forwards achieve the slowest speeds (24.5–25.6 $km.h^{-1}$) and Outside Backs the fastest (31.7–33.8 $km.h^{-1}$) (Tee & Coopoo, 2015; Cahill et al., 2013). However, inconsistencies are reported on whether Inside Backs achieve faster speeds than Loose Forwards (Cahill et al., 2013) or whether no difference exists (Tee and Coopoo, 2015). The results of Tee and Coopoo (2015) are comparable with those of the current study, which suggests that no difference in maximum speeds achieved exists between the Loose Forwards and Inside Backs. As Tight Forwards are generally closer to the ball during play and Outside Backs the furthest, it can be surmised that more opportunities to sprint would be provided in the wider channels. Loose Forwards often play a pseudo-back-line role on attack and defence, which might account for the indifference with the Inside Backs.

The sprint count of the current study paralleled the findings of the maximum speeds, where the Outside Backs (20.2 ± 9.3) completed more sprints than the Tight Forwards (2.9 ± 3.2) and Loose Forwards (10.8 ± 10.2), and both the Loose Forwards and Inside Backs (16.2 ± 10.2) completed more than the Tight Forwards. The only study, to the author's knowledge, to report sprints in professional rugby match-play per positional subgroups was Tee and Coopoo (2015), who found the Loose Forwards and Outside Backs to complete more sprints than the Tight Forwards. Fewer differences between the positional subgroups are reported by Tee and Coopoo (2015). The current study and that of Tee and Coopoo (2015) reported on a sample from the same competition and identical sprint thresholds. Therefore the differences are likely due to team-specific strategies, which might give certain positions more opportunity to sprint. The large standard deviations reported by both studies emphasise the sporadic nature of sprints, where the count achieved might be more likely as a result of opportunities that arise, as opposed to player ability.

The current study suggests that the Inside Backs (6233 ± 607 m) and Outside Backs (6099 ± 629 m) cover more total distance than the Tight Forwards (5348 ± 481 m) and Loose Forwards (5376 ± 523 m), with no difference observed between the Back and Forward positional subgroups. The findings of the current study were supported by Lindsay and colleagues (2015), who found both the Inside Backs (7970 ± 1065 m) and Outside Backs (7637 ± 776) to cover more total distance than the Front Row (6572 ± 1018 m), Second Row (7165 ± 648 m) and Loose Forwards (7980 ± 2907 m) when equated to 92.6 minutes of play. Although the total distance covered during match-play has been well researched, the findings are not unanimous (Jones et al., 2015; Tee & Coopoo, 2015; Cahill et al., 2013). Literature suggests that, when isolated, the scrum-half covers the most distance (Tee and Coopoo, 2015; Cahill and colleagues, 2013), but discrepancies in the differences between the remaining positional subgroups are reported (Jones et al., 2015; Tee & Coopoo, 2015; Cahill et al., 2013).

In the current study, the findings for distance accumulated walking mirrored those of total distance, where both the Inside Backs (3245 ± 370 m) and Outside Backs (3250 ± 344 m) walked further than the Tight Forwards (2809 ± 201 m) and Loose Forwards (2776 ± 234 m). Jones and colleagues (2015) concluded that the Outside Backs cover more distance walking than the Tight Forwards, Loose Forwards and Inside Backs (excluding the scrum-half). Similar findings reported that Inside Backs and Outside Backs cover more distance walking than the Loose Forwards (Tee & Coopoo, 2015). Although slight differences are observed between positional subgroups, the Back positional subgroups tend to cover more distance walking than the Forward positional subgroups. This is likely due to their positioning on the field, where they might move at a low-intensity towards wider channels during stoppages in play in preparation for restarts.

The sole difference for the distance jogged in the current study, was that the Outside Backs (1735 ± 315 m) covered less distance than the Inside Backs (1914 ± 330 m). No other differences between the positional subgroups were found (Tight Forwards: 2042 ± 338 m; Loose Forwards: 1711 ± 238 m). While variations in findings of literature exist, some similarities are seen. Jones and colleagues (2015) found no difference between any of the positional subgroups for distance covered jogging. Outside Backs have been reported to cover less distance jogging than the Tight Forwards, Loose Forwards and Scrumhalves (Tee and Coopoo, 2015), and the Inside Backs to cover the most (Lindsay et al., 2015). However, the study by Lindsay and colleagues (2015) reported on distance over seven kilometres per hour, which included jogging, striding and sprinting. The inconsistencies in findings suggest that jogging might be influenced largely by team-specific factors.

The current study suggests that the Tight Forwards (471 ± 203 m) cover fewer metres striding than the Loose Forwards (776 ± 300 m), Inside Backs (848 ± 289 m), and Outside Backs (785 ± 229 m). Literature suggests that the scrum-half covers the most distance striding, aside from the Loose Forwards (Jones et al., 2015; Tee & Coopoo, 2015). The current study included the scrum-half in the Inside Backs group, which might explain no difference being observed with the Outside Backs. Lindsay and colleagues (2015) support the notion that the Loose Forwards cover more distance striding than the Tight Forwards, but a contradictory finding suggests that the Inside Backs and Outside Backs cover more distance striding than both the Tight Forwards and Loose Forwards. The striding metres reported by Lindsay and colleagues (2015) included sprint metres, which might explain the conflicting result.

When assessing the distance covered sprinting, the current study found the Outside Backs (321 ± 141 m) to cover more distance than the Tight Forwards (26 ± 28 m), Loose Forwards (111 ± 105 m), and Inside Backs (221 ± 136 m). Furthermore, the Inside Backs covered more distance sprinting than the Tight Forwards. The Tight Forwards are often reported to cover the least distance sprinting (Jones et al., 2015; Tee & Coopoo, 2015). While some literature supports the notion that Outside Backs cover the most distance sprinting (Lindsay et al., 2015; Cahill et al., 2013), other literature found no difference between the Inside Backs and Outside Backs (Jones et al., 2015; Tee & Coopoo, 2015). Although findings differ, the general trend shows the Forward positional subgroups to cover less distance sprinting than the Back positional subgroups, particularly the Outside Backs, which is a reflection of each group's positional roles and responsibilities.

