The Tackle in Rugby Union: Understanding training and match behaviours to develop better coaching strategies for skill acquisition, performance, and injury prevention

by

Mogammat Sharief Hendricks

Thesis presented for the Degree of
DOCTOR OF PHILOSOPHY
in the Department of Human Biology
Faculty of Health Sciences
UCT/MRC Exercise Science and Sports Medicine Research Unit
UNIVERSITY OF CAPE TOWN
South Africa
August 2012

Dedicated to my Mom

Table of Contents

Acknowledgements

Professor Micheal Lambert

Words cannot describe how grateful I am to have met you, and work with you. Thank you for your support, patience, guidance, and insight throughtout my PhD. I have learnt so many things from you that are beyond the realm of academics. Your work ethos, compassion, kindness, sincerity, and humility have been exemplary. You are an inspiration to all your students, and I consider you my mentor. It has truly been an honour and privilege to work with you.

Professor Timothy Nooks

Your teachings have modified the way I think, and approach life and its challenges. Providing me with the opportunity to attend international conferences during the course of my thesis has broadened my horizon beyond the scope of a PhD. Think big, be bold and aspire to 'be perfect'.

ESSM Staff and Students

Thank you for the support, and providing an environment conducive for 'being perfect'.

Financial Support

National Research Foundation/German Academic Exchange Service, Medical Research Council of South Africa, Frank Foreman Scholarship, Glickman/Elliot Scholarship, University of Cape Town Equity Scholarship, Doctoral Research Scholarship, UCT Rugby Personal Trust Bursary and the Exercise Science and Sports Medicine Scholarship. Thank you for allowing me to focus all my energy into this thesis, and not having to worry about financial issues. Without your support, this thesis would not have been possible.

Special Thanks

Special thanks to the following people for their time, effort, and contribution they have made to the thesis. Graham Bentz, Nicholas Tam, coaches and managers of the respective teams, Esme Jordaan, David Karpul, Fred Nicolls, Bevan Matthews and Brad Roode for their assistance with data collection and analysis in the different chapters. Mike Posthumus, Benoit Capostagno, James Brown, Colleen Saunders, Nicholas Tam, Wayne Viljoen (SA Rugby), Clint Readhead (SA Rugby), Justin Durandt (Sport Science Institute of South Africa High Performance), for sharing your thoughts and ideas with me regarding this thesis. Also, thank you to the reviewers of the published and provisionally accepted chapters for their valuable and constructive feedback, which has substantially improved the quality and standard of the work in this thesis.

Friends and family

For your unconditional support and love throughout this thesis. Finally, very special thanks to my mother, Faeza, my wife Ilk-nür, and parents in-law Faheema and Armien for always being there.

DOCTORAL DEGREES BOARD
UNIVERSITY OF CAPE TOWN
Student Administration Building,
Private Bag X3, Rondebosch, 7701
Tel: **+27 21 650 2202** Fax: **+27 21 650 4913**
E-mail: **janine.isaacs@uct.ac.za**

Please complete Sections 1 and 2 and return to the Doctoral Degrees Board, University of Cape Town, when submitting your thesis for examination.

PhD Thesis title	

1. DECLARATIONS:

I _____(full name) hereby:

(a) grant the University of Cape Town free licence to reproduce the above thesis in whole or in part, for the purpose of research;

(b) declare that:

(i) the above thesis is my own unaided work, both in concept and execution, and that apart from the normal guidance from my supervisor, I have received no assistance except as stated below:

_____

_____

(ii) neither the substance nor any part of the above thesis has been submitted in the past, or is being, or is to be submitted for a degree at this University or at any other university. except as stated below:

_____

_____

I am now presenting the thesis for examination for the degree of PhD.

Candidate's Signature		**Date**	

Academic Outputs

Publications

1. S Hendricks and M Lambert. Tackling in rugby: coaching strategies for effective technique and injury prevention (Review). *International* Journal *of Sports Science and Coaching*, 2010, 5(1), 117-135.
2. S Hendricks, E Jordaan and MI Lambert. Attitude and behaviour of junior rugby union players towards tackling during training and match play. *Safety Science*, 2012, 50, 266-284.
3. S Hendricks and M Lambert. Attitude and behaviour of junior rugby union players towards tackling during training and match play: Response to letter to the editor. *Safety Science*, 2012, 50(4), 1155-1156.
4. S Hendricks, D Karpul, F Nicolls and MI Lambert. Velocity and acceleration before contact in the tackle during rugby union matches. *Journal of Sport Sciences*, 2011, 30 (12), 1215-1224.
5. S Hendricks, D Karpul, and MI Lambert. Momentum and Kinetic Energy before the tackle in Rugby Union. Provisionally accepted in *Journal of Applied Biomechanics*.
6. S Hendricks, B Matthews, B Roode, M Lambert. Tackle characteristics that may increase the likelihood of a successful tackle outcome in rugby union. *European Journal of Sport Science.* In review.
7. S Hendricks, B Matthews, B Roode, M Lambert. Defensive Strategies in Rugby Union. *Perceptual and Motor Skills*. In review.

Other Publications:

1. Sharief Hendricks. The science of tackles. Sports Illustrated. May 2010 edition.

List of Tables

List of Figures

Thesis Abstract

The Tackle in Rugby Union: Understanding training and match behaviours to develop better coaching strategies for skill acquisition, performance and injury prevention

Mogammat Sharief Hendricks

Background: Rugby Union is a popular international team sport characterised by frequent high impact bodily collisions known as the tackle. This aspect of the game exposes players to muscle damage and a high risk of injury. Tackle-related injuries account for up to 61% of all injuries during a rugby match. Furthermore, players' ability to win the tackle contest has an influence on the outcome of the match. Given the nature and frequency of the tackle situation, tackle contact skills are a prerequisite for participation in rugby union. However, coaching and training drills prescribed to train the tackle to date are largely based on anecdotal evidence. To develop effective tackle training strategies (i.e. technical skills training, physical conditioning, training drills, and equipment) that will produce a successful outcome and reduce the risk of injury for both the ball-carrier and tackler, studying the tackle in real match situations is warranted. Therefore, in accordance with this goal the purpose of this thesis was to; (i) assess the current attitudes and behaviours of players during training and match play, and (ii) study the tackle and defensive strategies in real match situations. Methods: A questionnaire was developed to assess attitudes and behaviours of players' towards injury prevention and performance when training the tackle and during match play. The physical components of the tackle (velocity, acceleration, momentum and kinetic energy) in real match conditions were analysed using a two-dimensional scaled version of the field. In addition, tackler and defensive characteristics that increased the likelihood of a successful tackle or phase outcome were analysed in real match situations. Results: Based on the results from players' current training and match playing attitudes and behaviours, aspects of tackle training that require modification or improvement were identified. In particular, players, coaches, and administrators need to find the most suitable balance between injury prevention and performance during training within their team setting. Analysis of the physical components of the tackle, tackler characteristics, and defensive strategies in real match situations reveal some of the complexities of the tackle in match conditions. Conclusions: Given this evidence, it is recommended that as a player advances his/her tackle contact skills, task and environmental components that simulate match conditions should be incorporated into coaching and training the tackle.

Chapter 1 Literature Review

S Hendricks and M Lambert. Tackling in rugby: coaching strategies for effective technique and injury prevention (Review). *International* Journal *of Sports Science and Coaching*, 2010, 5(1), 117-135.

1.1 Introduction

Although rugby union and rugby league are two different collision sports, each with their own set of rules, similarities between the sports do exist. For example, the main objective of both sports is to gain territory by advancing the ball down the field towards the opposition try-line and scoring as many points as possible. An effective way of preventing an attacking team from gaining territory and scoring points is by tackling the player with the ball in an attempt to stop forward momentum and gain possession of the ball. Accordingly, both sports expose players to frequent high impact collisions [1]. Although the tackle is an event common to rugby union and rugby league, definitions on what may be considered a tackle may differ under the different governing bodies. This will be discussed further in the next section.

The physical nature of the tackle exposes both players (i.e. tackler and player being tackled) to injury. While injury is always a risk during collisions, the risk of injury during the tackle can be reduced through the implementation of safe and effective technique [2]. Therefore, the purpose of this paper is to identify strategies that can be coached during training and implemented during matches to ensure that the risk of injury during the tackle is reduced without comprising the efficacy of the event. This will be approached by discussing the studies on the descriptive epidemiology of rugby union and rugby league and progressing to the studies on analytical epidemiology.

1.2 Defining the Tackle

In rugby union, according to the International Rugby Board (IRB) a tackle occurs "*when a ball carrier (a player carrying the ball) is held by one or more opponents and is brought to ground"* [3].The opposition player that goes to ground with the ball carrier is referred to as the *tackler* [3]. The purpose

of tackling is to prevent the ball-carrier from gaining territory and minimise the chance of the ball-carrier's team from retaining position of the ball [4]. A recent study by Quarrie and Hopkins (2008) [5] used a slightly different definition; *"when the ball-carrier was contacted (hit and/or held) by an opponent without reference to whether the ball-carrier went to ground"* [5]. The tackle definition for rugby league is more intricate as rugby league has the "*play-the-ball*" rule instead of a ruck. According to Australian Rugby Football League a tackle in rugby league occurs when the ball-carrier is held by one or more opposing players and (i) remains held up in such a manner that the ball-carrier is unable to progress further (upright); (ii) makes contact with the ground (grounded); (iii) when the ball-carrier succumbs to the tackle (succumbing); (iv) when the ball-carrier is lying on the ground and the opposing player places a hand on him (hand on player already grounded) [6]. During a rugby union match forwards are involved in an average of 17 tackles per match and backline players 7 tackles per a match[7]. In comparison, rugby league forwards can be involved in 32-55 tackles a match and backline players 19-29 tackles per a match, depending on the level of play [8-12].

In rugby union, tackles have been identified from the direction which the tackler makes contact with the ball-carrier [5]. Tackles have also been further characterised by the manner in which tacklers makes contact with the ball-carrier namely, an *arm-tackle*- the tackler impedes/stop the ball-carrier by using the upper limbs; *collision-tackle*- tackler impedes/stops ball-carrier without the use of arm(s); *jersey-tackle*- tackler holds the jersey of the ball-carrier; *lift-tackle*- tackler raises ball-carrier's hips above the ball-carriers head; *shoulder-tackle*- tackler impedes/stops ball-carrier with shoulder as the first point of contact followed by the use of his arm(s); *smother-tackle*- tackler uses chest and wraps both arms around ball-carrier ; *tap-tackle*- tackler trips ball-carrier using a hand on either lower limb (below the knee) of the ball-carrier; *situational-tackle*- tackler assesses the situation and attempts a tackle; *goal-line tackle*- tackler defends his goal-line [2;13].

1.3 Defining an Injury

When participating in collision sports, there will always be a risk of injury as the dynamic impact of the collision may overload the musculoskeletal system beyond its limit [14]. For an accurate comparison of injuries and injury trends, it is important to have a consistent definition. In accordance, the following definition of an injury for rugby union and rugby league is similar and defined as: "*any physical complaint, which was caused by a transfer of energy that exceeded the body's ability to maintain its structural and/or functional integrity that was sustained by a player during a match or training, irrespective of the need for medical attention or time-loss from the sport activities* [15;16]. The definition further categorize injuries into *''medical-attention injury" – an injury that results in a player receiving medical attention) and; "time-loss injury" - an injury that results in a player being unable to take a full part in future training or match play* [15;16].

1.4 Injury Epidemiology

After rugby union became a professional sport in 1995, players could devote more time preparing for matches and as a consequence became heavier, stronger, more powerful and have shown an increase in mental strength [17-32]. Professionalism also meant that coaches and their supporting staff had more time and resources to investigate and apply various aspects of the game in an attempt to obtain a competitive advantage over their opposition. This for of research into the game increased the knowledge base and refined aspects of the game such as fitness conditioning, strength and power training, periodization, different ruck and scrum techniques, game strategies, running lines etc. This enhanced knowledge benefited not only professional teams but was also applied to amateur teams. Consequently, the overall game of rugby, from amateur to professional, became more physical, quicker and consisted of more frequent and forceful contact events. However, the growth and development of the game also had disadvantages. The increase in physical demands on the players

increased the risk of injury, particularly during the tackle. Numerous studies after 1995 have established that during a rugby union match players are at the highest risk of injury (defined as the product of incidence and severity) [19;33] during the tackle [19;20;34;35;35-40] (Table 1.1). In addition, the majority of injuries that occurred during the Rugby Union World Cups of 1995, 2003 and 2007 were sustained during the tackle [41-43]. Similarly, injuries as a result of the tackle have accounted for up to 61% of all injuries that occur during a rugby match, consequently preventing players from taking any further part in rugby activity [2;5;20;34;37;39;40;43-48]. During the 2006 Woman's Rugby World Cup 64% of all injuries occurred during the tackle [49]. Likewise in rugby league, the tackle event has been shown to be the major cause of injuries at the amateur [50], semi-professional [10;51;52] and professional level [53;54].

Table 1.1 summarizes the injury reporting studies on rugby union from 1993 to 2007. The definition of an injury in these studies were similar with injuries defined as any injury sustained during a rugby related event that prevented the player from taking any further part in the remainder of the match or training session. It is clear that the risk of injury associated with the tackle is highest in all of these studies compared to other phases of play.

Table 1.1 Injuries associated with different phases of play in amateur and professional rugby union players (1993-2007): The tackle event places players at highest risk of injury compared to the other facets of play (bold). All data are expressed as a % of the total number of injuries sustained

	Bird et al. [47] *1993 (Club senior)*	**Lee et al.* [55] *1993-1994 (Club Senior)*	*Jakoet et al* [43] *1995 (World Cup)*	*Bottini et al.* [48] *1991-1997 (Club Senior)*	*Targett* [46] *1996-1997 (Super 12)*	*Holtzhausen et al.* [34] *1999 (Super 12)*	*Bathgate et al.* [45] *1994-2000 (Professional Senior)*	**Brooks et al.* [44] *2002-2003 (Professional Senior)*	*Best* [41] *et al. 2003 (World Cup)*	*Fuller et al.* [42] *2007 (World Cup)*
Tackle	**40**	**49**	**56**	**24**	**46**	**61**	**58**	**35**	**39**	**35**
Ruck	17	15	23	14	36	17	15	16	6	13
Maul	12	n/a	n/a	16	#	#	#	#	n/a	5
Scrum	7	8	1	8	8	5	2	5	5	5
Line-Out	n/a	n/a	0	n/a	5	5	0	n/a	3	1
Open Play	9	n/a	11	36	5	7	20	18	28	31
Other	15	n/a	9	3	n/a	5	5	23	19	11

n/a – data not collected

- data of maul injuries was combined with ruck injuries

* - data do not add up to 100%

1.5 Tackle Injury Epidemiology

The tackle is the facet of the game where players are most likely to be injured (Table 1.1). Since the onset professionalism in rugby union, the number of tackles has increased substantially [18]. Besides the increased risk of injury associated with an increased number of tackles during a match, this has also been shown to have physiological consequences. It has been shown that the number of tackles during a rugby match (either made or received) is positively associated with increased blood creatine kinase activity, a marker of muscle damage [36]. This increase in the number of tackles may be due to the "use-it-or-lose-it" law introduced in 1994 just before the onset of professionalism [18]. This law prevented the ball from being delayed in a maul for long periods, therefore increasing the risk of losing the ball [18]. Ball-carriers started to make deliberate contact with a tackler in order to set up a ruck where the ball had a lesser risk of being turned over and the "use-it-or-lose-it" law did not apply [18]. This explanation by Quarrie and Hopkins (2007) was supported by the findings of an increase in ruck events per match from 25 in 1972 to 150 in 2004 and a decrease in maul events from 50 in 1972 to less than 25 in 2004 [18].

During the tackle event in rugby league and rugby union both the tackler and ball-carrier are at risk of injury [5;10;19;38;40;43;47;50-54;56-58]. In rugby union one study has shown that the ball-carrier is most at risk [44] whereas another study suggests that the tackler is at a higher risk [37]. In rugby league, at the amateur level tacklers were shown to be at highest risk of injury [50;58] compared to professional players where the ball-carrier is most likely to sustain an injury [10;51;52].

1.5.1 Tackler Injury Mechanisms

Most injuries of the tackler occur at the head, neck, and/or shoulder region [13;38;56] (Figure 1.1). Injuries to the head, neck and/or shoulder region of the tackler may be caused by the tackler aiming too far

below the waist in the tackle [5]. With this type of action, the tackler makes contact with the moving legs of the ball-carrier with an associated high risk of causing injury.

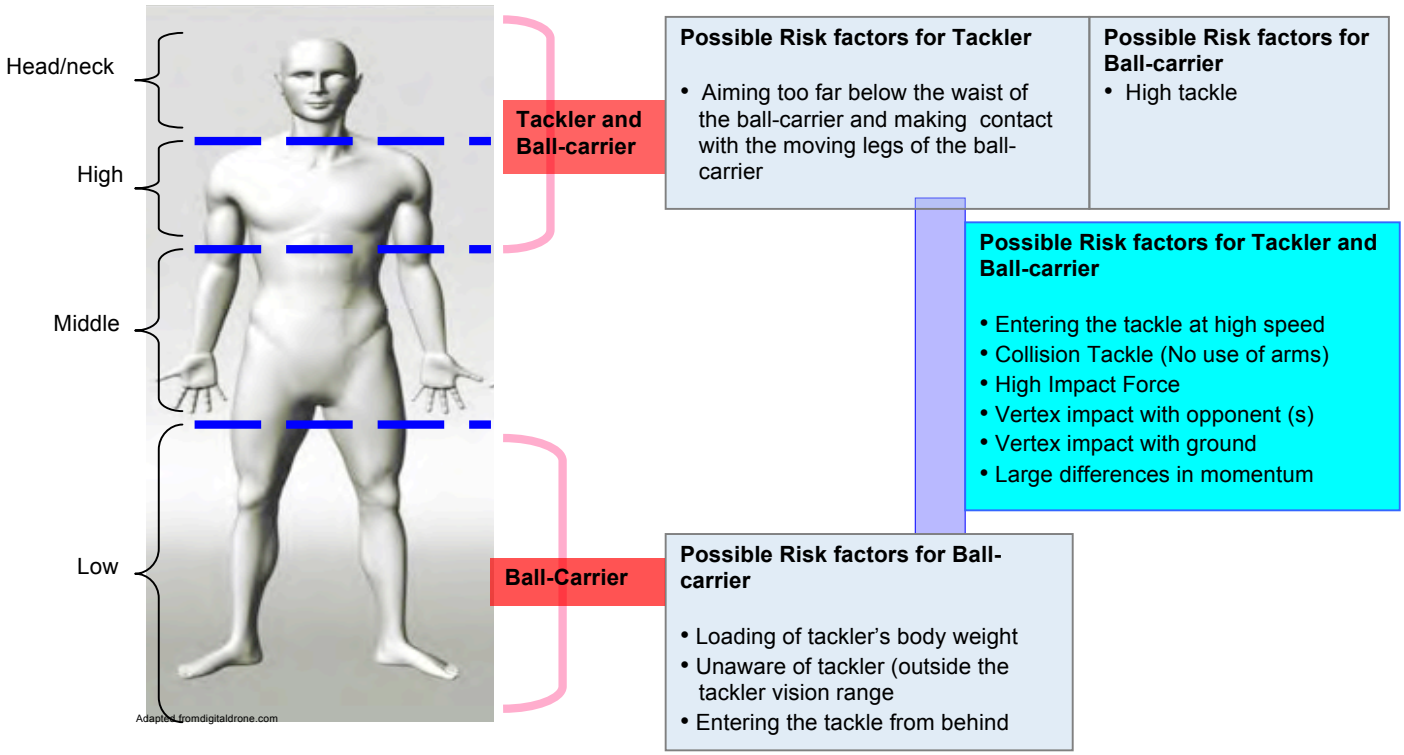

Figure 1.1 Site of tackle injury and possible risk factors for tackle injuries for both tackler and ball-carrier

1.5.2 Ball-Carrier Injury Mechanisms

The ball-carrier is injured mainly at the lower limb and the head/neck region [13;38;56]. Lower limb injuries to the ball-carrier may be a consequence of the tackler loading his body weight onto the ball-carriers legs and/or making contact with the tackler during a low tackle [5]. The ball-carrier has a high risk of injury when tackled from behind [5] This can be attributed to the ball-carrier being unaware of the imminent tackle, particularly if the tackler is beyond the ball-carriers range of vision [57]. This places the ball-carrier at a disadvantage, as the ball-carrier is unable to prepare and protect himself for the tackle. For the head/neck region of the ball-carrier, high tackles seem to be the main cause of injury [13].