Overall, the current study suggests that the Back positional subgroups tend to cover more distance walking and sprinting, where differences seen jogging and striding are varied. Although research indicates that the Back positional subgroups spend more distance sprinting, discrepancies in literature for other speed zones can be due to a number of factors. The discrepancies might be explained by teams operating in different environments, where various competitions, playing environments and coach-driven game-plans are all factors that might affect the strategy and therefore the match-play requirements of players.

The fourth hypothesis stated that the majority of contact demands (total contacts, carries, rucks, tackles, scrums, and mauls) will be greater for the Loose Forwards than the Tight Forwards, Inside Backs, and Outside Backs. Although the majority of contact involvements were greater for the Loose Forwards when compared to the Inside Backs and Outside Backs, the majority of contact involvements were similar for the Tight Forwards and Loose Forwards. Therefore, the hypothesis is rejected.

The final objective for full match analysis was to compare the contact demands (total contacts, carries, rucks, tackles, scrums, and mauls) of Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs throughout an entire match.

The current study found the Outside Backs (17.6 ± 5.0) to engage in the fewest total contact events per match of all positional subgroups. The Tight Forwards (62.6 ± 8.3) and Loose Forwards (65.8 ± 10.2) were similar in number and both had more total contacts than the Inside Backs (24.5 ± 7.3). The positional roles explain these results, where the Forwards are often closest to the ball and the breakdown, providing more opportunity to be involved in contact, and have the additional role of scrums and mauls that are unique to their positional group. The Inside Backs form the next level of players that would be closer to the ball during play, with the Outside Backs being the furthest and, therefore, having the lowest opportunity for contact involvements. Lindsay and colleagues (2015) assessed relative total contact involvements, which equated to 92.6 minutes of play reflect 47.2 ± 10.2 (Front Row), 50.0 ± 0.1 (Second Row), 59.2 ± 33.3 (Loose Forwards), 36.1 ± 18.5 (Inside Backs), and 28.7 ± 8.3 (Outside Backs). Similarly to the current study, all Forward positional subgroups were concluded to participate in more total contacts than all Back positional subgroups (Lindsay et al., 2015). The fewer contacts experienced by the Forwards is likely due to scrums and mauls not being included in their study. The greater number for the Inside Backs and Outside Backs suggest that the team under study implemented a team-specific strategy that relied more heavily on their Backs. In contrast to the current study, no difference was found between the Inside Backs and Outside Backs. As the methodology and competition were similar in the study by Lindsay and colleagues (2015), it can be surmised that it is team-specific strategies and tactics that account for this difference.

Similarly to total contacts, the current study suggests that the Outside Backs are involved in the least amount of tackles (4.2 ± 2.0). No difference was found between the Tight Forwards (10.0 ± 4.4) and Loose Forwards (11.8 ± 4.5), however, the Loose Forwards had a greater tackle count than the Inside Backs (8.5 ± 3.5). The Outside Backs attempting the fewest tackles (1.5–6.5) and the Loose Forwards the most (7.2–15.3) is commonly reported in literature (Campbell et al., 2018; Lindsay et al., 2015; Eaton and George, 2006), with the results comparable with that of the current study. This suggests that the positional demands of tackling are similar amongst different teams and competitions. As tackling is defensive, a team, for the most part, is limited in its ability to control which position is attempting tackles and is reactive to the opposition attacking strategies.

The current study saw the Loose Forwards (9.1 ± 3.8) complete more carries into contact than the Tight Forwards (5.0 ± 3.2) and Outside Backs (5.6 ± 2.6), and no difference with the Inside Backs (6.6 ± 3.3). No further differences were found between positional subgroups. Contrasting findings by Lindsay and colleagues (2015), when equated to reflect 92.6 minutes of play, suggest that the Inside Backs (10.2 ± 6.5) and Outside Backs (11.1 ± 5.6) are involved in more carries into contact than the Front Row (5.6 ± 4.6), Second Row (9.3 ± 1.9), and Loose Forwards (8.3 ± 5.6). In addition, the Second Row and Loose Forwards had more carries than the Front Row. The current study and that of Lindsay and colleagues (2015) share similar methodology and each respective team competed in the same competition, therefore, it is likely that the differences seen are as a result of team-specific strategies and tactics. Unlike the reactive nature of defence and tackles, a team is in control of their attacking structures and the position-specific demands of carries are more likely to be influenced by team-specific strategies and tactics. As literature focussing on contact involvements in rugby match-play often omits positional subgroups (Jones et al., 2015) or a count of carries (Campbell et al., 2018; Deutsch et al., 2006; Eaton and George, 2006), direct comparisons with other literature at the professional level is challenging.

Assessment of ruck involvements in the current study found both the Tight Forwards (22.8 ± 5.8) and Loose Forwards (22.3 ± 7.8) to have more involvements than the Inside Backs (9.5 ± 5.1) and Outside Backs (5.6 ± 2.6), with no difference between the Forward and Back positional subgroups. These findings are supported by literature (Campbell et al., 2018; Lindsay et al., 2015). When equated to 92.6 minutes of play, Lindsay and colleagues (2015) found the Front Row (29.6 ± 8.3), Second Row (25.9 ± 5.6), and Back Row (34.3 ± 38.9) to participate in more rucks than the Inside Backs (13.9 ± 10.2) and Outside Backs (10.2 ± 2.8). For the most part, Lindsay and colleagues' (2015) findings are comparable, with notably more ruck involvements for the Loose Forwards. However, the standard deviation is so large that their result for Loose Forwards would not necessarily be considered different from that of the current study. Campbell and colleagues (2018) only reported on the Forward positional subgroups for ruck involvements per match and found no difference between the Front Row (10.9 ± 4.5), Second Row (15.0 ± 6.4), and Back Row (12.9 ± 4.2). The ruck involvements are notably lower than the current study and other literature (Lindsay et al., 2015). Campbell and colleagues' (2018) definition of a ruck involvement is not stated and might differ from that of the current study and other literature. Another possible explanation is the level of competition (Premier Grade), which might see fewer total rucks than Super Rugby.