Coaches need to discourage players from high and dangerous tackles which are illegal in both rugby union and rugby league [3;6].

1.5.3 Common Injury Mechanisms

Mechanisms of cervical spine and spinal cord injuries to both ball carrier and tackler have been reported to be the result of vertex impacts (The crown of the head) of the head with either the opposing player or the ground and the subsequent hyperflexion of the neck that occurs during the contact [2;59;60].

A study by Quarrie and Hopkins (2008) on tackle injuries for New Zealand teams during the 2003 to 2005 Super 12 competition revealed that tackler's entering the tackle from different directions result in different injury profiles in terms of rate per 1000 tackles or rate per 1000 player-hours, replacement rate and injury burden (days off from rugby activity due to injury) [5]. They found ball-carriers and tacklers were injured and replaced at a higher rate per 1000 tackles due to tackles made from behind (ball-carriers injured 3.8/1000 tackles and replaced 2.2/1000 tackles; tacklers injured 3.1/1000 tackles and replaced 2.2/1000 tackles) and from the side (ball-carriers injured 3.7/1000 tacklesand replaced 1.4/1000 tackles; tacklers injured 1.6/1000 tackles and replaced 0.9/1000 tackles) compared to tackles from the front (ball-carriers injured 2.8/1000 tackles and replaced 1/1000 tackles; tacklers injured 1.4/1000 tackles and replaced 0.7/1000 tackles). However, when taking into account the number of player hours the injury profile changes. Ball-carriers and tacklers were injured and replaced at a higher rate per 1000 player-hours as a result from tackles from the front (ball-carriers injured 4.3/1000 player-hours and replaced 1.5/1000 player-hours; tacklers injured 7.7/1000 and replaced 3.4/1000 player-hours) compared to tackles from the side (ball-carriers injured 3.3/1000 player-hours and replaced 1.3/1000 player-hours; tacklers injured 4.3/1000 and replaced 2.4/1000 player-hours) or behind (ball-carriers injured 0.5/1000 player-hours and replaced 0.3/1000 player-hours; tacklers injured 0.9/1000 and replaced 0.6/1000 player-hours). Front on tackles caused the highest burden to tacklers (180 days

off/1000 player-hours) and side on tackle caused the highest burden to ball-carriers (180 days off/1000 player- hours) [5].

The collision-tackle (tackler impedes/stops ball-carrier without use of arms(s) had a significantly higher propensity for injury to both tackler and ball-carrier compared to the other tackles [13]. Furthermore, players entering the tackle at high speed and tackles with high impact increased the risk of injury [5;13]. Also, large differences in momentum between the tackler and ball-carrier (defined as the product of velocity and mass) during the tackle favoured the player with the higher momentum, with the player with lower momentum being at a higher risk of injury [57]. This emphasises the importance of a player's physical conditioning, body position, mass, and velocity of movement during the tackle in order to develop momentum quicker [57], and apply that momentum in the correct manner.

Recent studies on tackle injuries in rugby union suggest that backline players are at higher risk of injury than forwards [5;13]. This finding was attributed to the relatively high speed of backline tacklers when going into a tackle compared to forward tacklers, resulting in higher impact forces during the contact [5]. The faster movements of the backline players from both the attacking and defending sides allows for less time to make decisions about technique and the forthcoming tackle that needs to be executed. Subsequently, less time is spent on the preparation phase of the tackle (discussed in section 5.1) resulting in reduced tackling proficiency [1]. Defensive structures may contribute to a reduction of these injuries as defending players will be able to premeditate who they need to tackle which allows for better preparation for tackle. In rugby league, forwards are at a higher risk of injury during the tackle (for both ball-carrier and the tackler) compared to backline players due to forwards being involved in more tackle events [9;10;51;53;54;58;61]. However, a pooled data analysis of injury incidences in professional rugby league has shown that there is no predisposition to injury when playing as a forward or back [62].

1.6 Tackle Theory

It is logical to assume that knowledge about safe and effective technique during the tackle can reduce the risk of injury while at the same time producing a successful outcome of the contact event. It follows that any coaching programme for tackling should have this concept as a foundation. Indeed, programs designed to achieve this goal have been developed in different countries. For example, the New Zealand Rugby Union *RugbySmart* [63;64] and Australia Rugby Union *SmartRugby* [4] are both well established programs in their respective countries with valuable information for safe and effective contact skills knowledge. The New Zealand RugbySmart program has been instrumental in the reduction of rugby injuries in New Zealand since its implementation in 2001 [59;63-67]. South Africa has also recently launched their own BokSmart program [68]. Other examples of coaching resources are the South African Rugby Union Coaches Logbook [69], the New Zealand Rugby Union Coaching Toolbox [70] and the Australian Rugby Union Online Coaching Centre [71]. Teams from the United Kingdom (England, Ireland, Scotland and Wales) contain similar coaching and player resources on their respective websites but lack national initiatives such as RugbySmart, SmartRugby and BokSmart Rugby. The International Rugby Board has a worldwide initiative following the success of RugbySmart and SmartRugby [72]. Rugby League has similar programmes; an example of this is New Zealand Rugby League LeagueSmart [73]. Most of the information in these programs and coaching resources have been provided by academics, coaches, and players and therefore provide a sound source of information. In the next sections, the dynamics of contact in the tackle jointly for tackler and ball-carrier as well as techniques specific to the tackler and ball-carrier will be discussed.

1.6.1 Making Contact in the Tackle

The contact situation in rugby may be considered a 'ballistic' movement [14]. A 'ballistic' movement comprises 3 phases, namely (i) the preparation phase (ii) the action phase (iii) and the recovery phase [14]. During the preparation phase the body prepares for contact by adopting an advantageous body position and the necessary muscle groups are activated. The action phase describes the point when contact is made with the opposition player. The recovery phase describes the following through of the movement. Coaches often focus attention on the action phase during contact technique training at the exclusion of the preparation and recovery phases. The application of these phases will be described when different techniques of the tackler and ball-carrier are compared.

As discussed earlier the difference in momentum may be a determinant of injury and success in contact [5;38;57]. During a collision in rugby league and rugby union, players can only increase their momentum by increasing their velocity [74;75]. Therefore, coaches need to emphasise to players the importance of leg drive and staying on their feet during the contact. This strategy will ensure that the player has control over his velocity, and extend the period over which this force is applied during the contact.

1.6.2 Current Techniques for the Tackler

The majority of the coaching techniques have been described using the front-on tackle as the example (Table 1.2). The variety of descriptions in the table suggests that there is no consistency, even within the same programme (NZRU 2007-2008). Evidently, these programmes do seem to agree on making contact with the shoulder on the same side of the leading leg. However, this technique is not universal. The technique whereby a tackler makes contact with the shoulder on the same side of the leading leg is opposed by another technique of making contact with the opposite shoulder of the leading leg [1;35;76-78]. Tackling technique using the opposite shoulder to the leading leg has been described by Gabbett in 4

Table 1.2 Current Coaching Techniques described described for the front tackle [4;63;64;68;73]

	NZRU RugbySmart 2008	NZRU RugbySmart 2007	ARU SmartRugby 2008	SA Rugby BokSmart	NZ LeagueSmart
1.	Sight target	Sight Target	Position the ball carrier	Track the attacking player	Sight Target
2.	Move forward into tackle	Position inside the ball carrier	Approach in an upright position with hands up in front, and thumbs up	Stay square to your opponent for as long as possible	Hands above waist, elbows in
3.	Move slightly inside the ball-carrier (inside shoulder)	Run in pre-tackle stance	Sight the target – above the knees	Run towards your attacking player's inside shoulder	Move in close to the runner
4.	Face up!	Chin up	Balance and dip the body late, keeping the head up., looking forward	Deny them space	Keep your eyes on the target
5.	Keep feet alive and position lead foot close to ball carrier	Eyes open	Place lead foot in close	Shuffle and do not cross your feet	Head up and away to the side
6.	Drive with legs to make firm contact with the shoulder and with the head to the side	Back straight	Position head to the side of opponent (ear against thigh), and look forwards	Keep your face up during the tackle	Contact with your lead shoulder
7.	Punch arms forward and wrap around the ball-carrier	Hands above hips	Drive with legs and make firm contact with front shoulder	Keep your eyes open and sight your target	Wrap arms "Bear hug"
8.	Continue power drive through to complete the tackle	Go forward	Wrap arms and lock (hand to elbow), cheek to thigh (no gaps) and squeeze	Focus on the core of the attacker	
9.	Regain feet and recover ball	Zero in on target	Finish on top of the ball carrier	Keep your spine in line	
10.		Drive with legs to make firm contact with the shoulder on the target	Quickly regain feet	Align your head outside of the tackler and not in front	
11.		Head behind ball carriers body		Shorter, faster steps as you approach	
12.		Lock on with the arms around the ball carrier		Keep your elbows low and hands up (boxer stance)	
13.		Continue power drive		Dip and step into the tackle with lead foot	
14.		Regain feet		Punch and wrap the arms(hit-and-stick)	
15.		Recover ball		Maintain leg drive into the tackle	
16.				Once on the ground, regain feet quickly	
17.				Compete for the ball	

studies [1;35;76;77]. These studies quantified tackling ability by awarding a point for a technical criterion achieved. The technical criteria included (i) accelerating into the contact zone, (ii) contacting the target in the center of gravity, (iii) contacting the target with the opposite shoulder to leading leg, (iv) body position square/aligned, (v) arms wrapping around the target on contact, (vi) leg drive on contact (vii) watching the target onto the shoulder, and (viii) center of gravity forward of base support [1;35;76;77]. These studies did not however measure the outcome of the tackle (i.e. whether the tackler or ball-carrier won the tackle). This indicates the practical problems associated with defining tackling technique, not only among coaches and players but also among sport scientists.

1.6.3 Risk Reduction and Performance Efficacy for Tackler

Often, tacklers sacrifice momentum by diving into a front-on tackle. It is possible that this technique has evolved after rugby players have tried to mimic the American football spear tackle. Furthermore, this habit can be acquired after training inappropriately with a tackle bag. Players are taught from a young age to dive into a tackle bag rather than driving into the bag using their legs [79]. As mentioned earlier, the magnitude of momentum may be a determinant of injury [5;38;57]. Coaches need to make players aware that to lower the risk of injury and execute an effective tackle, players should leg drive into the tackle and keep their feet on the ground as long as possible.

Furthermore, coaches should not only focus on the front-on tackle during training but should also practice tackles from behind, from the side and situational tackles. A classic front-on tackle described in textbooks and coaching manuals is one where the player uses the shoulder and drives into the tackle using the legs [4;63;64;68-71]. The nature of the game requires players to assess the situation and act accordingly, usually spontaneously. Information that players need to get and then interpret before making a tackle are the speed and size of the ball-carrier, the direction the ball-carrier is running to, playing position of the ball-carrier, position on field, position relative to ruck/maul/scrum/lineout and

the tackler's own ability among other things. Nonetheless, the classic front-on tackle with its explicit set of rules (Table 1.2) should form the basic principles of tackling and coaches should train these elementary instructions until these rules become implicit and automated. Once the player grasps these basic principles, the player will most likely be able to execute a safe and effective tackle despite not applying all the rules. Furthermore, once the coach is satisfied with the player's basic tackling skills the coach can start introducing other variables to training the tackle. Communication between coach and player needs to be clear and direct to provide thorough instruction, demonstration, guidance, and feedback. In order to do this effectively, coaches need to equip themselves with sound knowledge of tackle technique during contact [80] as rugby union players were shown to be more confident and believed more in their ability (self-efficacy) to execute a skill when they perceived their coaches to have thorough knowledge of technique and implementing this knowledge [81].

1.6.4 Ball-Carrier Techniques

Another fundamental aspect of rugby is being able to run with the ball in hand and subsequently making contact with the opposing players and the ground without losing control of the ball. The ball-carrier has to make a decision within seconds based on the prevailing circumstances. The primary role of the ball-carrier should be to gain territory by means of avoiding contact with players from the opposing team. However, if contact is inevitable the ball-carrier should try to reduce the impact of the tackler or tacklers. Following contact the ball-carrier should make the ball available for his/her teammates in order to continue play [4].

1.6.5 Current Techniques for the Ball-Carrier

Ball-carrier techniques have been described by the The New Zealand RugbySmart, Australia's SmartRugby, SA Rugby Coaches Logbook, and New Zealand LeagueSmart (Table 1.3). In contrast to the lack of information in the scientific literature on effective techniques for the tackler, effective ball-carrying techniques have been investigated ranging from the effects of ball-carrying technique on sprint speed [82;83], to factors associated with success in contact and effective ball-carrying characteristics [84-89], to differences in playing styles of the northern and southern hemisphere [90].

1.6.6 Risk Reduction and Performance Efficacy for Ball-Carrier

When attempting to avoid contact and advance beyond the advantage-line the prescribed pattern of running with the ball is at an oblique and angular direction towards the defensive line, with the execution of an evasive manoeuvre such as side stepping one or two body lengths before the defender [85;87]. Running with the ball in both hands [82;83] allows the ball-carrier to pass the ball to the left and right whereas carrying the ball in one-arm allows for a player to 'hand-off' or 'fend' the tackler but forfeits the opportunity to accurately pass the ball to a teammate [82]. However, sprinting speed is significantly compromised when running with the ball in both hands [82]. Running with the ball in both hands and running at an oblique and angular direction towards the defensive line increases the number of decisions the tackler has to make [82;83]. Subsequently the tackler's reaction time is slower and the likelihood of gaining territory increases [85;87]. When making contact is inevitable, there are factors that need to be considered for the ball-carrier to be dominant and successful. Analysis of ball-carries in the 2006 Super 14 competiton has showed that ball-carriers executing a fend (the use of the hand/arm to push defenders away) upon contact resulted in more tackle breaks and created more opportunities to offload the ball in contact [88;89]. If the ball-carrier is unable to fend the tackler, the aim of the ball-carrier should be to protect himself/herself and make the ball available to his/her team-mates [4]. As mentioned

Table 1.3 Current Coaching Techniques described when taking the ball into contact [4;63;64;68;73]

	NZRU RugbySmart 2007/2008	ARU SmartRugby 2008	SA Rugby BokSmart	NZ LeagueSmart "The Hit-Up"
1.	Focus on contact zone	Hold ball in two hands, fingers spread	(Pre-contact) Do not look for unnecessary contact	Look for space (Prior to contact)
2.	Chin off chest	Keep hips square	Run evasive lines	Correct ball carry
3.	Eyes open	Lower centre of gravity, leaning forward and broadening the base of feet (this assists stability)	Look your defenders in the eye to engage them	Run between defenders into gaps
4.	Ball in two hands	Hug ball into chest and squeeze hard on the ball with both hands when going to the ground	Identify the defender's weak shoulder	Footwork: In and out, out and in, or straight between defenders
5.	Low body position	Make contact with 'hard parts' of the body such as hips and then shoulders in a rolling motion	Look for the defender's feet crossing over	Protect the ball in trailing arm (Point of contact)
6.	Body before ball	On NO account put out an arm to break the fall	See if the defender plants their feet	Lower body position
7.	Small steps on approach	Exercise options immediately	Look for exposed or out of shape defensive lines	Angle body to contact with your lead shoulder
8.	Wide 'power' step into contact		Exploit available options	Drive with legs into contact
9.	Plant front foot close to defender's feet		(In contact) Carry the ball in two hands	Options after Contact:
10.	Contact side on with hard parts of the body: e.g. shoulder, hips		Keep your face up and eyes open	a) Drive forward and downward to get onto hands and knees for a quick play the ball
11.	Maintain low stable base, chin off chest, eyes open		Take small steps on approach	b) Turn and spin around backward to offload or get free of the tackle
12.	Transfer ball at appropriate time		Maintain a low body position	
13.			Focus on the pint of contact	
14.			Take a wide power step into contact	c) Turn and twist forwards to offload through the defensive line
157.			Present the hard parts of the body to the tackler	
16.			Protect the ball	
17.			Drive through the tackle with the legs	
18.			Present and transfer the ball when appropriate	

earlier, vertex impacts of the head with the opposing player or the ground and hyperflexion of the neck during contact are the major causes of cervical spine and spinal cord injuries [2;59;60]. These type of injuries can be reduced by teaching players to enter contact with their heads up and eyes open and to focus on where they want to make contact with the tackler [2;60]. A low body position should also be adopted by the ball-carrier when entering contact [86]. A low body position lowers the centre of gravity and widens the base of support [86]. These factors lead to the overall stability of the player [74] and result in better ball retention compared to a medium or high body position [84;86]. This may be explained by the protection of the ball by the body when assuming the low body position [86]. Once contact is made with the tackler, the ball-carrier turning towards the supporting players has proved to be successful in retaining the ball [84;86]. If the ball carrier is unable to pass the ball to a supporting player, the next option is to go to ground. Lack of attention in the techniques for going to ground after contact has lead to serious injury [2;59;60;91]. Upton et al. (1996) showed that high school rugby players in the Western Cape only spent a total 16 minutes practising falling techniques prior to the first full-contact match of the season [91]. This highlighted the point that coaches do not focus sufficiently on the recovery phase of the movement (mentioned earlier). This study was conducted 13 years ago, and the game has evolved noticeably since then. However, not much is known about the current state of training methods.

1.7 Injury prevention and Injury Management in the Tackle

In terms of injury prevention and injury management in the tackle, the principles of the Haddon Matrix have been applied. The Haddon Matrix was developed in the 1980's to systematically reduce the risk and prevent motor vehicle accidents [92-98]. Applying basic principles of public health the Haddon Matrix consists of a chart of three rows describing the time of the event (i.e. pre event, event, post event) and four columns describing factors that may contribute to the event taking place [92-98]. From this design, each cell in the matrix can be used to identify strategies for reducing the risk with regards to the time

(pre, event, post) and contributing factors (host, agent, physical environment and social environment) [92-98]. This matrix has been expanded with the addition of more dimensions [92] which incorporates criteria such effectiveness, cost, freedom, equity, stigmatization, preferences of the affected community or individuals and feasibility [92]. The Haddon Matrix has also been applied to sport [95-98]. Based on our current understanding of the tackle, we propose a Haddon Matrix be applied to the tackle for the ball-carrier and tackler (Table 1.4). Additional dimensions may also cover aspects such implementation, effectiveness, attitudes and behaviours, cost, management, policies and other criteria that can be identified [92;95-106]. This design can be modified as the sports evolve because of changes to the rules.

Table 1.4 The Haddon Matrix applied to the tackle event

	Host (Tackler or Ball-Carrier)	**Agent (Opponent)**	**Physical Environment (field)**	**Social Environment (norms, rules)**
Pre-event	Physical Conditioning, Safe Technique, Knowledge, Preparation/Training.	Opponents level of play, emphasise safe play, Tactics/Attitude	Maintain and prepare fields for play	Promote safe play, improve rules for safety of players, punishment for foul play
Event	Improve technique, aware of their head and body parts during the tackle	Avoid contact, head placement when going into contact	Have medical support on each side-line, close proximity, first aid kits available	Less emphasis on 'win at all costs', emphasis on training the tackle (technique)
Post -event	Post-Injury Care, rehabilitation	On-field assistance, assess situation, call for help	Transportation for injured, referee's stopping the game	Professional help, family and social support, Funds

Summary of Literature Review

The risk of injury during the tackle will remain in both rugby union and rugby league. Although it may not seem possible to prevent all tackle injuries, despite all the recommendations [107], attempts to reduce the risk at all levels of play, is essential for the promotion of these sports [99;107] . Using a model or framework when attempting to reduce the risk of injury and improve performance serves as a logical starting point. Models help to conceptualise the different factors that may contribute to a particular phenomenon or situation, such as the tackle, their possible interrelationships and causal sequences [108]. Tackle epidemiology studies have provided an understanding of how injury occurs during the tackle. Information from these studies however only explains the mechanism of injury, usually from a biomechanical perspective [109-111] and the factors associated with the injury. Not much is known about the risk factors that are more distant to the outcome. For example, risk factors to consider in future studies are the factors intrinsic to the player such as body composition, knowledge of technique, physical and mental capacities, age, genetics, etc [106;109-112]. Also extrinsic factors such as coaching, attitude and behaviour, equipment, environment, etc. also need to be considered [106;109-112]. A deeper insight into these risk factors and their interaction will allow us to comprehensively identify strategies for injury prevention. Furthermore, to develop effective tackle training strategies (i.e. technical skills training, physical conditioning, training drills, and equipment) that will reproduce a successful outcome and reduce the risk of injury for both the ball-carrier and tackler, studying the tackle in real match situations is warranted.

Conclusion

The tackle is common to rugby union and rugby league. Although definitions of the tackle may differ among the two sports, the fundamental purpose of the tackle in rugby union and rugby league remains

the same; i.e. to prevent the attacking team from gaining territory and possession of the ball to score points. The tackle event in rugby union and rugby league had the highest propensity to cause injury compared to other aspects of the game with both ball-carrier and tackler being at risk. Therefore, coaches need to educate themselves with sound knowledge of technique during contact in order to reduce the risk of injury[59;63-67;80]. The next step in reducing tackle injuries, without compromising the efficacy of the event, is to identify strategies that can be coached during training and implemented during matches. Furthermore, the traditional training drills and practices used for coaching the tackle, which are based on anecdotal evidence, should be thoroughly investigated.

Objectives of this Thesis

Given the importance of tackling in rugby union, the nature and frequency of the tackle during matches, and high risk of injury during the tackle, the motivation and long term outcome of this thesis is to identify and develop coaching and training strategies for skill acquisition, performance and injury prevention during the tackle contest in rugby union. However, before such coaching and training strategies can be established, a better understanding of our current coaching and training methods was needed. Thereafter, a comprehensive insight on the complexities of the tackle in real match situations was necessary before any prescriptive tackle training guidelines could be formulated.

The next phase of the thesis consists of 5 studies. Each study is designed to answer a specific question(s), which contributes to fulfilling the objectives outlined above. The specific questions are described below (Chapters 2 – 6). The final section of the thesis (Chapter 7) summarizes the answers to each question and synthesises the findings of all the studies. Finally (p 155), the practical implications and recommendations for future research are discussed.

Specific Questions and Objectives

Chapter 2

- What are the current attitudes and behaviours of junior rugby union players in training and match play with regards to safety and performance in the tackle?

Chapter 3

- What are the ball-carrier and tackler velocities and acceleration values before contact in real match situations at different levels of play?

Chapter 4

- What are the momentum and kinetic energy values before contact in the tackle during real match situations for the ball-carrier and tackler in 3 different levels of competition?
- What is the magnitude of energy transfer during tackle situations, and describe this magnitude to in relation to the distance from set piece/breakdown and position?
- What is the relationship between the physical components before contact in the tackle and level of play, type of tackle, playing position, distance relative to set piece and the outcome of the tackle?

Chapter 5

- What are tackler characteristics that may increase the likelihood of a successful tackle outcome in rugby union?

Chapter 6

- What are the defensive strategies in rugby union that may increase likelihood of a successful phase outcome?

Chapter 2 Attitude and behaviour of junior rugby union players towards tackling during training and match play

S Hendricks, E Jordaan and MI Lambert. Attitude and behaviour of junior rugby union players towards tackling during training and match play. *Safety Science*, 2012, 50, 266-284.

2.1 Introduction

Rugby union is a sport that exposes players to frequent high impact collisions [1]. The main objective of the game is to gain territory by advancing the ball down the field towards the opposition try-line by carrying or kicking the ball. Points can be gained by placing the ball over the oppositions' try-line or kicking the ball between the goal posts. An effective way of preventing an attacking team from gaining territory and scoring points is by tackling the player with the ball in an attempt to stop forward momentum and gain possession of the ball. According to the International rugby Board (IRB) a tackle occurs *"when a ball-carrier (a player carrying the ball) is held by one or more opponents and brought to ground"* [3]. The opposition player that holds or goes to ground with the ball-carrier is referred to as the *tackler* [3]. A recent study by Quarrie and Hopkins [5] used a slightly different definition for the tackle; *"when the ball-carrier was contacted (hit and/or held) by an opponent without reference to whether the ball-carrier went to ground"* [5].

Epidemiological studies on rugby injuries show that players are at the highest risk of injury during the tackle compared to any other facet of play [19;20;34;35;35-40] whether they be the ball-carrier [44] or tackler [37] . The risk injury in the tackle occurs at all levels of play, from amateur [47;48;55] to professional [34;41-46] and juniors [55;113-117] to seniors [34;41-48;55]. Injury mechanisms and risk factors for the tackle for both ball-carrier and tackler have been identified from a biomechanical perspective [5;13;38;56;118]. Risk factors for both ball-carrier and tackler include speed of collision and high impact force, body regions contacted by the opponent and ground, and direction from which the tackle is entered [5;13;38;56;118].

Conceptual sport injury prevention models and frameworks teach sport scientists and sports clinicians to look beyond injury mechanisms and injury biomechanics as a means of understanding injury [106;109-

[112]. A multi-factorial approach, as described by Meeuwisse [109], suggests considering risk factors outside the obvious mechanism of injury. Such factors can be intrinsic or extrinsic risk factors that the player is predisposed to long before the actual injury event occurs, but increases the vulnerability of the player or athlete getting injured. Intrinsic risk factors include age, body composition, knowledge of technique, implementation of technique, physical and mental capacities, previous injury, attitude and genetics [106;109-112]. Extrinsic risk factors include coaching, training, behavior, equipment, and environment [106;109-112].

The attitude and behavior of players/athletes towards safety has been identified as risk factors for injury in sports [66;105;119-123]. Attitude refers to '*the knowledge and beliefs of a person concerning the specific consequences of a certain form of behavior'* [105;106]. Examples of behavior are a player's training habits, on-field actions, interactions with coaches, opponents(s), referees or teammates and use of equipment. Off the field examples of behavior which may affect performance are diet or sleep [102;103;105;106;110;111;124]. Determinants of behavior include social influences (social norms), self-efficacy (ability to perform the intended skill) and attitude [102;103;105;106;124] and intention [125]. The relationship between behavior and attitude is not unilateral as a behavior may modify the attitude of an individual [102;103;124].

To design effective sports injury prevention strategies, it is important we understand the attitudes and behaviours of players towards safety [123]. Presently, published studies on the attitudes and behaviours of players towards safety in sport are lacking [123]. This is even more so in rugby, with studies on the attitudes and behaviours specifically for tackle almost non-existent. Most studies that do report safety attitudes and behaviours, usually relate these risk factors to the use of protective equipment [102;105;119;121;122]. Nonetheless, there are a couple of studies in the literature that addresses the attitude, and to some extent the behaviour, of players in team sports. The first study by Finch et al. [123] described the safety attitudes and beliefs of junior Australian football players. The second study examined the

attitudes, levels of emotional empathy and levels of aggression of youth hockey players in body checking leagues and non-body checking leagues [120]. Both studies made use of questionnaires to determine their outcomes. The main findings of the first study was that despite more than 90% of players believing it was not safe to play with an injury, 58% were willing to take the risk. This willingness to play with an injury increased to 77% if players thought their chances of being selected for a senior elite team would be affected [123]. In the second study, Emery et al. found players in the body checking league were more in favour of body checking than players in the non-body checking league. Not surprisingly, this attitude was also associated with increased aggression [120].

National injury prevention programs, such as the RugbySmart (New Zealand Rugby Union) [63;64], SmartRugby (Australia Rugby Union) [4] and BokSmart (South Africa Rugby Union) [68] aim to provide players, coaches and support staff at all levels with information on injury prevention. This ranges from under-6 to senior adult level [65;66]. These injury prevention programmes promote the safety first attitude [59;63-67;126]. Adopting this safety first attitude will in turn change the behaviour of the players [59;63-67;126].To make the concept more attractive to coaches and players, the programs advertise that 'safe technique is effective technique' [63;64;68] in an attempt to promote the concept that the safety first attitude will not only prevent injury, but also improve performance. Whilst it is logical that improving safety and performance should be the priority of any player or coach during training, we hypothesized that players and coaches place too much emphasis on performance and not enough on safety during training for the tackle. Therefore, the purpose of this study was to assess the attitude and behaviour of young, competitive rugby players during training and match play with regards to safety and performance in the tackle. Although the attitudes and behaviours of players were assessed only, we considered this an indirect indication of the coaches' perspective on safety and performance in the tackle.

2.2 Methods

2.2.1 Questionnaire Developmental Process

The developmental process of the questionnaire began with a list of possible general and specific tackle training open-ended questions we thought would be relevant to our main research question. Some questions were guided by previous research done on the tackle [38;57;77;91;102;118;120;126]. The list of questions was then presented to a panel of coaches; sport scientists and rugby administrators to further discuss the efficacy, reasoning, and validity of the questions. This process of refinement was conducted 2-3 times before a list of questions were finalised. The next step in the developmental process was to design the questionnaire itself with regards to structure, order, flow, and answerability. To effectively achieve the best design for our questionnaire, guidelines for designing surveys and social science research methods were used [127-131].

2.2.2 Question and item format and scale definitions

For the purpose of our study, We decided closed-ended questions would be more appropriate. Closed-ended questions provided the respondents with a pre-specified set of answers (items) and response categories [127;128]. Each question consisted of i) the question ii) the items – list of possible answers relating to the specific question being posed iii) response categories – a 5-point ordinal Likert Scale represented by a numerical value, where players had to rate the importance, frequency, and quantity of each item in the question (Figure 2.1). In some questions a 'Not Familiar' option was provided to prevent players from giving arbitrary answers if they were unsure [128]. For assessing players' attitude, players had to rate the importance of an item on the following scale: (1) Not at all important, (2) Not too important, (3) Undecided, (4) Somewhat important, (5) Very important [128]. To measure frequency of training and match behaviour the following descriptors were used: (1) Never, (2) Rarely, (3) Sometimes, (4) Frequently, (5) Always [128]. Quantity of training or match behaviour was determined on

the scale: (1) Not at all, (2) A little, (3) A fair amount, (4) Much, (5) Very much [128]. Even though all questions were closed-questions, a 'further comment' space was provided to cater for players who felt the need to add more information.

2.2.3 Questions Domains and Layout

The questionnaire consisted of four attitudinal questions (3 training and 1 match). In two of the attitudinal questions (Training Questions 2 and 3, Appendix A) players had to rate the importance of only two defined items pertinent to our research question i.e. injury prevention and improving performance. In the third training question (Training Question 6), players were asked to rate the importance of coaching methods. For this question, two separate items lists with the same items were provided for injury prevention and improving performance. For the match question, the list of attitudes and behaviours were constructed in such a manner where players were not specifically required to distinguish between injury prevention and performance. Instead, players had to rate the importance of items we felt may be a reflection of players' attitude towards injury prevention and performance. Injury prevention was defined as *"lowering the risk of getting injured during the tackle"* and improved tackle performance was defined as *"preventing the ball-carrier from gaining territory and the ball-carriers team from retaining the ball"*. For the behavioural questions, a comprehensive list of items was provided except for one question (Question 9). This training behaviour question asked that players rate the amount of time spent emphasising proper technique to prevent injuries and the amount of time spent emphasising proper technique to improve tackle performance. Keeping in mind our respondents were young, competitive rugby players, wording of all questions and items were as clear and unambiguous as possible and definitions where provided were necessary. Questions were divided into training questions and match questions. This was indicated as section A (Training) and section B (Match) in the questionnaire.

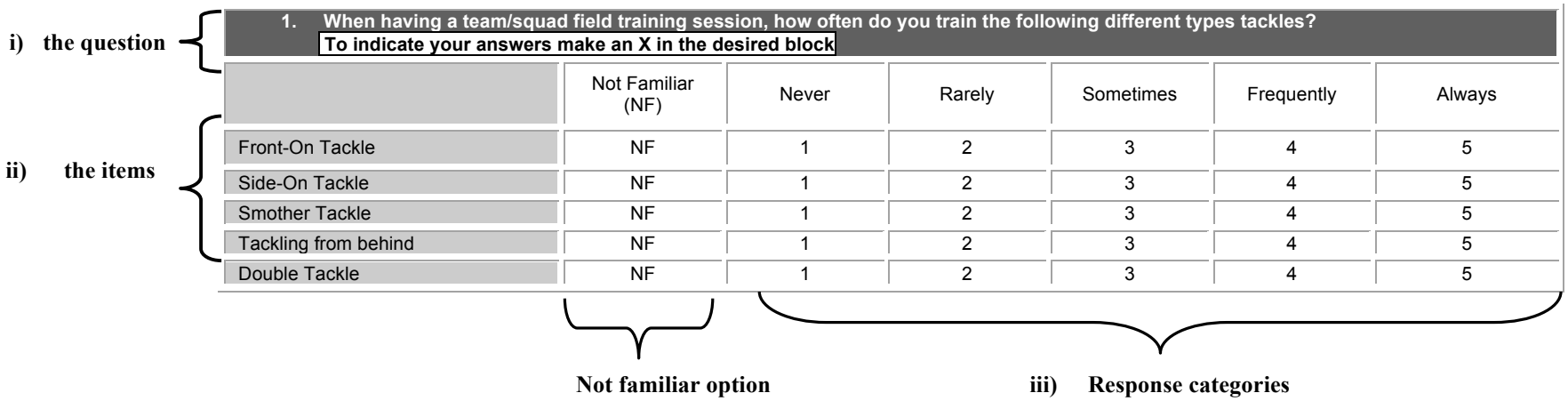

Figure 2.1 Question, item, and response category format. Each question consisted of i) the question ii) the items – list of possible answers relating to the specific question being posed iii) response categories – a 5-point ordinal Likert Scale represented by a numerical value, where players had to rate the importance, frequency, and quantity of each item in the question. A 'Not Familiar' option was also provided to prevent players from giving arbitrary answers if they were unsure

2.2.4 Final Questionnaire

The questionnaire consisted of 12 Training Questions with a total of 109 items and 4 Match Questions with a total of 52 items. Questions were in separate boxes from each other, and each question box was colour coded for players to differentiate between question, item, and response category on the scale (Figure 2.2). Depending on the amount of items on the list, no more than 3 questions were allowed per page. In addition, the cover page was attached to the questionnaire and provided space for players' personal information and playing history. This included school, playing position, highest level played and playing experience. The revised questionnaire was once again presented to the panel of coaches, sport scientists, and rugby administrators for final comments. The questionnaire was pre-tested with 24 University of Cape Town Varsity Cup players to expose any unclear or incomprehensible questions. Minor typographical errors were identified and corrected.

2.2.5 Participants

The questionnaire was administered at the Cape School's Week Rugby Festival that took place from 27 June 2009 to 1 July 2009. The Cape School's Week Rugby Festival comprises of 10 traditionally rugby playing schools from the Western, Northern and Eastern Cape regions in South Africa. Only the under 19 A (1st team) sides of each school participated in the rugby festival. Nine out of the 10 schools participated in the project (164 questionnaires returned out of possible 220 questionnaires, representing 75% response-rate). Three teams filled out the questionnaire in exam-like conditions, 2 teams filled out the questionnaire after a team meeting in a room and the remaining 4 teams' coaches or managers were handed the questionnaires which they returned at a later stage. In the cases where we were present, players completed the questionnaire in approximately 10 – 15 minutes. Informed consent was obtained

from the coaches or managers of each team and informed assent was obtained from each player. The University of Cape Town Research Ethics Committee granted ethics approval for this study.