As expected, the current study found no difference between Tight Forwards (17.2 ± 3.5) and Loose Forwards (17.3 ± 4.5) for the number of scrum involvements. This finding parallels that of literature, where Forward positional subgroups have been found to be involved in 21–29 scrums per match (Campbell et al., 2018; Eaton and George, 2006). The slightly greater number of scrums reported in literature might be due to variations in the level of competition

(Campbell et al., 2018; Eaton and George, 2006). A lower level of competition might result in more handling errors and, therefore, scrums. As the scrum is a role that is unique to the Forwards, where all Forward positions participate in order to restart play, it is logical that no difference would be seen between the Forward positional subgroups. In the rare case of a yellow or red card to a Forward, one of the Loose Forwards might total fewer scrums than that of the Tight Forwards, and in some cases, a Back might be required to join the scrum. However, due to the infrequency of these scenarios, there is no difference between Tight Forwards and Loose Forwards and the demand on the Back positional subgroups is negligible.

In contrast to scrum involvements, the current study suggests that Tight Forwards (7.6 ± 3.1) are involved in more mauls than the Loose Forwards (5.2 ± 2.9). Campbell and colleagues (2018) split the Forwards into the Front Row (3.1 ± 2.7), Second Row (3.3 ± 3.0) and Loose Forwards (2.9 ± 2.6), and found no difference between any of the positional subgroups. The difference found and the slightly greater number of involvements of the current study is likely due to team-specific strategies and tactics. While, in most cases, a defensive maul requires involvement, attacking mauls are employed by choice and if deemed a strength of the team, the maul might be actioned more often. As the number of maul involvements previously reported on is often done so in unison with ruck involvements (Deutsch et al., 2006; Eaton and George, 2006), comparisons with additional literature are challenging.

Tight Forwards' and Loose Forwards' total contact demands are higher than that of the Inside Backs and Outside Backs, with the Outside Backs having the lowest of all positional subgroups. The greater demand of Forward positional subgroups is primarily due to their more frequent involvement in rucks, scrums and mauls. However, the differences observed in the number of tackles and carries is less exaggerated and varies amongst the positional subgroups.

C. TEMPORAL PATTERN ANALYSIS

The second aim of the current study was to determine the position-specific within-group differences of Forwards, Backs, and positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs) during each eighth of a match in terms of total distance and contact involvements, over a period of Two Super Rugby seasons.

Linked to the aim of determining the position-specific within-group differences in temporal patterns between Forwards, Backs, and positional subgroups, it was hypothesised that match periods one and five will have a further total distance and more contact involvements compared to all remaining match periods for Forwards and Backs, is rejected. Although the temporal pattern hypothesised was evident in locomotive demands, the pattern of contact demands was sporadic.

In accordance with the above-mentioned hypothesis, an objective was to compare within-group, the differences in total distance between the eight periods of match-play for Forwards and Backs. The eight periods of match-play each represent an eighth of the match in sequence.

Analysis of the Forwards saw match periods one (768 ± 151 m) and five (756 ± 137 m) to be comparable, with more distance covered in these two periods than all remaining periods (Figure 4.7). Match periods one and five represent the first quarter of each half, and it is likely that the higher intensity is due to limited physical demand in the build-up to the quarters and each team looking to dominate the early stages of the match. However, the Forwards either cannot maintain this intensity for the remaining quarters as a result of physical fatigue, or employ a slow-positive pacing strategy throughout each half. Jones and colleagues (2015) assessed a team as a whole, with similar findings of the first quarter of each half being more running-intense than the remaining periods. The only current literature, to the author's knowledge, that assessed the temporal patterns of Forwards and Backs in professional rugby is that of Tee and Coopoo (2017). Tee and Coopoo (2017) found no differences in any of the match periods for Forwards, indicating a flat pacing strategy. The conflicting results by Tee and Coopoo (2017) have a number of possible explanations: the team under study either paced themselves for the first period of each half, which allowed them to operate at the same intensity for the remaining quarters, or were trained as such that they were not limited by their physical capacity. Another possible explanation is that physical capacity is not a limiting factor and the strategies and tactics employed by the team resulted in more running metres throughout the match for the Forwards.

Similarly, the Backs covered more distance in match periods one (871 ± 152 m) and five (850 ± 157 m) compared to all other periods, indicating a slow-positive pacing strategy throughout each half (Figure 4.7). However, match period four (697 ± 115 m), the fourth quarter of the first half, was also lower than match period two (778 ± 128 m). This indicates a more exaggerated slow-positive pacing strategy by the Backs throughout the first half. A possible explanation for the Backs experiencing this steeper decline than the Forwards is that the running demands are greater for the Backs compared to the Forwards over all periods. With the greater running demand of the Backs, it can be surmised that it would be more challenging to maintain running intensity and, as a result, a greater drop off occurs.

Yet, this steeper drop off in the last quarter of the first half is not replicated in the second. This is likely due to either substitutions or psychological factors. As substitutions are most often made in the second half (Tee and Coopoo, 2015), the influx of fresh players might raise the pace of the game for the Backs already on the field and negate the drop off as seen in the final quarter of the first half. Another possible explanation is around psychological factors, where the Backs produce a greater effort as a result of an awareness that the end of the game is approaching. This phenomenon has been documented in endurance runners, where an increase in intensity is observed in the final stages of competition (Tucker et al., 2006). Contrary to the current study, Tee and Coopoo (2017) found the only drop-off for Backs to be in the final quarter of the second half, indicating that they either fatigue in the last quarter and their psychological factors do not override this, or the team-specific tactics of finishing a game require less running by the Backs.

Similarly to the locomotive demands assessed during temporal periods, an aim was to determine the within-group differences in total contact involvements between the eight periods of match-play for Forwards and Backs.

To the author's knowledge, there is currently no research quantifying the contact involvements of rugby through temporal pattern analysis. As a result, discussion of comparative literature is challenging and the focus will be on the results of the current study (Figure 4.8).