2.2.6 Data Analysis

For presentation purposes, data were divided into 3 sections, i) Attitude and behaviour towards injury prevention and improving performance; ii) Attitude and behaviour in training and match play; and iii) Factors that may influence tackle technique attitude and behaviour in training and match play.

i. Attitude and behaviour towards injury prevention and improving performance

In this section, the aim was to explicitly compare players' attitude and behaviour towards injury prevention and improving performance when training the tackle. In the questionnaire, training questions 2, 3 and 9 were designed for this. Question 2 and 3 assessed players' attitudes by asking players to rate how important proper technique and training the tackle is for injury prevention and improving performance. Question 9 required players to rate the amount of time spent emphasising proper technique to prevent injuries and the amount of time spent emphasising proper technique to improve tackle performance. Although these questions required the players to answer on a 5-point ordinal Likert scale, a decision was made to use parametric statistics since the means did not violate any assumptions of normality [132]. Mean ratings were calculated for each item i.e. injury prevention and improving performance by adding the representative numerical value of the response category (1 to 5) for each player and dividing it by the total number of players. Subsequently, mean injury prevention and improving performance ratings were compared with a paired t-test with a two-tailed p-value. The *a priori* alpha level of significance was set at $p<0.05$. For each item, mean ratings for attitude were termed 'attitudinal score (AS)' and mean ratings for behaviour were termed 'behavioural score (BS)'. An analysis of co-variance was also conducted for these three questions to verify that any differences

were not due to school, playing position, highest level played, playing experience or survey method. When an effect of school, playing position, highest level played, playing experience or survey method was found, an analysis of variance (ANOVA) was used (instead of a t-test) to compare injury prevention and improving performance with the co-variate(s) taken into account. A two-tailed p-value was used for the ANOVA, with the *a priori* alpha level of significance set at $p<0.05$. Accordingly, means were adjusted for the significant co-variates.

ii. Attitude and behaviour during training and match play and

iii. Factors that may influence tackle technique attitude and behaviour during training and match play

The purposes of these two sections were to obtain information on players' attitude and behavioural patterns and trends with regards to tackling in training and matches. Therefore, descriptive, rather than interpretive statistics were used. Data were expressed as the mean 95% confidence interval (95% CI) or as percent of each value on the 5-point Likert. An exception was Question 1*(How often do you train per week (includes gym, running, field sessions) during the different periods in the last season?)*, which was expressed as mean ± standard deviation (SD). Mean ratings were calculated for each item by adding the representative numerical value of the response category (1 to 5) for each player and dividing it by the total number of players. Thereafter, the mean ratings were ranked from highest to lowest in terms of importance, frequency, or quantity. Percentage frequencies represented the number of players that responded to each category on the 5-point Likert Scale. In some cases the lower two categories percentages and upper two categories percentages were combined, with the neutral category remaining as is. Included in the display of the data are each question and all the items with wording as specified in the questionnaire.

2.3 Results

2.3.1 Player Demographics

Players' mean age was 17±0.8 years. Players' mean height was 179.3±9.0 cm, weight was 84.5±13 kg, and their mean playing experience was 8±3 years.

2.3.2 Attitude and behaviour towards injury prevention and improving performance

Players reported, on average, that it was more important (t-test *p=0.00001)* to learn proper technique for performance improvements (AS-Q2-proper technique for improving performance 4.63±0.65 on a scale 1= not at all important to 5 = very important) than reducing the risk of getting injured (AS-Q2-proper technique for injury prevention 4.20±1.12). In addition, players reported that it was more important (ANOVA *p=0.10*) to train the tackle to improve performance (AS-Q3-training tackling for improving performance 4.48 ±1.00) than preventing injuries (AS-Q3-training tackling for injury prevention 4.05 ±0.88). When training the tackle, players felt coaches spend more time (ANOVA p=0.30) emphasising proper technique to improve performance (BS-Q9 time spent on improving performance 3.68 ±1.02 on a scale 1 = not at all to 5 = very much) than emphasising proper technique to prevent injuries (BS-Q9 time spent on injury prevention 3.20 ±1.02). Note: the analysis of co-variance revealed an effect of survey method for Question 3 and Question 9, and an effect of schools for Question 9 only. Therefore, the means of Question 3 and Question 9 were adjusted for survey method and the mean for Question 9 was adjusted for schools.

2.3.3 Attitude and Behaviour in

2.3.3.1 Training

Players reported training (includes gym, running, field sessions) on average 4 to 5 days a week during the different periods (off-season, pre-season and in-season) of the season. In the off-season period, 58%

of players reported that tackle technique training occured ‘never + rarely’. During the pre-season, 32% indicated ‘never + rarely’. For the in-season, 24% of players marked ‘never + rarely’.During training, players perform the “front-on tackle” most frequently (3.45 on a scale 1= never to 5 = always, 95% CI 3.27-3.62), followed by the “side-on” (2.77, 95% CI 2.61-2.94) and “smother tackles” (2.54, 95%CI 2.35-2.72). “Double” (2.31, 95% CI 2.11-2.50) and “behind” (2.23, 95% CI 2.05-2.41) tackles were the least frequently performed tackles during training. During matches, players performed “front-on” (3.94 on a scale 1 = not at all to 5 = very much, 95% CI 3.78-4.09) tackles the most, followed by “side-on” (3.86, 95% CI 3.73-4.00) and “smother tackles” (3.23, 95% CI 3.06-3.41). “Behind” (3.09, 95% CI 2.92-3.26) and “double” (2.76, 95% CI 2.56-2.96) tackles were the least executed tackles during matches.

Table 2.1 ranks the mean ratings of importance for different drills and equipment used to train the tackle. Mean ratings are ranked for a) Injury Prevention and b) Improving Performance. The ranked mean ratings for Injury Prevention and Improving Performance were then juxtaposed to the ranked mean ratings of frequency for the different drills and equipment used to train the tackle in the last season.

Table 2.2 ranks the mean ratings of frequency for emphasis placed on the different pointers given before contact, during contact and after contact. Before contact, players indicated most of the emphasis is placed on “body position before contact”, “aiming for the waist” and “lowering their centre of gravity”.

Table 2.1 Ranks the mean ratings of importance for drills and equipment used to train the tackle for a) injury prevention and b) improving performance, compared to the ranked mean ratings of frequency for drills and equipment used in the last season. Data reported as mean and 95% confidence intervals.

Coaches use various drills to train tackling and may spend more time on different aspects of the tackle. Please rate what method of coaching is important to you for:

What method have you been coached in the last season?

a) Injury Prevention

b) Improving Performance

Rank	Injury Prevention Methods (Importance)	Mean ratings	95% CI	Improving Performance Methods (Importance)	Mean ratings	95% CI	Method Coached in the Last Season (Frequency)	Mean ratings	95%CI
1	Tackling Drill combined with fitness conditioning	4.26	4.12-4.39	Tackling Drill combined with fitness conditioning	4.25	4.11-4.39	Tackling Drill combined with fitness conditioning	4.03	3.87-4.19
2	Tackling Drill combined with ball skill exercise	4.16	4.02-4.30	Live tackling in a 1 player vs. 1 player grid	4.24	4.08-4.41	Using shield	3.85	3.71-3.99
3	Tackling Drill combined with reaction exercise	3.96	3.80-4.12	Tackling Drill combined with ball skill exercise	4.17	4.02-4.32	Using tackling bag	3.81	3.66-3.96
4	Tackling Drill combined with a vision exercise	3.88	3.72-4.04	Tackling Drill combined with reaction exercise	4.12	3.97-4.27	Tackling Drill combined with ball skill exercise	3.74	3.58-3.90
5	Live tackling in a 1 player vs. 1 player grid	3.86	3.67-4.04	Tackling Drill combined with a vision exercise	4.01	3.85-4.16	Given verbal instruction	3.73	3.56-3.89
6	A full contact practice match	3.75	3.55-3.95	A full contact practice match	3.93	3.74-4.12	Tackling Drill combined with reaction exercise	3.60	3.42-3.78
7	Demonstration	3.73	3.53-3.92	Demonstration	3.80	3.62-3.99	A full contact practice match	3.57	3.40-3.75
8	Using a body armour	3.61	3.44-3.78	Using a body armour	3.76	3.59-3.92	Demonstration	3.56	3.39-3.73
9	Using shield	3.61	3.45-3.76	Given verbal instruction	3.74	3.57-3.92	Tackling Drill combined with a vision exercise	3.52	3.34-3.71
10	Given verbal instruction	3.55	3.37-3.73	Using shield	3.72	3.55-3.88	Live tackling in a 1 player vs. 1 player grid	3.38	3.20-3.56
11	Using tackling bag	3.51	3.33-3.68	Using tackling bag	3.70	3.53-3.87	Using a body armour	3.38	3.19-3.57

1-not at all important; 2-Not too important; 3-undecided; 4-somewhat important; 5-very important

1-never; 2-rarely; 3-sometimes; 4-frequently; 5-always

Table 2.2 Ranks the mean ratings of frequency for emphasis placed on the different pointers given before contact, during contact and after contact. Data reported as mean and 95% confidence intervals.

Rank	Emphasis placed on pointers before contact (frequency)	Mean ratings	95%CI	Emphasis placed on pointers for contact (frequency)	Mean ratings	95%CI	Emphasis placed on pointers after contact (frequency)	Mean ratings	95%CI
1	Body position before the tackle	3.77	3.61-3.93	Using the legs to drive the tackle	3.91	3.74-4.07	Staying on feet	3.82	3.67-3.98
2	Aim for the waist	3.72	3.55-3.88	Accelerate into contact with the same shoulder as the front leg	3.69	3.52-3.85	Following through with the tackle	3.70	3.55-3.85
3	Lowering your centre of gravity	3.64	3.47-3.81	Direction from which to enter contact in the tackle	3.67	3.50-3.83	Prepare body position for going to ground after the tackle	3.54	3.36-3.73
4	Aim for the legs	3.59	3.42-3.77	Staying on feet	3.66	3.48-3.83	Use your bodyweight to bring the opponent down	3.47	3.30-3.65
5	Position of the arms	3.58	3.43-3.74	Head placement	3.62	3.45-3.78	Lift off and dive through the tackle	3.45	3.26-3.65
6	Footwork before the tackle	3.58	3.40-3.76	Position of your neck and spine	3.59	3.41-3.77			
7	Where your eyes should focus	3.52	3.34-3.69	Arm placement	3.49	3.32-3.66			
8	Approach	3.46	3.29-3.64	Eyes being open	3.48	3.30-3.67			
9	Aim for the ball only	3.19	3.01-3.37	Using your own bodyweight to bring the opposition player down	3.48	3.29-3.66			
10	Aim for the upper body	3.03	2.83-3.22	Accelerate into contact with the opposite shoulder to the front leg	3.45	3.27-3.63			
11	No target – just bring the opposition player down	2.86	2.64-3.07	Shoulder and chest placement	3.43	3.26-3.61			
12				Importance of safety	3.38	3.20-3.57			
13				Diving into the tackle	3.27	3.07-3.47			
14				Lifting the opposition player	3.20	3.00-3.40			

1-never; 2-rarely; 3-sometimes; 4-frequently; 5-always

Pointers that were emphasised the least before contact were “aiming for the ball only”, “aiming for the upper body only” and having “no target-just bring the opposition player down”. During contact, “using the legs to drive the tackle”, “accelerating into contact with the same shoulder as the front leg” and the “direction from which to enter contact” were emphasised the most. Least emphasis was placed on the “importance of safety”, “diving into the tackle” and “lifting the opposition player”. “Accelerating into contact with the same shoulder as the front leg” was emphasised more than “accelerating into contact with the opposite shoulder to the front leg”. After contact, “staying on your feet”, “following through with the tackle” and “preparing your body position for going to ground after the tackle” were emphasised the most. Pointers least emphasised after contact were “using your bodyweight to bring the opponent down”, and “lifting off and diving through the tackle”.

When training 1 vs. 1 live tackling, coaches commonly use a small grid (less than 10x10m) or a larger grid (more than 10x10m) to simulate match conditions. Also, some coaches may prefer to control the conditions in the grid by letting the tackler know what the ball-carrier is going to do or some coaches may prefer to have a less controllable grid where the tackler does not know what the ball-carrier is going to do. For these different grids, 21% of players rated ‘never + rarely’ for small-grids plus controlled conditions; 28% of players rated ‘never + rarely’ for small-grids plus less controlled conditions; 32% of players rated ‘never + rarely’ for large grid plus controlled conditions; and 35% rated ‘never + rarely’ for large grids plus less controlled conditions.

2.3.3.2 Match Play

Players reported that “bringing down the ball-carrier at all costs”, “preventing the ball-carrier from gaining position”, “preventing the ball-carriers team from retaining the ball” and putting in a “big hit” were most important to them when executing a tackle during a match (Table 2.3). These attitudes were

more important than “doing what was practiced”. Of least importance when making a tackle during a match were “own safety”, “going for the ball only”, “safety of both yourself and the ball-carrier” and “safety of the ball-carrier only”. In addition, players indicated factors that may have an effect on their attitudes and behaviour when tackling during a match (Figure 2.2). “Defending on their own try-line” and “defending within their own 22-metre line” frequently and always change their attitude and behaviour when tackling in a match. Also, playing a “final” or “local derby” was reported to frequently and always have an effect on their tackling attitude and behaviour

Table 2.3 Ranks the mean ratings of importance for various tackle attitudes and behaviours during a match. Data reported as mean and ±95% confidence intervals.

What is important to you when making a tackle during a match?

Rank	Tackle attitude and behaviour during a match (Importance)	Mean ratings	95% CI
1	Bringing down the ball-carrier at all costs	4.50	4.37-4.62
2	Preventing the ball-carrier from gaining position	4.41	4.29-4.53
3	Preventing the ball-carriers team from retaining the ball	4.35	4.21-4.49
4	Putting in a ‘Big Hit’	4.18	4.05-4.33
5	Proper technique	4.09	3.93-4.25
6	Staying on your feet	3.99	3.83-4.15
7	Doing what you practiced	3.90	3.74-4.06
8	Your own safety (lowering the risk of getting injured)	3.68	3.49-3.86
9	Going for the ball only	3.67	3.50-3.85
10	Safety of both you and the ball-carrier	3.39	3.20-3.57
11	Safety of the ball-carrier (lowering the risk of injuring the ball-carrier)	2.96	2.73-3.18

2.3.4 Factors that may influence tackle technique attitude and behaviour in training and match play

Method of coaching during practice such as “one-one demonstrations” or “demonstrations to the entire team” was reported to be influential when learning tackle technique (Figure 2.3). Additionally during practice, players felt that “identifying a problem in their own tackle technique” or the “teams tackle technique”, and consequently fixing the problem, improved their ability to execute an effective and safe tackle. With regards to the influence of media and books, “televised rugby matches” and “televised rugby shows” influences players’ tackle technique more than “rugby training videos” and “training books”. Other factors of note include “experience”, where 64% of players pointed out that their “experience” had a considerable influence on their tackle technique. Figure 2.4 shows players learn more about tackling technique as they get older. At the under 10 level, 50% of players reported that no learning, or a little learning occurred. At the same level, 22% of players indicated ‘a fair amount’ of learning occurs and the remaining 28% marked ‘much + very much’. This percentage ratio for the different response categories evolves with more players learning more as they get older: U10 25%, U13 40%, U15 55% and by U19 70% learning 'much + very much' of their tackling technique. Factors that players indicated will improve their tackling performance and lower their risk of injury the most (Table 2.4) were “personal fitness conditioning”, “determination” and “motivation”. “Training proper technique regularly” and “knowledge of proper technique” was ranked 12th and 13th respectively out of 17 factors. Factors such as “weather conditions” and “the crowd” were considered the least helpful in improving tackle ability.

Building on from the previous question, does your attitude and behaviour towards tackling during a match change according to the following factors?

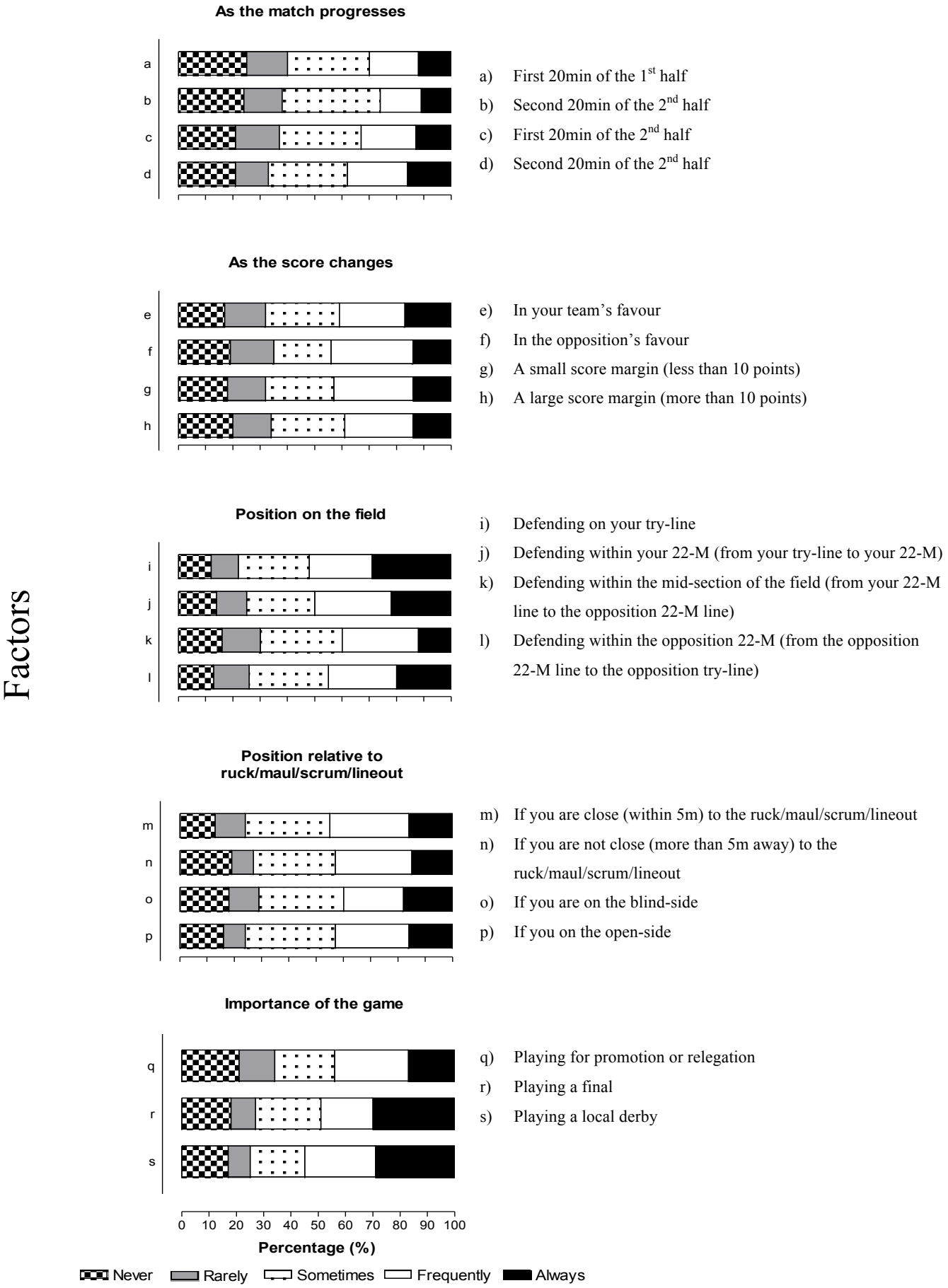

Figure 2.2 Reported factors that may have an effect on players tackling attitudes and behaviours during a match. Data reported as percentages (%)

How much influence have the following factors had on your tackle technique to prevent you from injuries *(i.e. lowering the risk of getting injured during the tackle)* and improve your tackling performance *(i.e. preventing the ball-carrier from gaining territory and the ball-carriers team from retaining the ball)* in the last season?