Analysis of the Forwards saw match period one (9.0 ± 2.8) having more contact involvements than match periods three (7.3 ± 2.3), four (7.5 ± 2.3), six (7.9 v 2.5) and seven (7.8 ± 2.3). Match period three, in addition to having fewer contacts than period one, has fewer contact involvements than match periods two (8.4 ± 2.6), five (8.2 ± 2.6) and eight (8.2 ± 2.7). The high number of contacts in the first match period is most likely due to the lack of any preceding load and, therefore, fatigue. The combination of more contact involvements in match period one and the drop off in periods three and four indicate that the intensity of contact involvements is not held, and declines throughout the half as a result of either pacing strategies or fatigue. This indicates that the Forwards employ a slow-positive pacing strategy in the first half and a flat-line pacing strategy in the second half.

Contrary to the Forwards, no differences were observed between any of the eight periods of match-play for the Backs. It is likely due to the lower total contact involvements of the backs, as discussed in research objective two. As a result of their positional roles, the Backs are provided less opportunity to engage in contact events. It is probable that the opportunity for the Backs to engage in contact events is the limiting factor, rather than fatigue or pacing strategies employed.

The sixth hypothesis contended that match periods one and five will have a further total distance and more contact involvements compared to all remaining match periods for all positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs). Match periods one and five saw further distances travelled when compared to all other periods for all positional subgroups (Table 4.1), however, this pattern was not observed for contact involvements for any of the positional subgroups. As a result, the hypothesis is rejected.

In order to provide part of the answer to the sixth hypothesis, an objective was to compare within-group, the differences in total distance between the eight periods of match-play for positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

While the positional subgroups do all display within-group differences, these differences reflect those of their respective positional groups: Forwards and Backs. Therefore the results parallel those of research objective five, where both the Tight Forwards and Loose Forwards either cannot maintain the initial intensity shown in the first (Tight Forwards: 758 ± 143 m, Loose Forwards: 775 ± 159 m) and fifth match periods (Tight Forwards: 758 ± 153 m, Loose Forwards: 754 ± 127 m), or employ a slow-positive pacing strategy throughout each half. The Inside Backs (880 ± 144 and 863 ± 167 m) and Outside Backs (863 ± 160 and 837 ± 148 m) had similar results to the Tight Forwards and Loose Forwards for the first and fifth quarters, with an additional lower intensity in match period four (Inside Backs: 711 ± 114 m, Outside Backs: 683 ± 115 m) compared to match period two (Inside Backs: 786 ± 117 m, Outside Backs: 771 ± 137 m). The exaggerated drop-off in intensity of the first half for the Inside and Outside Backs when compared to the second is possibly due to pacing strategies, substitutions and mental factors as discussed in research objective five.

As a result of positional roles, with Forward positional subgroups experiencing more contact involvements than Back positional subgroups (Figure 4.6), it is not surprising that Tight Forwards and Loose Forwards, and Inside Backs and Outside Backs experience similar temporal running patterns throughout a match. However, to the author's knowledge, no literature assessing temporal patterns of positional subgroups in rugby exists, and therefore comparisons with the current study are not currently possible.

The final objective relating to temporal pattern analysis, was to compare within-group, the contact involvements between the eight periods of match-play for positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

To the author's knowledge, there is currently no research that has assessed the temporal patterns of contact events for positional subgroups in rugby. As a result, comparisons with similar literature cannot be drawn and the novel findings of this study are discussed.

The Tight Forwards and Loose Forwards both displayed within-group differences (Table 4.2). The Tight Forwards were involved in more contact events in match period one (8.9 ± 2.4) than periods three (7.1 ± 2.2), four (7.5 ± 2.1), six (7.3 ± 2.3) and eight (7.7 ± 2.2). Additionally, match period three had fewer contact involvements than period two (8.6 ± 2.8). This indicates that the Tight Forwards experience the most contact in the first two periods, followed by their biggest drop-off in the third period and maintain the contact involvements for the remaining periods of the match. As contact involvements are a key role of all Forwards, the first two periods might represent the potential for the Tight Forwards to engage in contact events when they are physically fresh. Once fatigue accumulates in the third period, the Tight Forwards might be unable to maintain their intensity set during the first quarter of the first half.

The Loose Forwards exhibited a similar pattern to the Tight Forwards in the first half, where match period one (9.0 ± 3.1) had more contact involvements than periods three (7.5 ± 2.3) and four (7.5 ± 2.5), indicating a slow-positive pacing strategy for the first half. However, the second half showed a discrepancy, where match periods five (8.6 ± 2.4) and six (8.4 ± 2.5) were no different to periods one and two. This suggests that the half time break provides the Loose Forwards with sufficient recovery to operate at the required intensity for the first two periods of the second half, possibly compensating for the drop-off in Tight Forward contact involvements. Match period seven (7.9 ± 2.5) was lower than match period one, possibly indicating fatigue as a result of the high intensity of periods five and six. However, period eight (8.7 ± 3.0) saw a rise in intensity towards the end of the match, with more contact involvements than periods three and four. This increase in intensity might be due to the influence of substitutions, team-specific tactics, pacing, or psychological factors discussed in research objective five.

No within-group differences were observed for the Inside Backs and Outside Backs over any of the eight match-play periods (Table 4.2), which mimics the results of their positional group, the Backs. Similarly discussed in research objective six, the limited contact involvements experienced by the Inside Backs and Outside Backs are likely due to the opportunities presented to them to be involved in contact situations. As the number of contact involvements during each period of match-play is more likely governed by the opportunities presented, the sporadic nature of rugby results in no within-group differences for Inside Backs and Outside Backs between periods.

D. PEAK PERIOD ANALYSIS

The third aim of the current study was to describe and determine the between- and within-group locomotive and contact differences in peak periods of play (rolling averages of most-intense 1–10 minutes) for Forwards and Backs, and positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs) throughout match-play, over a period of two Super Rugby seasons.

The seventh hypothesis stated that Backs will cover more relative distance than Forwards across all ten peak period durations, and Forwards will have more relative contact involvements than Backs across all ten peak period durations. As both of these points of the hypothesis were evident in the results, the hypothesis is accepted.