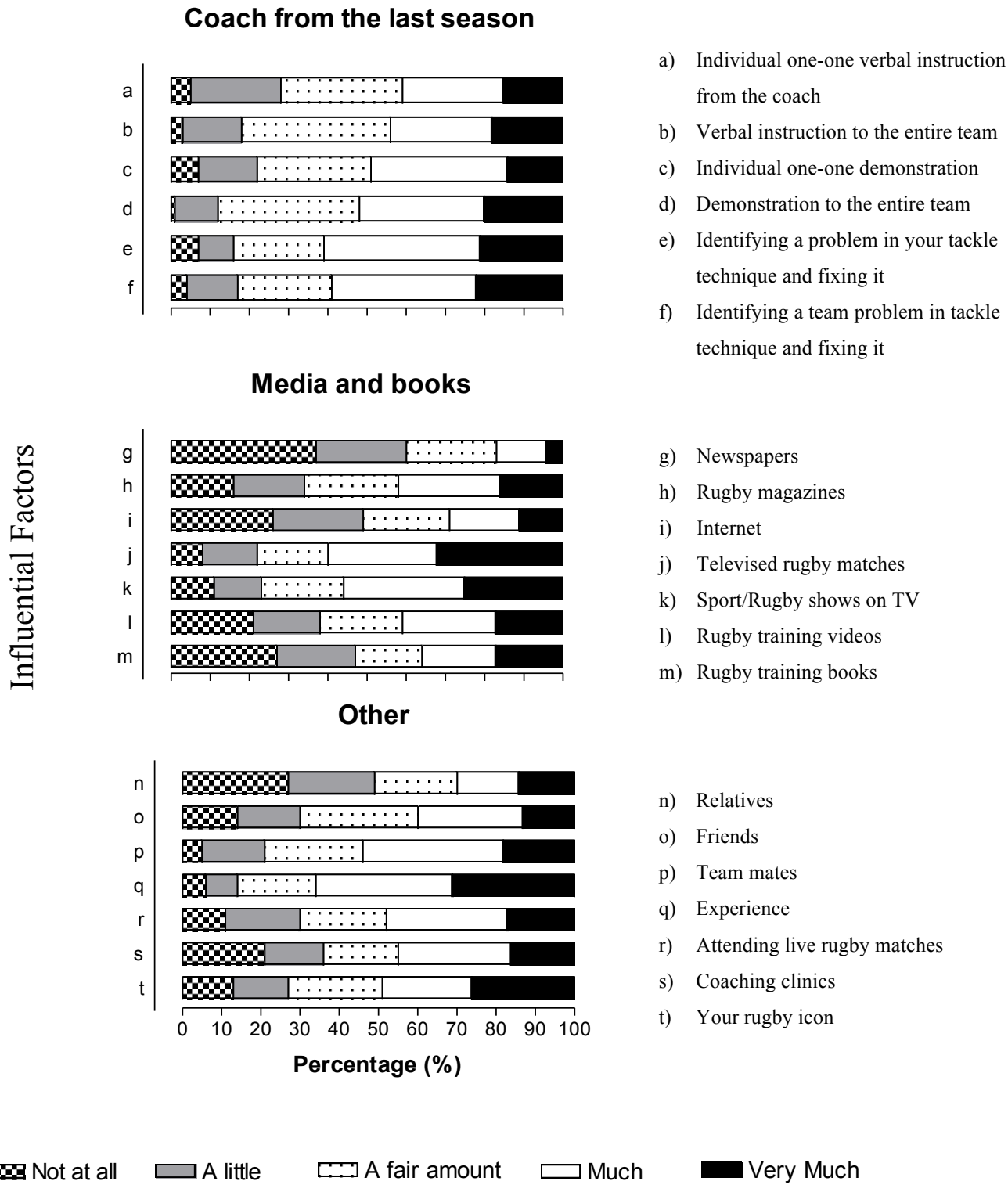

Figure 2.3 Reported factors that may influence players tackle technique. Data reported as percentages (%)

How much did you learn about tackling technique in the different age categories?

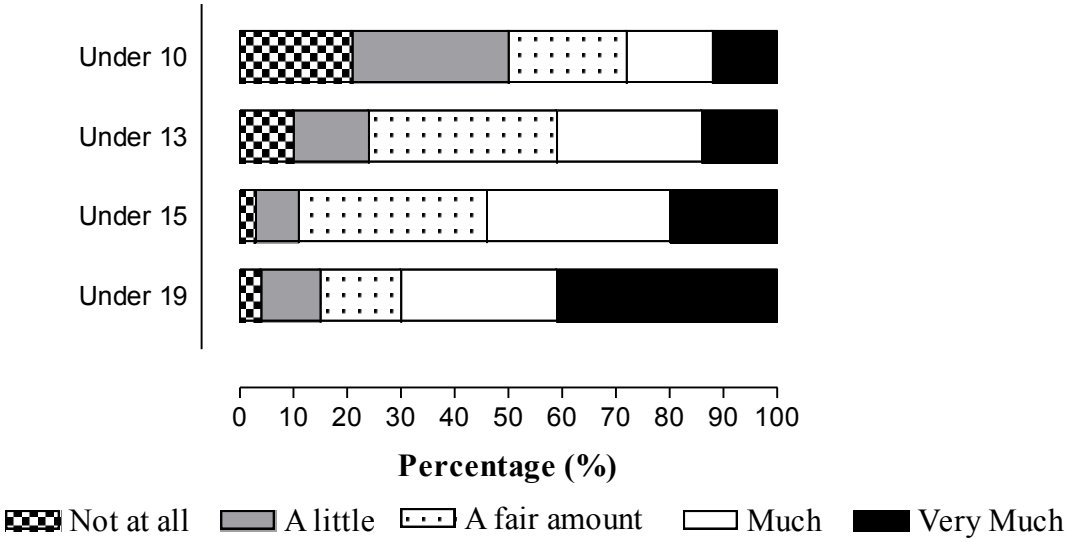

Figure 2.4 Reported age categories players learnt the most on tackling technique.
Data reported as percentages (%)

Table 2.4 Ranks factors players felt will improve their tackling performance and lower their risk of injury during the tackle according to the mean ratings of quantity. Data reported as mean and 95% confidence intervals.

What do you think may help you improve your tackle performance (preventing the ball-carrier from gaining territory and the ball-carriers team from retaining the ball) and lowering your risk of injury in a tackle during a rugby match?

Rank	Factors players felt will improve their tackle performance and lower their risk of injury during the tackle (Quantity)	Mean ratings	95% CI
1	Personal fitness conditioning (strength, speed, stamina)	4.38	4.25-4.51
2	Determination	4.29	4.16-4.42
3	Motivation	4.28	4.15-4.41
4	Defensive structures	4.28	4.15-4.41
5	Confidence	4.23	4.09-4.37
6	Stretching prior to the game	4.21	4.07-4.35
7	Attitude	4.16	4.01-4.30
8	Vision	4.15	4.03-4.28
9	Reaction time	4.14	4.01-4.28
10	Match day preparations	4.10	3.95-4.25
11	Rest prior to the game	4.08	3.93-4.22
12	Training proper technique regularly	4.08	3.92-4.23
13	Knowledge of proper technique	4.02	3.86-4.18
14	General flexibility	4.01	3.86-4.17
15	Using protective gear (shoulder pads, scrumcap)	3.67	3.47-3.88
16	Weather conditions	3.65	3.48-3.82
17	The crowd	3.47	3.28-3.67

2.4 Discussion

In the present study, players' mean attitudinal score was higher for improving performance than injury prevention when learning proper technique and when training the tackle. In addition, players felt more emphasis was placed on proper tackle technique to improve performance, than to prevent injuries. Despite a significant difference between the importance of injury prevention and performance in the study cohort when training the tackle, injury prevention was still considered important. This may imply that the players from this study are mindful of safety during training. In presenting our hypothesis, we noted that it is logical for any player or coach to have both performance and injury prevention as a priority when training the tackle. The tackle is a physical contest, and whilst the risk of injury will always be present, the aim (at least from a tackler point of view) is to dominate the contact situation and prevent the ball-carrier from gaining territory and the ball-carriers team from retaining the ball [1;68;77;118]. Therefore, players, coaches, and administrators need to find the most suitable balance between injury prevention and performance during training within their team setting. In other words, training the tackle should be customised according to the teams or individual level of play, age, skill level, experience, position etc. [77;118]. For example, an experienced senior professional player may not require the same amount of coaching emphasis on injury prevention and tackle technique compared to an inexperienced schoolboy player.

During matches players ranked that "bringing down the ball-carrier at all costs", "preventing the ball-carrier" and "opposition team from retaining position" and "putting in a 'Big Hit' " (top four ranked behaviours) more important than "safety of himself" or the "opposition player" (bottom 2 ranked behaviours). For this study, the top four items were considered performance based behaviours, whereas the least two ranked items were considered more safety based behaviours. Given this evidence, we may

be tempted to conclude that players do not in fact place much importance on safety during the tackle in match play. However, as we mentioned in the introduction, intention is a determinant of behaviour [125]. Unfortunately, we did not measure intention. Therefore, while we regard the top four items as performance based; it may not necessarily mean players did not consider safety.

In the study on youth hockey players in a non body checking and a body checking league, Emery et al. found a comparable result, where players in the body-checking league scored higher for items '*I would try to harm an opponent with a body check if it would increase my team's chance of winning'* and *'I would body check another player even if I knew it would injure them'* [120]. The authors attributed this behaviour to the normalization of violence in the hockey culture. The authors also added that despite these findings, the intention of the player during body-checking needs to be considered. Some players may intentionally be aggressive in an attempt to harm another player (hostile aggression), or aggressive with only the intention of producing a successful outcome (instrumental aggression). The same can be said for rugby and the tackle. As previously discussed, the tackle is a physical contest, and requires a high level of aggression. It seems players are willing to sacrifice the opponents' safety, as well as their own, to obtain a successful outcome. This highlights once again the risk taking perception and risk taking behaviour of adolescent players [97;121;123]. Further research, where intention can be measured and added to the equation would prove valuable [120].

Evidently, "combining a tackle drill with fitness conditioning" was ranked the most important for both injury prevention and improving performance. This high-ranking of "combining a tackle drill with fitness conditioning" was mirrored in the ranked mean ratings for frequency of the different drills and equipment used to train the tackle in the last season. This is a commendable attitude and behaviour as a poor level of fitness conditioning has been shown to reduce tackle technique proficiency which may predispose a player to injury [35]. Additionally, in the remaining top five ranked items, players indicated

that for both injury prevention and for improving performance, "a tackle drill should be combined either with ball skill exercises, reaction exercises, vision exercises" or conducted as a "live 1 vs 1 tackle situation". The fact that players ranked these abovementioned tackle drills as highly important may be a reflection of the playing level of these players in terms of tackle skills. For example, guidelines for developing tackling skills specifies that players who can handle the basic front-on tackle drill with added variables such as reaction time, decision making and fitness conditioning are at the intermediate level [118]. In addition, the players in this study had an average of 8 years experience, confirming that they were at an intermediate level.

"Verbal instruction", "using the shield" or "tackling bag" was ranked as the least important drill or equipment needed for injury prevention and performance. In spite of this opinion, players' ranked "verbal instruction", "using the shield" and "using the tackling the tackle bag" in the top five most frequently used methods in the last season. Also, one of the least ranked tackle drills in the last season was "live tackling in a 1 vs 1 player grid". These findings imply that coaches prefer using padded equipment such as the tackle bag or shield rather than live 1 vs. 1 tackling, perhaps in an attempt to safeguard the players from injury. While the use of the padded equipment may lower the risk of injury in training compared to live tackling, it can also be used to develop tackling skills [118]. However, when using tackling equipment such as the tackling bag or shield, careful consideration needs to given to the player(s) characteristics (level of play, age, skill level, experience, etc.) and the value of the tackle drill in preparing the player(s) for match conditions [118]. Furthermore, communication between the coach and player(s) need to be clear and direct so that player(s) understands the value of the drill and receives the proper instruction [118]. With that said, it has been suggested that tackle bags and shields do not mimic real match conditions, and that improper use of it may result in players developing incorrect tackle techniques during training. This has the potential to carry over into matches and place players at a higher risk of injury [1;77;118].

Expectedly, players have high volumes of general training during the pre-season phase of a rugby year [133;134]. In terms of tackle technique training, the amount of players that reported 'never + rarely' decreases from 58% in the off-season, to 32% in the pre-season, to 24% during the in-season. This evidence suggests a trend in tackle technique training where more players seem to train technique for tackle more as the rugby season approaches. This behaviour can be expected as coaches increase the amount of rugby specific and technical aspects of the game during this phase.

Players were asked which factors from their coach in the last season had the most influence on their tackle technique to prevent injuries and improve tackling performance. In response to this question, they rated "verbal instruction", "demonstration" or "problem identification on an individual basis or team basis". More than 50% of players reported that "problem identification in their own tackle technique" or "the entire teams tackle technique" had more influence on their tackling ability than "verbal instruction" or "demonstration", whether done on an individual basis or with the whole team. This finding may once again be evidence for the level of these players. As a player progresses, learning of new skills are affected by factors such as player experience, skill level, focus of attention and relevance to the player [135;136]. Therefore, players in this study may only find new, applicable information regarding their own or the teams tackle technique important. "Demonstration" was reported more influential than "verbal instruction". Despite this, both "verbal instruction" and "demonstration" is very useful in the early stages of skill development [135;136]. Sixty-four percent of the players also reported that their playing "experience" has a major impact on their tackle ability. Indeed, Gabbett and Ryan have shown that experience does have an effect on tackling technique once a player has participated in a certain number of matches [77]. Interestingly, players indicated that "televised rugby matches" and "televised sport/rugby shows" were more influential than "rugby training videos" or "rugby training books".

The influential role that media has on safety attitudes has been reported in young Australian Football League players [123]. Therefore national injury prevention programs, such as the RugbySmart (New Zealand Rugby Union) [63;64], SmartRugby (Australia Rugby Union) [4]and BokSmart (South Africa Rugby Union) [68] perhaps should consider using televised programs as an alternative means to convey information.

A somewhat linear pattern emerges for age and learning tackle technique, where more players are learning more as they get older. Though we did not ask players about what tackling skills or fundamentals were learned at any particular age, if players are learning fundamentals at later ages, it might be difficult to correct any bad habits acquired at a younger age and players might have already incurred serious injuries. Technical skills can be developed at ages as young as 7-9 years [137;138]. Although the majority of the technical instructions at this level will be explicit, emphasis on correct technique and safety in the tackle should start from a young age and increase as the player gets older [103;139]. Accordingly, national injury prevention programs, such as those mentioned earlier, generally try to encompass learning of proper techniques for injury prevention at all levels of play (from under 6 to senior adult level). This study however, was conducted before the BokSmart program was launched in South Africa, therefore the effects thereof are not present. A follow up study to test the effectiveness of the BokSmart program may therefore prove worthwhile. In 2006, Gianotti et al. evaluated the effectiveness of the RugbySmart program in New Zealand since its implementation in 2001[66]. Data collected pre-RugbySmart on the number of injuries sustained and on the safety attitudes and behaviour of players were compared with similar data collected post-RugbySmart [66]. Gianotti et al. found a decrease in the number of injuries sustained and improvements in the safety attitudes and behaviours of players since the programs implementation in 2001 [66]. Considering the findings of Gianotti et al., we may possibly find a different pattern emerging for learning tackle technique at the various playing

levels once the Boksmart programme is enforced in the same manner, i.e. compulsory for all coaches from under-6 grade to senior adults, as the New Zealand RugbySmart program. Also, probing the coaches' attitudes and behaviour will also contribute to a better understanding of training for the tackle.

From an injury risk factor viewpoint, this is the first study looking at tackling attitude and behaviour in training and match play. A key strength of this study is our large sample size. Nine out of the 10 schools in the rugby festival participated. This amounted to 164 returned questionnaires (out of a possible 220), representing 75% response rate. In addition, the questionnaire obtained a wealth of information with regards to tackling attitudes and behaviours in training and match play. Nevertheless, there are some noteworthy limitations to this study. Despite the intricate and systematic developmental process of the questionnaire, threats to the validity of the questionnaire do exist. In Training Question 10 (out of 12 Questions), and Match Question 4 (out of 4 Questions) players were asked to rate factors that have influenced their tackle technique, for both injury prevention and improving tackle performance. These two questions had the potential to confuse respondents, as the questions fulfilled the criteria for being double barrelled questions i.e. players had to consider both injury prevention and improving performance [129;140]. However, we did not want players to differentiate between injury prevention and improving performance for these two questions. We wanted to know what generally influences players overall tackle ability. We therefore included *"to prevent you from injuries"* and *"improve your tackle performance"* in the wording of the question, so that when players answered the question, they considered both aspects. Despite this, we cannot say for certain whether players did consider both. Given the nature of the items listed for these questions, we felt that the potential confusion in the questions interpretation would not have biased the results substantially. Even though we accounted for survey conditions during our analysis, the inconsistencies in the survey conditions renders the results to some bias. Ideally, all questionnaires should have been completed in exam conditions with the principle investigators present. Logistically however, this was challenging and

some questionnaires had to be completed during team meetings or returned at a later stage. During the team meetings, the principal investigators were present and could monitor the players during the survey, whereas the 4 teams that completed the questionnaire and returned it at a later stage could have been influenced by other factors. Caution should also be applied when generalising these findings as this cross-sectional study was conducted over a rugby festival containing traditionally rugby playing schools. Moreover, the results are considered as an indirect indication of the coach's perspective on safety and performance in the tackle, even though the coach's perspective for these teams was not surveyed.

2.5 Conclusion

This study compared players' attitude and behaviour towards injury prevention and improving performance when training the tackle, and described certain attitudes and behaviours in training and match play. In addition, factors that may influence these attitudes and behaviours in training and match play were disclosed. Comparing the attitudinal and behavioural mean scores in training, players seem to have a propensity towards improving performance. Despite this, a level of importance was shown towards injury prevention during training. Furthermore, a glance at the ranked mean ratings of importance for various tackle attitudes and behaviours during match play, may give the impression players do not place much importance on safety. While the relative importance for performance based attitudes and behaviours were ranked higher than injury prevention attitudes and behaviours, it does not necessarily mean players do not consider safety during matches. The tackle is a physical contest, and the aim (at least from a tackler point of view) is to dominate the contact situation and prevent the ball-carrier from gaining territory and the ball-carriers' team from retaining the ball. Players' willingness to succeed in the tackle situation, regardless of risk, may be reflected here.

From both an injury prevention and improving performance point of view, some training behaviours were commendable. However, the results from this study suggest improvements can be made when training the tackle. Players, coaches, and administrators need to find the most suitable balance between injury prevention and performance during training within their team setting. This process may be facilitated by modifying the current equipment and training drills used to train the tackle, and the time of season tackle technique training occurs. Equally important, players should learn proper tackle technique at a younger age, with the importance of safety emphasised from all information sources.

Chapter 3 Velocity and Acceleration before contact in the Tackle during Rugby Union matches

S Hendricks, D Karpul, F Nicolls and MI Lambert. Velocity and acceleration before contact in the tackle during rugby union matches. *Journal of Sport Sciences*, 2011, 30 (12), 1215-1224.

3.1 Introduction

Rugby Union is characterised by frequent bodily collisions known as the tackle. The nature of two or more bodies colliding at such a high frequency exposes players to muscle damage and a high risk of injury [118]. It therefore comes as no surprise that tackle related injuries account for up to 61% of all injuries during a rugby match [118]. Players' ability to win the tackle contest has also been shown to have an influence on the outcome of the match [1;77;87]. These findings, coupled to a need to further understand the complex dynamics of the tackle contest (whether for injury prevention, performance gains or research purposes), has triggered an increase in the number of studies on the tackle in recent times. These studies include identifying risk factors for injury [5;13;38;57;141], analysing techniques and their association with physiological and performance variables [1;35;76;77], identifying factors that may predict success in contact [87;88], and understanding the governing dynamics of tackler/ball-carrier interactions [142-151]. To conduct these studies, researchers commonly make use of video analysis to analyse the tackle in real match situations, or study the tackle under controlled conditions.

Due to the complex and dynamic nature of the tackle, multiple factors may contribute to a player's ability to win the tackle contest and prevail injury free. These factors are usually divided into intrinsic and extrinsic factors. Intrinsic factors are inherent to the player, and for the tackle constitute physical characteristics, attitude, skill or technique level, movement efficacy and experience [152]. In contrast, extrinsic factors are beyond the control of the player, and include coaching, training, behaviour, opponent's skill or technique level, opponent movement efficacy and environment [152]. More specifically, movement efficacy represents the velocity and acceleration of the ball-carrier and tackler during the tackle. Research suggests that these two physical components are important determinants of the tackle outcome [5;13;35;87;141;153].

Velocity and acceleration estimations at which players enter the tackle have been reported for both real match situations and under controlled conditions[1;5;13;35;57;76;77;82;83;87;87;141;143;153-155]. However, in real match situations these estimations of velocity have been subjectively described compared to controlled conditions where actual velocity and acceleration measurements were recorded [5;13;35;57;141]. In controlled settings, velocities range from 1.5 $m.s^{-1}$ to 4.6 $m.s^{-1}$ for the tackler, and from 1.5 $m.s^{-1}$ to 5.9 $m.s^{-1}$ for the ball-carrier [1;76;77;143;154;155] (Table 3.1). The range of these velocity measurements for both ball-carrier and tackler can be explained by the different study designs, aims and the level of players. Studies in controlled settings are further limited because the velocities of the ball-carrier and tacklers are usually measured in isolation [1;76;77;154;155]. Furthermore, to control the conditions of the tackle, either one [1;154], or both players [155] in the tackle were given instructions on their movement, limiting the velocity measurement and rendering the tackle unrealistic to match situations. Further limitations of studies conducted in controlled settings include no contact between the two opposing players [155], and the use of a stationary tackle bag as opposition [154]. With the use of video analysis, speed or velocity before the tackle has also been subjectively described in real match situations. These descriptive measurements have proven to be effective in characterizing different velocities as risk factors for injury and prerequisites for success in contact [5;13;57;141].

Video analysis in combination with computer generated algorithms is an accurate method to calculate linear distance over time [156;157]. This method relies predominately on ground markings as reference points to reconstruct a two-dimensional scaled version of a playing field [156;158]. A major advantage of this approach is that it is independent of camera angle to the plane of motion [159;160].

Table 3.1: Velocity Measurements for Ball-carrier and Tackler in Controlled Conditions

Authors	Year	Aim	Playing Level	Velocity ($m.s^{-1}$)	
Tackler					
(Gabbett & Kelly, 2007)[1]	2007	Assess the tackling proficiency of collision-sport athletes and the effects of increased line-speed on tackling proficiency	Sub-elite	Enforced Line-speed 3.8 Self-paced 3.2	
(Pain et al., 2008) [154]	2008	In vivo determination of the effect of shoulder pads on tackling forces in rugby	Not reported	Without pads Shoulder Run 4.5 Shoulder Crouch 3.2 Hip Run 4.6 Hip Crouch 2.4	With Pads Shoulder Run 4.4 Shoulder Crouch 3.5 Hip Run 4.4 Hip crouch 2.8
[1](Passos et al., 2008)[143]	2008	Information-governing dynamics of attacker-defender interactions	Junior (aged 11-12)	Try 2 Unsuccessful 1.5 (Tackle Break) Successful 1.5 (Tackle completed)	
(Gabbett & Ryan, 2009)[77]	2009	Investigate the relationship between tackling technique and playing level, experience, match performance and injury risk.	1st Grade National and State-based	1st Grade 2.8(2.4-3.5)#	State-based 2.8(1.8-3.2)#
(Gabbett, 2009)[76]	2009	Correlate tackling ability to physiological and anthropometric variables	1st Grade	Best tacklers 3.2	Worst tacklers 3.1
Ball-carrier					
(Passos et al., 2008)[143]	2008	Information-governing dynamics of attacker-defender interactions	Junior (aged 11-12)	Try 5 Unsuccessful 2(Tackle Break) Successful 1.5(Tackle completed)	
(Wheeler & Sayers, 2010)[155]	2010	Differences in agility running technique between reactive (R) and pre-planned (PP) conditions	National and International	Pre-change of direction phase Pre-planned 5.89 Reactive 5.71	Change of direction phase Pre-planned 5.22 Reactive 5.25

mean (range in parenthesis)

Therefore, it is possible to reconstruct playing fields from televised footage as knowledge of camera set-up is not required [159]. This method has been used in football [161;162], Australian Rules Football [163], Rugby League [163] and Rugby Union [151]. McIntosh et al. utilized this method to compare concussive head impacts in Australian Rules Football, Rugby League and Rugby Union [163]. One such comparison was players' velocity before the impact. Australian Rules Football players averaged 7 $m.s^{-1}$ (range 0.2 – 13.8) before impact, whereas the average velocity measured for Rugby League was 6 $m.s^{-1}$ (range 3.0 - 11.4), and the mean velocity before impact in Rugby Union was reported to be 5 $m.s^{-1}$ (range 3.5 – 7.7) [163]. Although McIntosh and colleagues [163] reported velocity before contact, it did not differentiate between the type of contact (i.e. tackle, ruck, collision), nor did it indicate the role of the players in the contact (i.e. ball-carrier or tackler).

To develop effective training strategies (i.e. technical skills training, physical conditioning, training drills and equipment used) that will produce a successful outcome and reduce the risk of injury for both ball-carrier and tackler, a further understanding of tackle dynamics in real match situations is warranted. Basic physical components of the tackle in real match situations, such as velocity and acceleration, are yet to be quantified and reported. Therefore, the purpose of this study was to determine the velocity and acceleration of the ball-carrier and tackler before contact for three different competitions using video analysis in combination with computer generated algorithms.

3.2 Methods

Nine rugby union matches in total from Super 14 2010 (3 matches) – an elite international competition consisting of full-time professional rugby players from provincial franchises in Australia, South Africa and New Zealand; Varsity Cup 2010 (2 matches) – a highly competitive national university competition consisting of semi-professional players; and Under 19 Currie Cup 2010 (4 matches) - competition consisting of highly trained school boy players were randomly selected and analysed for

this study. Televised recordings were used and self-recorded video footage was used for Varsity Cup matches. Ethics approval for this study was granted by the Research Ethics Committee. Front-on and side-on tackles which occurred during each match were coded using Sportscode Elite (Version 6.5.1, Sportstec, Australia). The tackle was identified *'when ball-carrier was contacted (hit and/or held) by an opponent (tackler) without reference to whether the ball-carrier went to ground'* [5;13].

Tackles were further classified into front-on and side-on tackles. Front-on tackles were coded when the anterior body parts of the ball-carrier were contacted first by the tackler [5], whereas side-on tackles were identified when the lateral body parts (on either side) of the ball-carrier were contacted first by the tackler [5]. The video footage of the tackle event had to fulfil the following visibility criteria i) Visual of 4 locations with known distances represented by the lines on the field, ii) Clear running path of the ball-carrier and primary tackler pre-tackle (at least for 0.5 seconds), iii) Camera had to remain fixed over this period. Tackle events that fulfilled these criteria (10 tackles x 3 competitions x 2 types of tackles = 60 tackles) were subsequently imported into Dartfish Teampro (Version 4.0.9.0, Dartfish, Switzerland). Apart from identifying front-on and side-on tackles, tackles were randomly selected irrespective of team, playing position, field location, set piece/breakdown that preceded the tackle, or any other tackle characteristic.

Using Dartfish Analyser, a timer was set to zero at the point of contact between the ball-carrier and primary tackler. The ball-carrier and tackler were then retracted for 0.5 seconds (25 frames) from the point of contact. This period is considered the pre-tackle phase [13]. Thereafter, the ball-carrier and tackler were tracked back to the point of contact for the 0.5 seconds. Ball-carriers were generally tracked from mid-section (hip area) and tacklers on the upper body. The rationale for this is that during most tackles, tacklers enter the tackle with their upper body as the first point of contact. A line was then drawn with the software through the tracked path of both the ball-carrier and tackler, and divided into

0.1 second intervals (Five 0.1 second intervals, six markings) (Figure 3.1). An image of the analysed tackle, with the marked 0.1 seconds intervals, was subsequently imported into Matlab (Version 6.5, Mathworks Inc, United States of America).

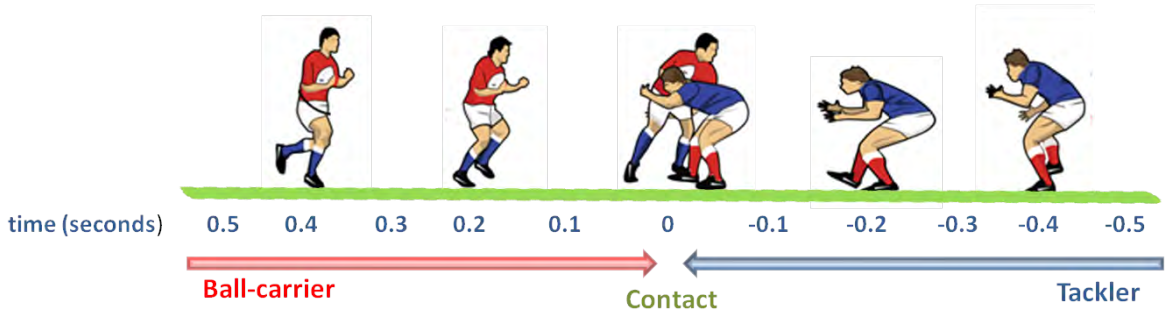

Figure 3.1: Graphic representation of time-to-contact measurement points

An algorithm to determine the planar location of a single point determined by pixel co-ordinates within an image was developed in Matlab. As mentioned earlier, one of the inclusion criteria for analysis of the tackle event was a visual of 4 locations with known distances represented by the lines on the field. This made it possible to enter four known x and y co-ordinates on the field. The program then created a 2D-axis (x; y) system in the plane of the field shown in the imported image from Dartfish. Once the 4 known co-ordinates were entered, and the 2D-axis system created, it was possible to obtain x; y co-ordinates of any point on the field. To obtain the co-ordinates, the analyser had to simply select any point on the field, and the algorithm would calculate the co-ordinates despite the projective distortion to the image created by the camera. For every tackle event, a new image and a new 2D-axis system was created, according to the known distances. Before a tackle was analysed, and to further validate the 2D-axis system, co-ordinates produced by the 2D-axis system had to correspond to the known distances of the playing field from the imported image.

The centre of the field (on the half-way line at the mid-point between the two touchlines) was chosen as the point of origin on the field (x=0; y=0) (Figure 3.2). After validation, the co-ordinates of the marked 0.1 second intervals were obtained for both the ball-carrier and the tackler. The distance between 2 co-ordinates (x and y) was calculated and divided by 0.1 seconds to produce the average velocity ($m.s^{-1}$) over that interval. This was repeated for the five 0.1 second intervals up to the point of contact for both ball-carrier and tackler. Average acceleration over the 0.5 seconds was calculated by subtracting the final velocity by the initial velocity, and dividing it by 0.4 (only four intervals of acceleration over the 0.5 seconds).

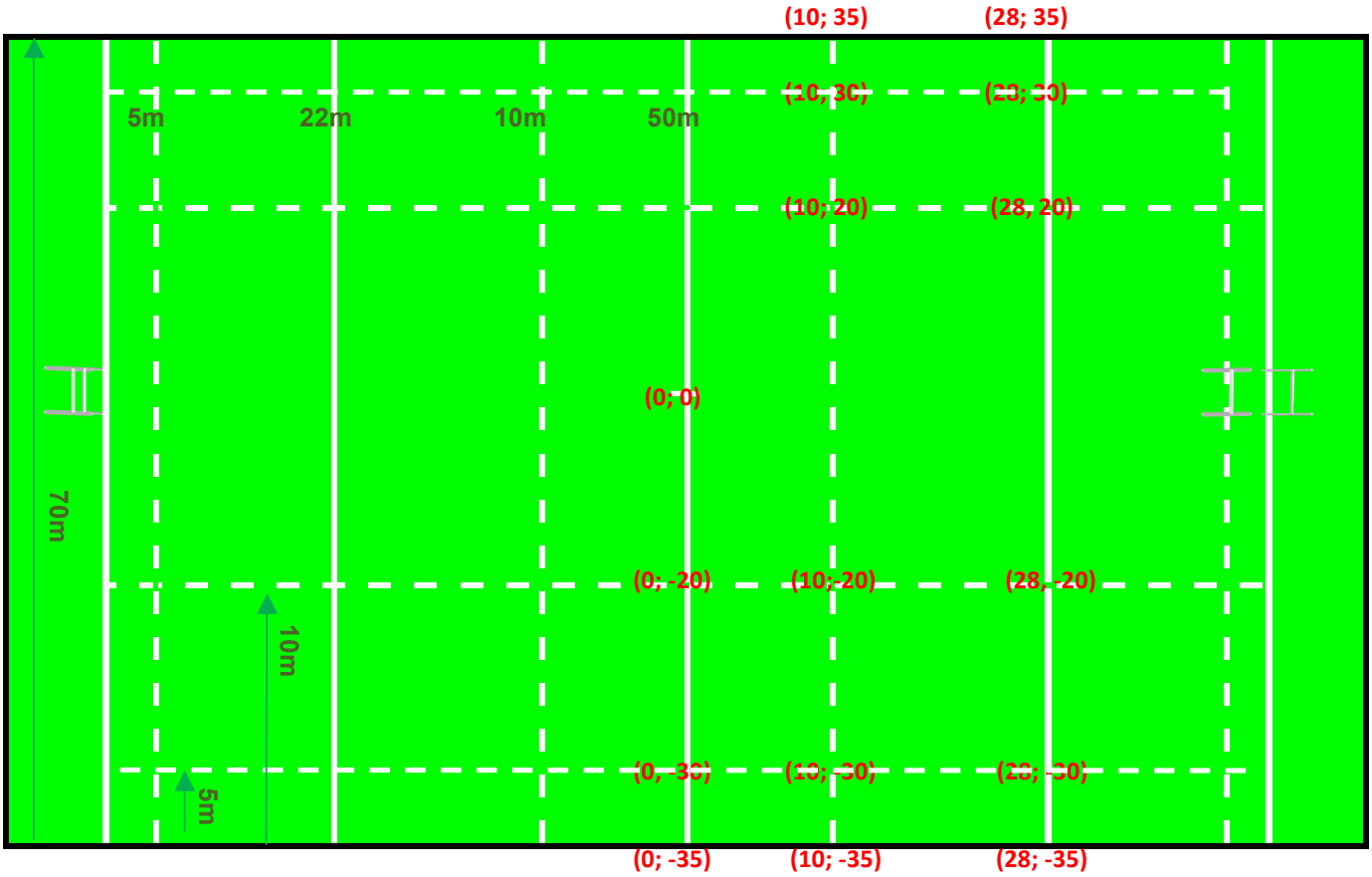

Figure 3.2: Graphic representation of a Rugby Field showing x and y co-ordinates determined from lines on the field. Note: This representation only shows some of the co-ordinates on one side of the field.

3.2.1 Validation

To test the validity of our methods, velocity measurements using the methods described above were compared to criterion velocity measurements. A contact zone was created and located at 3 different points between the two 15-metre lines – 1 furthest away from the camera, 1 in the centre on the field and 1 closest to the camera. The contact zone consisted of 6 cones placed 0.5 metres apart from each other. One Varsity cup backline player was asked to carry the ball into contact and execute a tackle in each contact zone 3 times, respectively (9 ball-carries and 9 tackles). When performing a ball-carry or tackle, the player was asked to execute with the same intensity as he would during a real match situation. In addition, an extra 2.5 metres was included before the contact zone to allow the player to gain speed and enter the contact zone at a velocity similar to what he would attain during a real match.

Another Varsity Cup player provided the opposition in each case. Each contact situation was recorded using a digital camera (Sony HDV, HVR-A1E, Japan) and imported into Dartfish Teampro.

Measurement velocity was determined using the methods described above. Criterion velocity was determined using the known distances indicated by the cones. In Dartfish Analyser, the known distances of the cones were set as reference points and recorded for the five 0.1 second intervals. As mentioned previously, a further validation was also conducted on each image by confirming that the co-ordinates produced by the 2D-axis system correspond to the known distances of the playing field.

3.2.2 Statistical Analysis

3.2.2.1 Validation

Correlation coefficients (r) were calculated to measure the relationship between the Criterion Velocity ($m.s^{-1}$) and the Measurement Velocity ($m.s^{-1}$). Standard error of the estimate (SEE) was determined to analyse the amount of error in themeasurement [164]. The Bland-Altman test was used to measure the mean difference and limits of agreement (LOA=mean difference±2SD) between the Criterion Velocity ($m.s^{-1}$) and the Measurement Velocity ($m.s^{-1}$) [165-167].

3.2.2.2 Velocity

Analysis of variance was used to compare the average velocity of the ball-carrier and tackler for front-on and side-on tackles across competitions. Analysis of variance was also used to compare the velocity of the ball-carrier and tackler in different competitions at each 0.1 time-to-contact interval during front-on and side-on tackles. A Tukey *post-hoc* test was used to further analyse any differences found. Independent *t*-tests were used to compare the average velocity, and each of the five 0.1 second intervals between ball-carrier and tackler during front-on and side-on tackles for all competitions and within each competition. All velocity data are reported as mean ± standard deviation (mean ± SD).

3.2.2.3 Acceleration

Analysis of variance was used to compare the mean acceleration of the ball-carrier and tackler for front-on and side-on tackles in all three competitions. Independent *t*-tests were used to compare mean acceleration between ball-carrier and tackler during front-on and side-on tackles for all competitions and within each competition. All acceleration data are reported as mean ± standard deviation (mean ± SD).