In order to better define peak periods of play, an objective was to compare the relative distance between Forwards and Backs across all ten peak period durations.

The finding that the Backs cover more relative distance over all moving average durations (Figure 4.9) is supported by literature (Cunningham et al., 2018; Read et al., 2018). Cunningham and colleagues (2018) investigated peak periods of one to five minutes and concluded that Backs cover more relative distance over all durations when compared to Forwards. Although Read and colleagues (2018) assessed academy players, a lower level group of players than that of the current study, for peak periods of 15s, 30s, 1, 2, 2.5, 3, 4, 5 and 10 minutes, and Backs were found to cover more relative distance in all periods. Given the roles and responsibilities of the Backs and the findings of the current study where they cover more total distance in most movement categories (Figures 4.1 and 4.2), it is logical that the Backs cover more distance over peak periods. Shorter duration periods might reflect common roles of Backs, such as chasing territorial kicks, sprinting on attack in an attempt to score or in defensive cover. Longer duration periods are likely to reveal the movement of Backs required to transition into position around the field of play, which consist of wider channels that are further from the breakdown than those required of Forwards.

Similarly to the last objective assessing relative distance during peak periods of play, another objective of the current study was to compare the relative contact involvements between Forwards and Backs across all ten peak period durations.

Comparisons with the current study are challenging, as there is a dearth in literature regarding total contact involvements and peak periods of play. The current study found the Forwards to engage in more contacts over all ten moving average durations when compared to the Backs (Figure 4.10). Pollard and colleagues (2018) assessed the peak collision demands through GPS while the ball is in play, and found Forwards have a greater total than Backs. Although only periods of 30–60, 61–90 and greater than 90 seconds were analysed, Pollard and colleagues' (2018) results reflected that of the current study for the one and two-minute durations. The results of the current study suggest that not only are Forwards involved in more contacts situations throughout an entire match, but their peak period demands are also greater than that of the Backs.

To further describe the within-group differences as per the third aim of the study, an objective was to compare within-group, the relative distance between each peak period duration and its respective ensuing duration for Forwards and Backs.

Within-group differences of Forwards saw moving average durations one to six to differ from their respective ensuing durations (Figure 4.9). This indicates that a plateau in running intensity occurs from seven minutes onwards. The results of the current study were synonymous with that of Cunningham and colleagues (2018), however, five minutes was the maximum duration reported. When comparing results of the current study with that of Cunningham and colleagues, they were found to be: 1 min: 140.9 ± 21.4 v 139.0 ± 38.2 $m.min^{-1}$, 2 min: 116.1 ± 16.9 v 111.1 ± 22.0 $m.min^{-1}$, 3 min: 103.8 ± 14.3 v 96.9 ± 16.1 $m.min^{-1}$, 4 min: 95.6 ± 12.2 v 90.6 ± 13.2 $m.min^{-1}$, and 5 min: 90.3 ± 11.3 v 85.7 ± 10.9 $m.min^{-1}$, respectively.

Within-group differences of Backs saw moving average durations one to seven to differ from their respective ensuing durations (Figure 4.9). Similarly to Forwards, the findings of the current study were synonymous with literature for peak durations one to four (Cunningham et al., 2018). The plateau in movement intensity occurs after eight minutes, one minute longer than Forwards. As a result of the more intense running nature of the Backs' roles, it is no surprise that their positional group would see a later plateau. Again, comparing the current study with that of Cunningham and colleagues (2018), the results were as follows: 1 min: 158.2 ± 20.7 v 160.1 ± 21.1 $m.min^{-1}$, 2 min: 129.1 ± 16.9 v 126.9 ± 16.7 $m.min^{-1}$, 3 min: 114.6 ± 13.7 v 110.6 ± 15.0 $m.min^{-1}$, 4 min: 105.7 ± 13.1 v 102.0 ± 13.4 $m.min^{-1}$, and 5 min: 100.1 ± 11.6 v 96.5 ± 13.6 $m.min^{-1}$, respectively. The likeness in data of the current study and that of Cunningham and colleagues (2018) suggests that the peak periods of play for positional groups are similar between European international level competition and Super Rugby.

Another objective of this study was to compare within-group, the relative contact involvements between each peak period duration and its respective ensuing duration for Forwards and Backs.

Within-group differences were observed for both Forwards and Backs. Forwards saw more relative contact involvements for moving average durations one through six with their respective ensuing durations, while Backs saw more for moving average durations one through five. This indicates that Forwards' relative contact involvement intensity plateaus from seven minutes onwards, while Backs plateaus from six minutes onwards. The plateaus of relative contact involvements for Forwards and Backs are inverse when compared to those of relative distance discussed in Research Objective Nine. This finding is expected, as Forwards are involved in more contact situations throughout the match as a result of their positional roles. A notable difference is that Forwards' relative contact and distance plateaus occur at a similar time, while the Backs' relative contact involvements plateau two minutes before their relative distance. This is likely due to the scarcity of contact involvements for Backs, where there might be a lack of opportunity to engage in contact, rather than a lack of capacity to maintain the intensity. The difference might be exaggerated by the roles of the Backs and the nature of the game, where they will still need to move into position between periods of ball-in-play, but no contact involvement opportunities are provided.

Relating to the aim of describing peak periods of play, an objective was to determine an equation to provide the peak relative distance as a function of time for Forwards and Backs.

Utilising the ten peak periods, a graph of the relative distance (*y*-axis) and moving average duration (*x*-axis) can be plotted. A curve is then applied where predicted values are plotted as a function of time using the Power Law. In a practical setting, once a training drill duration is selected the equation of the curve provides a movement intensity in metres per minute that best represents the positional peak period of play over that specific duration. The equations for peak relative distance for Forwards and Backs are $y = 137.93x^{-0.26}$ and $y = 157.08x^{-0.271}$, respectively.

Similarly to the predictive equation of peak relative distance, an objective was to determine an equation to provide the peak relative contact involvements as a function of time for Forwards and Backs.