3.3 Results

3.3.1 Validation

Figure 3.3 shows an acceptable level of reproducibility and agreement between the Criterion Velocity and the Measurement Velocity for both ball-carrier and tackler. For the ball-carrier, higher correlation coefficients and smaller SEE values were found closer to the point of contact. Also, the mean differences between the Criterion Velocity and Measurement Velocity for the ball-carrier over the 0.5 second pre-tackle period were below 0.5 $m.s^{-1}$ (Figure 3.3). For the tackler, high correlation coefficients and small SEE values are distributed over the 0.5 second pre-tackle period. The mean difference between the Criterion Velocity and Measurement Velocity at 0.5 seconds to contact for the tackler was 0.62 $m.s^{-1}$, and decreased thereafter at each time-to-contact interval (Figure 3.3).

3.3.2 Velocity before a Front-on Tackle

During the front-on tackle the average velocity over the 0.5 second period for the ball-carrier in each respective competition were 4.8±2.9 $m.s^{-1}$ (Super 14), 5.2±1 $m.s^{-1}$ (Varsity Cup), and 4.9±1.7$m.s^{-1}$ (Under 19) (Table 3.2). The average velocities for the corresponding tackler were 5.0±1.8$m.s^{-1}$ (Super 14), 6.4±2.6$m.s^{-1}$ (Varsity Cup) and 5.7±1.9$m.s^{-1}$ (Under 19). No significant differences were found between the competitions for the ball-carrier and tackler when comparing each 0.1 time interval (Figure 3.4).

No significant differences were found between the average velocities of the ball-carrier and tackler overall for all competitions and within each competition. However, a significant difference between the ball-carrier and tackler was found at the 0.5 second time-to-contact interval, overall for all competitions and specifically within the Varsity Cup ($p<0.05$). At this time-to-contact interval the overall movement velocity of the tackler was $6.6\pm3.1 m.s^{-1}$, whereas overall movement velocity of the ball-carrier was 5.0 ± 2.5 $m.s^{-1}$. At the 0.5 second time-to-contact interval in the Varsity Cup, tacklers were entering the pre-contact phase at $7.1\pm3.5 m.s^{-1}$ compared to ball-carriers who enter the pre-contact phase at $4.6\pm1 m.s^{-1}$. For the remaining time-to-contact points, no significant differences were found, for all competitions and within each competition.

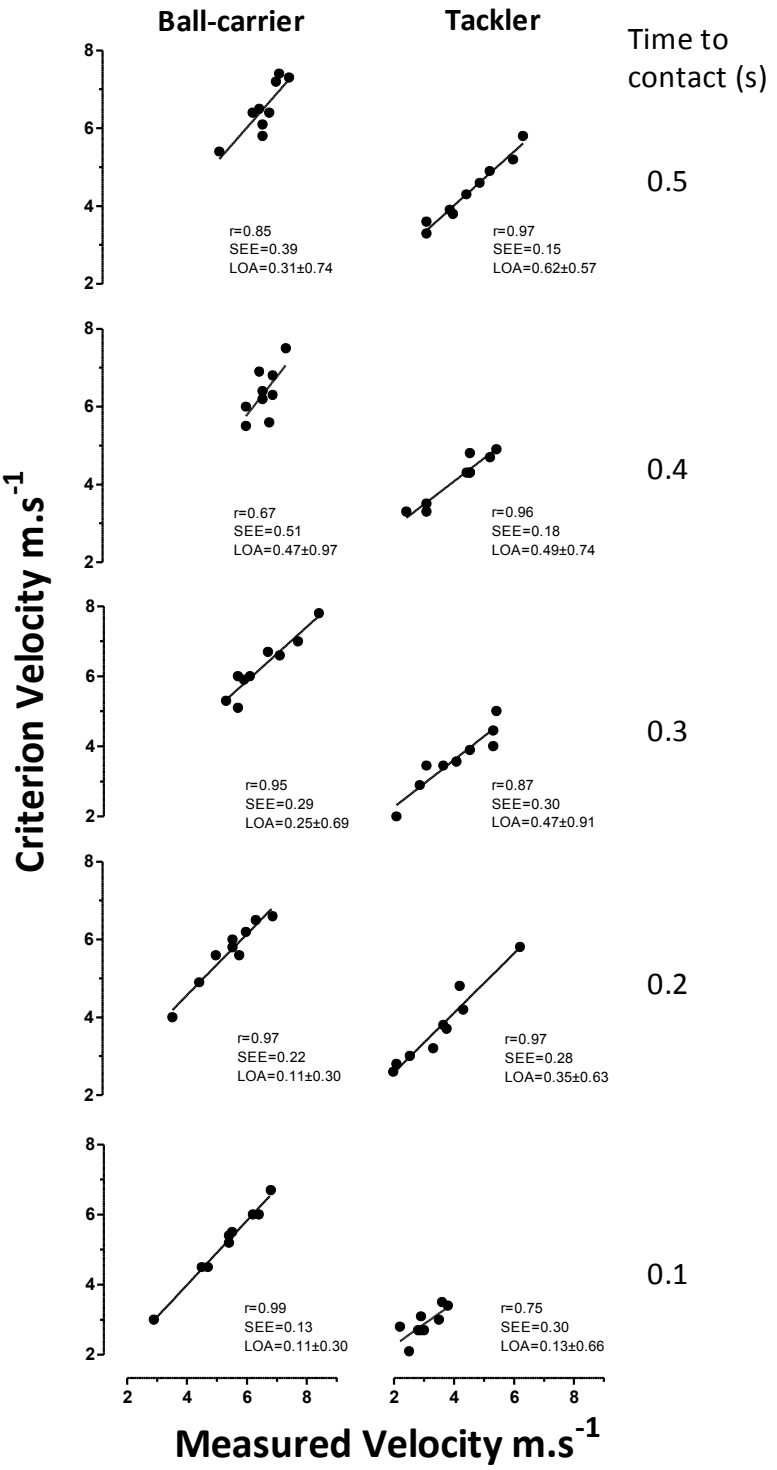

Figure 3.3: Relationship between Criterion Velocity and Measurement Velocity at each 0.1 second interval during the 0.5 seconds before contact. r = Correlation Coefficient. SEE = Standard Error of the Estimate. LOA = Limits of Agreement

Table 3.2 Average velocity and velocity ranges for ball-carrier and tackler before contact during front-on and side-on tackles at each 0.1 second time interval.

Front-on					
		Ball-carrier Velocity ($m.s^{-1}$)		**Tackler Velocity ($m.s^{-1}$)**	
		Mean	**Range**	**Mean**	**Range**
Time-to-contact (seconds)					
[#] 0.5	S14	5.3	1.8 - 5.4	6.3	3.3 - 14.6
	[*] VC	4.6	3.1 - 6.1	7.1	2.7 - 11.5
	U19	5.1	2.0 - 9.3	6.5	3.3 - 10.8
0.4	S14	4.8	1.1 - 9.9	4.3	1.0 - 9.8
	VC	4.7	2.8 - 7.3	7.3	1.4 - 15.2
	U19	5.2	1.8 - 11.2	5.0	2.9 - 10.1
0.3	S14	5.0	1.5 - 13.2	4.5	0.7 - 7.5
	VC	5.8	3.3 - 8.5	6.8	1.4 - 13.9
	U19	4.6	1.8 - 8.0	6.3	2.7 - 10.2
0.2	S14	4.2	0.7 - 9.8	4.1	1.5 - 8.8
	VC	5.4	3.4 - 7.8	6.4	1.7 - 14.3
	U19	4.6	1.8 - 9.5	5.5	3.0 - 9.4
0.1	S14	4.8	0.7 - 12.6	5.6	1.7 - 11.2
	VC	5.4	2.6 - 8.9	4.5	2.6 - 8.2
	U19	4.8	1.4 - 11.8	5.4	1.0 - 8.8
Average over 0.5 sec to contact	**S14**	**4.8**	**1.2 - 12.2**	**5.0**	**1.6 - 7.9**
	VC	**5.2**	**3.8 - 6.5**	**6.4**	**2.4 - 10.8**
	U19	**4.9**	**2.9 - 7.9**	**5.7**	**3.5 - 8.9**
0.5	S14	5.2	1.7 - 13.9	6.2	2.1 - 14.7
	VC	5.8	2.3 - 9.6	7.3 **	3.4 - 15.1
	*U19	4.6	2.9 - 7.6	3.1 **	1.5 - 5.4
0.4	S14	4.9	1.9 - 11.0	5.1	1.2 - 12.2
	VC	6.2	2.3 - 12.1	5.8	1.0 - 10.9
	U19	6.3	1.4 - 9.0	3.7	1.4 - 6.0
0.3	S14	4.9	2.4 - 9.7	6.2	2.9 - 12.5
	VC	6.0	2.3 - 9.0	4.7	0.7 - 9.1
	U19	4.6	2.4 - 6.7	3.7	1.5 - 5.6
0.2	S14	4.6	1.0 - 11.0	4.4	1.6 - 10.8
	VC	5.3	1.4 - 11.1	4.5	0.7 - 7.5
	U19	4.4	1.8 - 10.4	4.7	2.3 - 8.1
0.1	S14	4.7	1.2 - 12.2	5.2	1.9 - 9.2
	VC	5.5	1.5 - 13.2	5.2	2.7 - 9.0
	U19	3.7	1.6 - 6.2	4.2	1.5 - 6.6
Average over 0.5 sec to contact	**S14**	**4.9**	**2.7 - 9.1**	**5.4**	**2.2 - 8.8**
	VC	**5.8**	**2.6 - 9.2**	**5.5**	**3.1 - 9.6**
	U19	**4.7**	**2.7 - 7.2**	**3.9**	**2.0 - 5.8**

[#] - overall significant difference for all competitions ($p<0.05$).
[*] - significant difference between ball-carrier and tackler within competition ($p<0.05$).
[**] - significant difference between competitions ($p<0.05$).

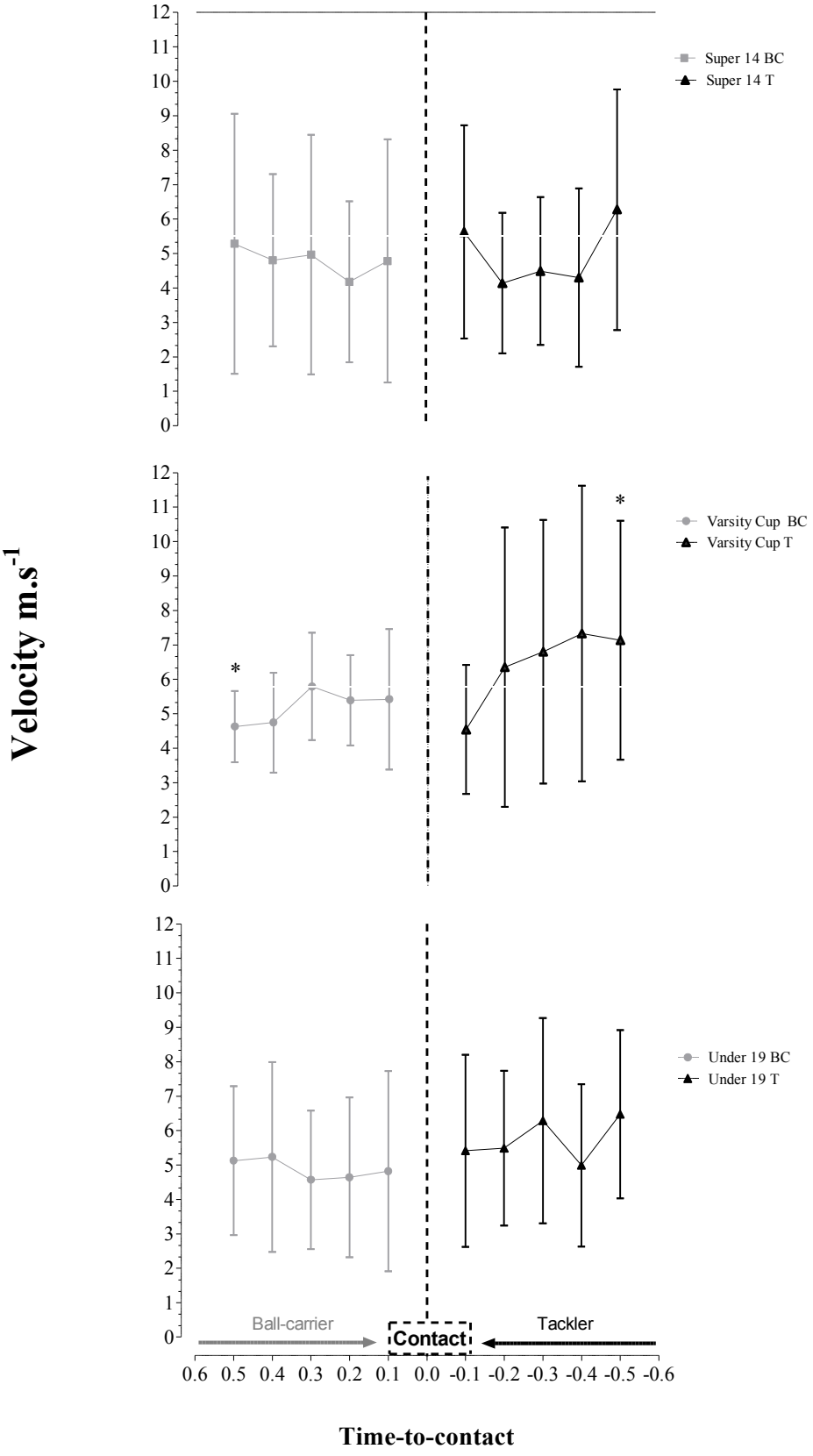

Figure 3.4: Ball-carrier (positive) and Tackler (negative) velocities before contact during a front-on tackle in Super 14, Varsity Cup and Under 19. Velocities measured at each 0.1 second interval for 0.5 seconds. Data reported as mean ± standard deviation. * - Ball-carrier significantly different from tackler at 0.5 seconds to contact ($p<0.05$).

3.3.3 Velocity before a Side-on Tackle

During the side-on tackle the average velocity over the 0.5 second period for the ball-carrier in each respective competition were 4.9±2.1 $m.s^{-1}$ (Super 14), 5.8±1.8$m.s^{-1}$ (Varsity Cup), and 4.7±1.3$m.s^{-1}$ (Under 19) (Table 3.2). The average velocity for the corresponding tacklers were 5.4±2.2$m.s^{-1}$ (Super 14), 5.5±2.1$m.s^{-1}$ (Varsity Cup) and 3.9±1.1$m.s^{-1}$(Under 19). No significant difference was found between the average velocities of the three competitions for both ball-carrier and tackler.

A significant difference was found between the tacklers of the different competitions at the 0.5 seconds time-to-contact interval ($p<0.05$) (Figure 3.5). A Tukey *post-hoc* test revealed that this significant difference was between Varsity Cup and Under 19 ($p<0.05$). No significant difference was found between the average velocities of the ball-carrier and tackler overall for all competitions and within each competition. Significant differences between the tackler and ball-carrier were found at the 0.5 second and 0.4 second time-to-contact intervals in the Under 19 competition ($p<0.05$).

3.3.4 Acceleration before a Front-on and Side-on tackle

No significant differences were found between the mean accelerations of the three competitions for both ball-carrier and tackler during front-on and side-on tackles (Table 3.3). No significant difference was found between ball-carrier and tackler overall for all competitions. However, a significant difference was found between the mean acceleration of the ball-carrier and tackler during a front-on tackle in the Varsity Cup.

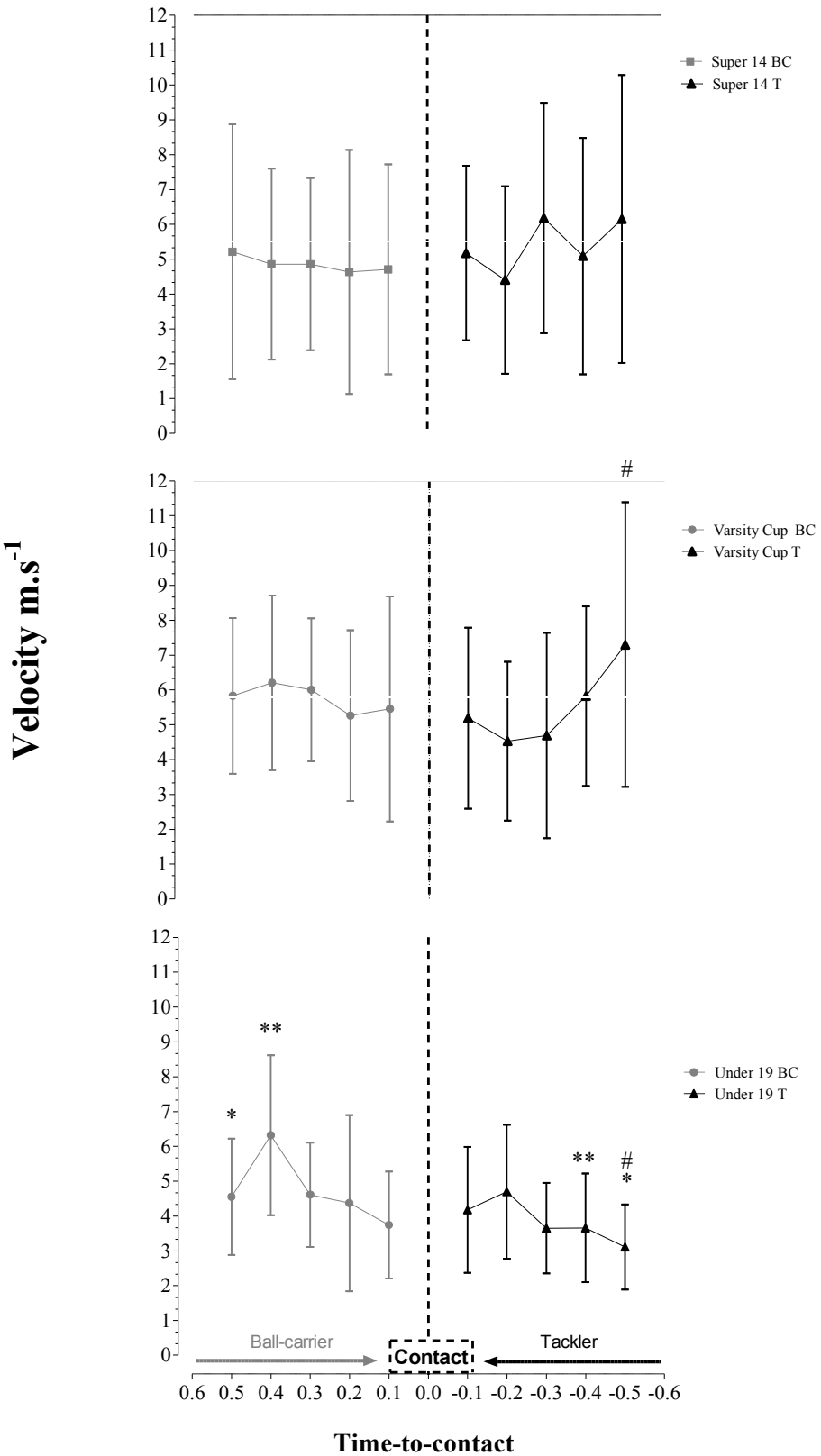

Figure 3.5: Ball-carrier (positive) and Tackler (negative) velocities before contact during a side-on tackle in Super 14, Varsity Cup and Under 19. Velocities measured at each 0.1 second interval for 0.5 seconds. Data reported as mean ± standard deviation. * - Ball-carrier significantliy different from tackler at 0.5 seconds to contact ($p<0.05$). ** - Ball-carrier significantly different from tackler at 0.4 seconds to contact ($p<0.05$). # - Varsity Cup significantly different from Under 19 at 0.5 seconds to contact ($p<0.05$).