Power Law, as used to derive the equations to estimate peak running intensities as a function of time (Objective Thirteen), provided equations for the peak contact involvements as a function of time. The equations are $y = 2.8701x^{-0.451}$ for Forwards and $y = 1.9644x^{-0.626}$ for Backs.

The eighth and final hypothesis of the current study contended that Inside Backs and Outside Backs will cover more relative distance than Tight Forwards and Loose Forwards across all ten peak period durations, and Tight Forwards and Loose Forwards will have more relative contact involvements than Inside Backs and Outside Backs across all ten peak period durations. The hypothesis is accepted, as Inside Backs and Outside Backs covered more relative distance across all durations, and Tight Forwards and Loose Forwards were involved in more contact situations.

Relating to the final hypothesis (hypothesis eight), an objective was to compare the relative distance between positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs) across all ten peak period durations.

No between-group differences were observed between the Tight Forwards and Loose Forwards, or the Inside Backs and Outside Backs. However, both Back positional subgroups moved at higher intensities than Forward positional subgroups across all moving average durations. The finding that no differences exist between Forward and Back positional subgroups indicates that, although there are differences in distances covered in specific speed zones (Figure 4.5), no differences occur in peak running intensities during match-play. Conflicting research found the Tight Forwards to move at a lower intensity across all ten moving average durations, the Halfbacks to move at higher intensities when compared to all other positional subgroups over moving average durations one to eight, and no difference between the Loose Forwards and Outside Backs over all durations (Delaney et al., 2017c).

A possible reason for these differences can be explained by methodological differences. Literature further dividing the Tight Forwards into Front Row and Second Row found the Front Row to move at a lower intensity across all peak durations when compared to the Second Row (Cunningham et al., 2018, Read et al., 2018). The current study had a greater Second Row contribution to the Tight Forwards' sample (Front Row: 21%, Second Row: 79%), where the study by Delaney and colleagues (2017c) had a greater contribution for the Front Row (Front Row: 59%, Second Row: 41%), which might explain the lower Tight Forward intensities seen by Delaney and colleagues (2017c). Scrum-halves have more intense movement demands during peak periods when compared to Inside Backs and Outside Backs (Read et al., 2018), therefore the positional groupings used by Delaney and colleagues (2017c) of scrum-halves and fly-halves together likely explains their higher intensities when compared to the Outside Back category, which included wingers and fullbacks, as well as centres. Delaney and colleagues' (2017c) conflicting result of no difference between the Loose Forwards and Outside Backs could be due to two factors. Firstly, methodological differences where the centres were included as Outside Backs. Secondly, when compared to the current study, the movement intensity of the Outside Backs was higher (175 ± 22 v 159 ± 22 $m.min^{-1}$), however, that of Loose Forwards were considerably higher (169 ± 23 v 140 ± 23 $m.min^{-1}$). This indicates that the team under study in Delaney and colleagues' (2017c) research might have been required to operate at a higher intensity to employ team-specific tactics and strategies.

Another objective was to compare the relative contact involvements between positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs) across all ten peak period durations.

No differences were observed between the Tight Forwards and Loose Forwards, however, both engaged in more contact involvements across all moving average durations when compared to the Inside Backs and Outside Backs. A dearth in literature focussing on contact involvements during peak periods of play for positional subgroups makes comparisons difficult. No between-group differences for Forward and Back positional groups were observed, but both Tight Forwards and Loose Forwards had a greater number of contact involvements than Inside Backs and Outside Backs across all moving average durations. This suggests that positional groupings of Forwards and Backs might be sufficient when quantifying peak periods of contact involvements. However, further research assessing individual positions might yield different results for each positional. Interestingly, although Outside Backs have lower total contact involvements throughout a match than Inside Backs (Figure 4.6), the current findings suggest that their contact involvements during peak periods of play do not differ, and, therefore, they should be physically prepared as such.

In order to better describe the within-group differences for the third aim of the current study, an objective was to compare within-group, the relative distance between each peak period duration and its respective ensuing duration for positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

Within-group differences suggest that the Tight Forwards see differences for moving average durations one through four with their respective ensuing durations and plateau from duration five onwards. Loose Forwards, Inside Backs and Outside Backs see drop-offs in movement intensity for durations one through six with their respective ensuing durations and a plateau from seven minutes onwards. Limited relevant literature makes comparisons challenging, however, the current study suggests that Tight Forwards plateau in peak running intensity earlier than the remaining positional subgroups. The Tight Forwards share similar roles and responsibilities to the Loose Forwards in open play, therefore it is unlikely that the earlier plateau seen is as a result of position-specific demands. As the Tight Forwards are the heaviest of the positional groups (Table 4.1) and their physical conditioning is largely focused being effective in scrums, it can be surmised that relative bodyweight movement is more demanding and their movement capacity is the limiting factor in the earlier plateau.

The next objective of this study was to compare within-group, the relative contact involvements between each peak period duration and its respective ensuing duration for positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

Within-group differences of the current study saw the Tight Forwards, Loose Forwards and Outside Backs to have drop-offs in intensity between moving average durations one to five with their respective ensuing durations, and the Outside Backs one to four. The earlier plateau of the Outside Backs reflects their match-play demands, where they have the lowest total contact involvements of the positional subgroups (Figure 4.6). As peak duration increases, the Outside Backs are more likely to spend more time covering distance than in contact situations.

For the purpose of practical application of peak period analysis, an objective of the current study was to determine an equation to provide the peak relative distance as a function of time for positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

Given that no differences were observed between Forward and Back positional subgroups, the Power Law equations provided for Forwards and Backs (Research Objective Nine) might appropriately reflect each of their respective subgroups. However, for transparency, the derived equations of the positional subgroups are $y = 2.7568x^{-0.446}$ for Tight Forwards, $y = 3.0432x^{-0.466}$ for Loose Forwards, $y = 1.9339x^{-0.572}$ for Inside Backs, and $y = 1.9132x^{-0.668}$ for Outside Backs.

The final objective of this study was to determine an equation to provide the peak relative contact involvements as a function of time for positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).

Similarly to Objective Nineteen, the equation for Forwards (Research Objective Ten) might appropriately reflect the Forward positional subgroups as no between-group differences were observed. In contrast, differences between the Inside Backs and Outside Backs advocates the use of individual equations for each group. The equations provided by Power Law are: Tight Forwards: $y = 2.7568x^{-0.446}$, Loose Forwards: $y = 3.0432x^{-0.466}$, Inside Backs: $y = 1.9339x^{-0.572}$, and Outside Backs: $y = 1.9132x^{-0.668}$.

E. CONCLUSION

As a final conclusion to the study, Table 5.1 provides an overview of the hypotheses covered and their outcomes.

Table 5.1 Hypotheses and outcomes.

Hypotheses	Outcomes
1. The majority of locomotive demands (maximum speed, sprint count, total distance, distance walking, distance jogging, distance striding, and distance sprinting) will be greater for Backs than Forwards.	Accepted Differences were observed, where Backs achieved faster maximum speeds, completed more sprints, covered more total distance, and distance walking, striding and sprinting.
2. The majority of contact demands (total contacts, carries, rucks, tackles, scrums, and mauls) will be greater for Forwards than Backs.	Accepted Forwards were involved in more total contacts, tackles, rucks, scrums and mauls than Backs.
3. The majority of locomotive demands (maximum speed, sprint count, total distance, distance walking, distance jogging, distance striding, and distance sprinting) will be greater for Outside Backs than Tight Forwards, Loose Forwards, and Inside Backs.	Rejected Various differences were observed between the positional subgroups across all locomotive characteristics, however, sprint distance was the only measure where Outside Backs had a significantly greater demand than all the remaining groups.

4. The majority of contact demands (total contacts, carries, rucks, tackles, scrums, and mauls) will be greater for Loose Forwards than Tight Forwards, Inside Backs, and Outside Backs.	Rejected Although the majority of contact involvements were greater for the Loose Forwards when compared to the Inside Backs and Outside Backs, the majority of contact involvements were similar for the Tight Forwards and Loose Forwards
5. Match periods one and five will have a further total distance and more contact involvements compared to all remaining match periods for Forwards and Backs	Rejected Although the temporal pattern hypothesised was evident in locomotive demands, the pattern of contact demands was sporadic.
6. Match periods one and five will have a further total distance and more contact involvements compared to all remaining match periods for all positional subgroups (Tight Forwards, Loose Forwards, Inside Backs, and Outside Backs).	Rejected Match periods one and five saw further distances travelled when compared to all other periods for all positional subgroups, however, this pattern was not observed for contact involvements for any of the positional subgroups.
7. Backs will cover more relative distance than Forwards across all ten peak period durations, and Forwards will have more relative contact	Accepted Both points of the hypothesis were evident in the results.

involvements than Backs across all ten peak period durations.	
8. Inside Backs and Outside Backs will cover more relative distance than Tight Forwards and Loose Forwards across all ten peak period durations, and Tight Forwards and Loose Forwards will have more relative contact involvements than Inside Backs and Outside Backs across all ten peak period durations.	Accepted Inside Backs and Outside Backs covered more relative distance across all durations, and Tight Forwards and Loose Forwards were involved in more contact situations.

The current study found Backs to cover more distance than Forwards across all movement variables, except distance covered while jogging. Inversely, Forwards had more involvements than Backs across all contact variables, aside from the number of carries. Lower-intensity movement variables indicate a distinct polarisation between Forward and Back positional subgroups, where higher-intensity movement saw more variation between each positional subgroup. Forward positional subgroups were involved in more total contacts and rucks than Back positional subgroups, with greater variation in the number of tackles and carries reported between positional subgroups.

Temporal pattern analysis of movement intensity suggests that both Forwards and Backs exhibit a slow-positive pacing strategy throughout each half, where the Backs have a more exaggerated drop-off in the first half. Tight Forwards and Loose Forwards replicate the temporal movement patterns of Forwards, where Inside Backs and Outside Backs replicate those of the Backs. Contact involvement patterns are sporadic for the Backs, with no differences observed between any of the match periods, which is mirrored by the Inside Backs and Outside Backs. Temporal contact patterns of Forwards suggest a slow-positive pacing strategy in the first half and a flat-line pacing strategy in the second, with variation seen between the Forward positional subgroups.

Analysis of peak periods suggests that running intensities are greater for the Backs when compared to Forwards, and that of the Inside Backs and Outside Backs are greater than the Tight Forwards and Loose Forwards across all ten durations. The inverse is true for peak periods assessing contact involvements, where intensities are greater for the Forwards when compared to the Backs, and the Tight Forwards and Loose Forwards have greater intensities than the Inside Backs and Outside Backs across all ten durations.

The results of the current study indicate similarities and differences in match-play demands between positional groups and positional subgroups, therefore, preparation for competition and subsequent recovery should be tailored accordingly. Some suggestions on tailoring these aspects will be presented in Section G under Practical Applications.

F. LIMITATIONS AND FUTURE RECOMMENDATIONS

A limitation of the current study is a sample that represents a single team in a single competition. It is acknowledged that the sample size, as well as the teams' strategies and tactics differ and the current study might not represent all professional rugby teams. In addition, different match frequency according to fixtures might affect the results.

The positional groupings of Forwards and Backs, and Tight Forwards, Loose Forwards, Inside Backs and Outside Backs provide general groupings that are practical to use in training environments, however, well-resourced teams would find benefit in further dividing positional groups into individual positions. Similarly, as a result of certain positions, such as the props and scrum-half, who are commonly substituted, the sample of positional groups and subgroups is skewed towards certain individual positions.

It is acknowledged that player effort during match-play is not controlled by the author, and it was assumed that maximum effort was given by all players included in the study.

Cunningham and colleagues (2018) have reported on the benefits of using rolling averages versus fixed length epochs. While the current study used rolling one-minute periods similarly to Delaney and colleagues (2015), it is suggested that using rolling averages off the GPS sample rates provides a more accurate representation of the peak periods of play (Cunningham et al., 2018).

The GPS units used in the current study recorded at a sampling rate of 5 Hz (interpolated into 15 Hz). Although this sampling rate is relatively high, further technological advancements might provide more accurate results and access to more validated metrics.

In light of the above-mentioned limitations and the availability of GPS at the professional level, future studies should aim to make use of multiple teams with individualised positions. Team comparisons should be made to assess the influence of team-specific strategies and tactics on the performance variables. With the validity of more modern GPS units, an acceleration load metric should be included in future studies as a measure of the demands associated with changes in speed, which are not accounted for in the current study. Similarly, as external markers are most commonly reported on, similar studies assessing internal load would prove beneficial. In addition, a combination of the contact and locomotive data could prove beneficial in the form of a repeated high-intensity effort measure. Finally, future studies should aim to describe the training demands of teams in an alike fashion, as the goal for most of the variables in the current study is to enhance performance and player availability during matches through improved training.

G. PRACTICAL APPLICATIONS

Full match analysis provides insight into the volume of movement and contact demands experienced by positional groups and subgroups during competition. These demands should be considered and tailored according to position when preparing for competition in the form of team training sessions, game-replacement sessions, return-to-play protocols and post-match recovery. For example, the total running and high-speed exposures required in training for Backs will be higher than that of Forwards in an attempt to reduce injury risk and enhance performance, whereas Forwards might need superior recovery protocols to mitigate damage associated with their high contact loads sustained during match-play. Also noteworthy, is the large standard deviation of the sprint count in all positions and the chance that Forwards will often fail to achieve a single sprint during match-play, but need to be prepared to sprint if required. Given the current literature supporting the notion that regular high-speed exposures have a protective effect, it is recommended that players are exposed to high-speed efforts in training.

Fatigue trends throughout a match indicate periods of specific fatigue, which could identify weaknesses or influence substitution times. As substitutions in the first half are unlikely, the exaggerated drop-off in movement intensity of the Backs in the first half might call for movement-specific conditioning to counter this decline. Similarly, the decline in contact intensity seen by Forwards and their respective subgroups might require them to undergo more general conditioning. Another possible solution is to apply the Hawthorne Effect (Stand, 2000), where measuring players’ performance consistently and creating awareness of their drop-offs in intensity might lead to mind-set shifts and inadvertently improve intensity.

Analysis of peak periods provides equations on which to base specific training intensities in order to best prepare layers according to peak periods of play. Coaches and performance staff are able to calculate optimal drill intensity once a duration has been decided on using the provided equations. For movement intensity: Forwards ($y = 137.93x^{-0.26}$), Backs ($y = 157.08x^{-0.271}$), Tight Forwards ($y = 137.85x^{-0.252}$), Loose Forwards ($y = 141.05x^{-0.272}$), Inside Backs ($y = 152.86x^{-0.257}$), and Outside Backs ($y = 158.04x^{-0.276}$). For contact involvement intensity: Forwards ($y = 2.8701x^{-0.451}$), Backs ($y = 1.9644x^{-0.626}$), Tight Forwards ($y = 2.7568x^{-0.446}$), Loose Forwards ($y = 3.0432x^{-0.466}$), Inside Backs ($y = 1.9339x^{-0.572}$), and Outside Backs ($y = 1.9132x^{-0.668}$). It should be noted that these provide an estimation of the mean peak periods of each match, where the upper end of the standard deviation of each point on the curve should be used as an indicator of "worst-case" scenario intensities.

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APPENDIX A

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Approval Notice

Stipulated documents/requirements

04-Jun-2014
Owen, Shaun S

Proposal #: HS1042/2014

Title:Training loads and match demands of a Super Rugby team during a competitive season.

Dear Mr Shaun Owen,

Your **Stipulated documents/requirements** received on **14-May-2014**, was reviewed by members of the **Research Ethics Committee: Human Research (Humanities)** via Expedited review procedures on **04-Jun-2014** and was approved. Sincerely,

Clarissa GRAHAM
REC Coordinator
Research Ethics Committee: Human Research (Humanities)

APPENDIX B

Fika sports management systems

11 April 2014

Dr R Venter
Departement of Sport Science
Stellenbosch University

Dear Dr Venter

Re Shaun Owen - MSc study on the use of gps technology in rugby

This letter serves to confirm that we (Fika) has arranged for Shaun to do his MSc study project with the Western Province - Stormers rugby team, during the 2014 Super Rugby season.
There will be no cost to access the data that will be generated by the devices (WP has subsequently decided to acquire the units) ,it will however , be expected of Shaun to do some additional work and data mining ,over and above the work done for his study project.
The scope of additional work has been discussed with Shaun and he will work closely with Fika ,in this regard.
He will also be expected to enter into a NDA with all the relevant parties , as some of the data have to be treated as private and confidential.

We further confirm that all data components will be stored on a secure server and that permission has been granted to use some of the relevant data for his study and publication.

May I suggest that you budget for a travel allowance of R 7500.00 .
(S'bosch to Cape Town x twice a week x five months x two rand/km = 90km x 2 x 5 x R 2.00 = R 7 200.00)

Kind Regards

Carel du Plessis
Director

Suite 172, P-bag X 7, Tygervalley, 7536, Tel : + 27 21 914 8304, Fax : + 27 21 914 7395, e-mail: sales@fikasms.co.za
Fika Sports Management Systems (Pty) Ltd. Registration number:1997/ 009860 / 07 .

20 May 2014

Dr R Venter
Department of Sport Science
Stellenbosch University

Dear Dr Venter

Re Shaun Owen – Formal permission for MSc study data

This letter serves to confirm that I (Stephan du Toit) give permission for Shaun Owen to use the height and weight records of the DHL Stormers Super Rugby Squad for the 2014 season.

* and 2015

Sincerely

Stephan du Toit

To Whom it May Concern 7 April 2014

I hereby give permission for Shaun Owen to use the video, global positioning system and rate of perceived exertion data of the DHL Stormers Super Rugby Squad for the 2014 *and 2015 season. Any feedback of the collected data will be used to monitor recovery and overtraining, and will not compromise a player's position in the team.

If you have any questions, I can be contacted on 082 850 3366.

Sincerely,

Stephan du Toit

GREG HECHTER