Table 3.3 Average acceleration for ball-carrier and tackler before contact during the front-on and side-on tackle in Super 14, Varsity Cup and Under 19. Data reported as mean ± standard deviation.

	Front On				Side On			
	Ball-carrier ($m.s^2$)		Tackler ($m.s^2$)		Ball-carrier ($m.s^2$)		Tackler ($m.s^2$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Super 14	-1.24	4.88	-1.62	9.62	-1.26	8.67	-2.44	10.12
Varsity Cup	1.98*	4.95	-6.49	10.64	-0.95	9.99	-5.28	6.30
Under 19	-0.76	8.56	-2.65	8.84	-2.02	6.24	2.67	3.59

*- ball-carrier significantliy different from tackler ($p<0.05$).

3.5 Discussion

This is the first study to objectively report the velocity and acceleration of both ball-carrier and tackler in real match situations. Moreover, these velocities and accelerations were revealed for front-on and side-on tackles across three competitions. When entering a front-on tackle, no significant differences were found between the competitions for both the ball-carrier and tackler when comparing the average velocity, average acceleration, and the velocity at each time-to-contact interval. This was also evident during the side-on tackle (except for the tackler at the 0.5 seconds to contact interval where a difference was found between Varsity Cup and Under 19). These findings suggest that the velocity at which players enter the tackle may not be a good indicator of playing level. This explanation is supported by the velocity measurements for the ball-carrier and tackler in controlled conditions where players at national and international level do not differ substantially from sub-elite, amateur or junior levels [1;76;77;143;154;155]. Alternatively, the three competitions used in this study did not differ enough to note any pre-tackle velocity disparities since all three competitions consist of high-level players, with

considerable experience and quality training habits. Further research, with perhaps a greater disparity in playing level (example amateur vs. professional) and a larger sample size is needed to make any conclusive remarks.

When comparing the velocities between ball-carriers and tacklers before contact in front-on and side-on tackles, significant differences were found at the furthest points from contact – 0.4 and 0.5 seconds away from contact. As contact approaches, these differences between the ball-carrier and tackler were found to be insignificant. Furthermore, for both front-on and side tackles, the ball-carriers' velocity along each time-to-contact interval seemed relatively stable compared to the variability in the tacklers' time-to-contact intervals. These results suggest that when tacklers enter the pre-tackle phase at a velocity considerably different to that of the ball-carrier (whether higher or lower), a counterbalance reaction is initiated.

Tacklers achieve this counter balance during the last moments in the pre-tackle phase by adjusting their velocity accordingly. These findings support studies by Passos et al. on the governing dynamics between attacker (ball-carrier) and defender (tackler) interactions [143]. According to Passos et al., in a 1 versus 1 attacker-defender situation, two potential control parameters that may affect the outcome of an attacker-defender situation in rugby union are interpersonal distance and relative velocity [143]. The outcome in this study was characterised by whether or not contact was made between the attacker and defender. In the cases where contact was made (analogous to all the tackles in this study), a critical period from 4 metres of interpersonal distance to contact (0 metres interpersonal distance) was found. Within this critical period, contact was predictable when the defender was able to adjust his velocity so that the relative velocity is reduced and maintained below 2 $m.s^{-1}$ [143].

Outside this period, relative velocity did not seem to have much effect due to players still deciding what action to take (i.e. to pass, side-step, execute the tackle, etc) [143]. Applying the Passos et al. theory to the present study, a critical period - defined by a specific interpersonal distance and a definitive relative velocity range before contact may provide a rationale for our results. The significant differences outside the 0.3 second time-to-contact interval for front-on and side-on tackles in Varsity Cup and Under 19 players respectively, suggests that these players probably reach a critical period at this time-to-contact interval. Within the subsequent 0.3 seconds, tacklers are able to attain a suitable relative velocity that will afford a tackle on the ball-carrier. Interestingly, no significant differences were found at each time-to-contact interval between the ball-carrier and tackler for front-on and side-on tackles in the Super 14 competition. The differences between ball-carrier and tackler outside the 0.3 second time-to-contact interval in Varsity Cup and Under 19, and absence of a significant difference at Super 14, may be indicative of the level play (compared to entering the tackle at increasing velocities at higher levels as we discussed earlier in this section). Tacklers at an elite level may be able to make a decision quicker and therefore stabilise their velocity sooner to counter balance the velocity of the ball-carrier. In other words, the critical period, specific interpersonal distance and definitive relative velocity range, may change according to playing level and situation. A more comprehensive analysis studying the relative velocity in contact and non-contact situations is warranted to substantiate this.

For all competitions, the mean velocity of the ball-carrier at each time-to-contact interval and overall average velocity is comparable to the velocities of the ball-carrier studied under controlled conditions[143;155]. In contrast, the mean velocities of the tackler seem higher than tackler velocity measurements recorded in controlled settings. This is not surprising however, since the present study measured the movement velocity of the tacklers' upper body. The rationale for this is that during most tackles, tacklers enter the tackle with their upper body as the first point of contact. Also, as pointed out in the introduction, velocity measurements in control settings may be limited. The large standard

deviations and range of velocities in the present study may arguably represent the dynamic and variable nature of the tackle in real match situations. In addition, it may also be a representation of players' ability to adapt their movement velocity in accordance with their situation. However, since the present study did not characterise the tackle or tackle situation, no definitive conclusions can be reached in this regard.

The purpose of this study was to investigate two of these components, i.e. velocity and acceleration, for the ball-carrier and tackler in three different competitions. Although this was achieved, there are noteworthy limitations. Perhaps the most noteworthy limitation is the sample size of each group. This limitation could have been avoided had we analysed 60 tackles of a single group, using one type of tackle. However, given the importance of the tackle in rugby union at all levels, and the lack of published data on the velocity and acceleration profiles of the ball-carrier and tackler in real match situations, the present study design was decided upon. Also, the velocity and acceleration of two types of tackles in three competitions affords the necessary insight into the current velocity and acceleration profiles of ball-carriers and tacklers in real match situations. This insight now provides the necessary basis for future studies. Even though ten tackles in each group may limit the generalisation of the study, we consider ten tackles representative of each competition, as the velocity and acceleration may not differ greatly should the sample size increase. Similar to most tackle velocity studies, this study generally treated the ball-carrier and tackler as single entities. Although we tried to control for this by tracking from the upper body of the tackler and mid-section of the ball-carrier, velocity measurements of individual body parts just before contact would provide much more insight into the dynamics of the tackle. For example, although a ball-carrier's velocity is 5 $m.s^{-1}$ before contact, the velocity of his fend (an effective push manoeuvre) can be 10 $m.s^{-1}$. The 2D-axis system may also contain a small amount of artefact since the measurement plane was positioned at field level, and the player was measured at a point above the field level. Furthermore, we assumed that the ball-carrier and the tackler generally maintained a linear motion path over the 0.5 second period towards the contact. Given these limitations

of the 2D-axis system, it is possible that small changes in direction such as subtle evasive manoeuvres by the ball-carrier, or fine technique positioning by the tackler just before contact, that may have had an influence on the velocity measurement, were obscured. In this regard, despite an acceptable level of reproducibility and agreement between criterion movement velocity and measurement movement velocity, a sensitive analysis of the 2D-axis system is proposed.

Using an innovative video analysis method, the velocities at which ball-carriers and tacklers in Super 14, Varsity Cup and Under 19 competitions enter front-on and side-on tackles in real match situations is now known. While the evidence is not conclusive, the current study suggests that when tacklers enter the pre-tackle phase at a velocity considerably different to that of the ball-carrier (whether higher or lower), tacklers adjust their velocity accordingly to reach a suitable relative velocity before making contact with the ball-carrier. This insight into the physical components of the tackle in real match situations, which arguably governs the dynamics of the tackle, provides a basis for future studies. Further research characterising the tackle, the tackle situation, and tackle outcome, in relation to pre-tackle velocity and acceleration is recommended for a more comprehensive understanding of tackle in real match situations. This understanding will prove invaluable for developing effective training strategies for injury prevention and performance.

Chapter 4 Momentum and Kinetic Energy before the Tackle in Rugby Union

S Hendricks, D Karpul, and MI Lambert. Momentum and Kinetic Energy before the tackle in Rugby Union. Provisionally accepted in *Journal of Applied Biomechanics*.

4.1 Introduction

The physical demands of rugby union are characterized by intermittent short duration, high intensity exercise with frequent collisions between players [1;77;118]. These physical collisions usually occur during the tackle. According to the International Rugby Board (IRB), a tackle occurs *"when a ball-carrier (a player carrying the ball) is held by one or more opponents and brought to ground"* [3]. The opposition player that holds and goes to ground with the ball-carrier is referred to as the *tackler* [3]. The application of this definition is mainly used to implement the laws of the game. Appropriately, other definitions to identify the tackle for research purposes have been proposed. For example, Quarrie and Hopkins defined the tackle *'when ball-carrier was contacted (hit and/or held) by an opponent without reference to whether the ball-carrier went to ground'* [5]. Similarly, in a more recent study, Fuller et al identified a tackle to be *'any event where one or more tacklers attempted to stop or impede the ball-carrier whether or not the ball-carrier was brought to ground'* [13].

Epidemiological studies on rugby injuries show that players are at the highest risk of injury during the tackle compared to any other facet of play [19;20;34-40] whether they be the ball-carrier [44] or tackler [37] . From a biomechanical perspective, injury mechanisms and risk factors for the tackle for both ball-carrier and tackler have been identified [5;13;38;56;118]. One such risk factor for injury is a large difference in momentum between ball-carrier and tackler [36;40;57;118;141;168;169]. Momentum can be defined as the quantity of motion of a moving body, measured as a product of its mass and velocity. The energy that a body possesses during this motion is known as kinetic energy. Differences in momentum can also correlate with a disparity in the kinetic energy between the ball-carrier and tackler before contact. However unlike momentum, which is conserved after the collision, kinetic energy is dispersed into other forms of energy between the players in the tackle deforming the musculoskeletal system which

may cause muscle damage and increase the risk injury (some energy is also lost in other forms as heat and sound) [5;36;118;141].

To reduce the risk of injury, improve performance and develop skill, understanding the physical dynamics of tackle collisions in real match situations is necessary for the design and development of proper training drills, equipment, planning and management of training and players, and studying tackles in the laboratory. Methods however, to determine kinematics and kinetics of collisions in real match situations without instrumenting the player remain difficult. With that said, systems to estimate velocity, acceleration, momentum and energy transfer at impact, and its association with concussion in American football, Australian rules football, rugby league and rugby union have been developed [163;170-172]. Considering all the external and internal forces acting on live bodies during a collision in real life, measuring physical components in a biomechanically complex situation like the tackle renders it virtually impossible. Nevertheless, simplifying real match contact situations and applying basic physical principles of classic collisions, conservation of momentum and energy principles and making the necessary assumptions that are associated with these estimations are needed to understand match demands and collision dynamics [163;170-172]. Indeed, this type of match analysis has proved valuable in reconstructing and modelling collisions in the laboratory for further analysis [163;171-173]. Although velocity, acceleration, momentum and energy transfer at impact, and its association with concussion have been reported in rugby union and other collision sports [163], little is known about the tackle in rugby union. Studies that have reported on the kinetics contact situations in rugby union matches failed to differentiate between the type of contact (tackle, ruck, collision) or indicate role of the players in the contact (i.e ball-carrier or tackler) [163].

The physical demands and injury risk profile of players in team collision sports has been proposed to depend largely on the positional role of the player [5;9;13;76;174;175]. Rugby union consists of fifteen (Numbers 1-15) individual positions. These positions are further divided into forwards (Numbers 1-8) and backs (numbers 9-15) with each position having a specific role. Forwards are typically heavier and taller, and primarily compete for possession of the ball at set pieces and breakdown points [5]. Conversely, backs are usually quicker and more agile, and mainly gain territory and score the points [5]. In terms of tackling demands, forwards are reported to be involved in approximately 18-25 tackles per a match, compared to the backs 15-18 tackles [5;176]. The different positional demands of forwards and backs have been proposed to influence the momentum and kinetic energy of players before contact [5;13;56;118;168;177;178]. It is generally believed that backline players generate more momentum and kinetic energy than forwards before contact due to their distance from the set piece/breakdown (more running space further away from the set piece/breakdown) and faster running speeds [5;13;118;168;177;178]. In contrast, it has also been suggested that forwards develop more momentum than backs before contact because of their greater body mass [56]. Momentum and kinetic energy in these studies however are usually described from subjective speed measurements or inferred from the playing position and distance from the set piece/breakdown [5;13;56;57;118;141;168;177;178], therefore the validity of these deductions are yet to be proved.

A better understanding of the momentum and energy loads placed on players during the tackle will prove invaluable for designing and developing better training strategies to reduce the risk of injury, improve performance and developing skill. Therefore, the purpose of this study was to firstly quantify momentum and kinetic energy before contact in the tackle during real match situations for the ball-carrier and tackler in 3 different levels of competition. Therafter, estimate the magnitude of energy transfer during tackle situations and relate this magnitude to distance from set piece/breakdown and position. Next, the study explored the relationship between these physical components, position,

distance from set piece and the outcome of the tackle. We hypothesised that momentum and kinetic energy values would not be different between the competitions, and that entering the tackle with a higher momentum or kinetic energy than the opponent does not predict a dominant tackle.

4.2 Methods

4.2.1 Velocity Measurement

Velocity before contact in the tackle was measured as described by Hendricks et al [179]. Nine rugby union matches in total from Super 14 2010 (three matches) – an elite international competition consisting of teams of full-time professional rugby players from provincial franchises in Australia, South Africa and New Zealand; Varsity Cup 2010 (two matches) – a highly competitive national university competition consisting of semi-professional players; and Under 19 Currie Cup 2010 (four matches) - competition consisting of highly trained junior players were randomly analysed for this study. Televised recordings were used for the Super 14 and Under 19 Currie Cup and self-recorded video footage was used for Varsity Cup matches.

Front-on and side-on tackles that occurred during each match were then coded for using Sportscode Elite (Version 6.5.1, Sportstec, Australia). Tackles were identified *'when ball-carrier was contacted (hit and/or held) by an opponent without reference to whether the ball-carrier went to ground'* [5]. Tackles were further classified into front-on and side-on tackles. Front-on tackles were coded when the anterior body parts of the ball-carrier were contacted first by the tackler [5], whereas side-on tackles were identified when the lateral body parts (on either side) of the ball-carrier were contacted first by the tackler [5]. The video footage of the tackle event had to fulfil the following visibility criteria i) visual of 4 locations with known distances represented by the lines on the field, ii) clear running path for at least 0.5 seconds of the ball-carrier and primary tackler pre-tackle, iii) camera had to remain fixed over this

period. Tackle events that fulfilled these criteria (10 tackles x 3 competitions x 2 types of tackles = 60 tackles) were subsequently imported into Dartfish Teampro (Version 4.0.9.0 Switzerland).

Using Dartfish Analyser, a timer was set to zero at the point of contact between the ball-carrier and primary tackler. The ball-carrier and tackler were then retracted for 0.5 seconds (25 frames) from the point of contact. This period is considered the pre-tackle phase [13]. Thereafter, the ball-carrier and tackler were tracked forward to the point of contact for the 0.5 seconds. Ball-carriers were generally tracked from mid-section (hip area) and tacklers on the upper body. A line was then drawn with the software through the tracked path of both the ball-carrier and tackler, and divided into 0.1 second intervals (five 0.1 second intervals, six markings). An image of the analysed tackle, with the marked 0.1 seconds intervals, was subsequently imported into Matlab (Version 6.5, Mathworks Inc, United States of America).

An algorithm to determine the planar location of a single point determined by pixel co-ordinates within an image was developed in Matlab (Version 6.5, Mathworks Inc, United States of America). As mentioned earlier, one of the inclusion criteria for analysis of the tackle event was a visual of 4 locations with known distances represented by the lines on the field. This made it possible to enter four known x and y co-ordinates on the field. The program then created a 2D-axis (x; y) system in the plane of the field shown in the imported image from Dartfish. Once the 4 known co-ordinates were entered, and the 2D-axis system created, it was possible to obtain x; y co-ordinates of any point on the field. To obtain the co-ordinates, the analyser had to simply select any point on the field, and the algorithm would calculate the co-ordinates despite the projective distortion to the image created by the camera. For every tackle event, a new image and a new 2D-axis system was created, according to the known distances. Before a tackle was analysed, and to further validate the 2D-axis system, co-ordinates produced by the 2D-axis system had to correspond to the known distances of the playing field from the

imported image. The centre of the field (on the half-way line at the mid-point between the two touchlines) was chosen as the point of origin on the field (x=0; y=0).

After the validation, the co-ordinates of the marked 0.1 second intervals were obtained for both the ball-carrier and the tackler. The distance between 2 co-ordinates (x and y) was calculated and divided by 0.1 seconds to produce the average velocity ($m \cdot s^{-1}$) over that interval. This was repeated for the five 0.1 second intervals up to the point of contact for both ball-carrier and tackler. Average velocity over the 0.5 seconds was subsequently calculated. Validity of the velocity measurements described above has by shown by Hendricks et al [179]. In summary, the relationship between criterion velocity and measurement velocity for the ball-carrier were at 0.5 seconds before contact (r=correlation coefficient=0.85, SEE=Standard Error of the Estimate=0.39, Limits of Agreement=0.31±0.74); 0.4 seconds before contact (r=0.67, SEE=0.51,LOA=0.47±0.97); 0.3 seconds before contact (r=0.95, SEE=0.29,LOA=0.25±0.69); 0.2 seconds before contact (r=0.97, SEE=0.22,LOA=0.11±0.30); 0.1 seconds before contact (r=0.99, SEE=0.13,LOA=0.11±0.30). Relationship between criterion velocity and measurement velocity for the tackler were at 0.5 seconds before contact (r=correlation coefficient=0.97, SEE=Standard Error of the Estimate=0.15, Limits of Agreement=0.62±0.57); 0.4 seconds before contact (r=0.96, SEE=0.18,LOA=0.49±0.74); 0.3 seconds before contact (r=0.87, SEE=0.30,LOA=0.47±0.91); 0.2 seconds before contact (r=0.97, SEE=0.28,LOA=0.35±0.63); 0.1 seconds before contact (r=0.75, SEE=0.30,LOA=0.13±0.66).

4.2.2 Players playing Position and Mass

Players' playing position was identified during the initial velocity measurement. Thereafter, players were divided into 2 position groups i.e. forwards and backs. Players' masses were then obtained from their player profiles either from their National Union, Super 14 franchise or Provincial Union.

4.2.3 Momentum

Assuming all external forces acting on the ball-carrier and tackler are zero, momentum (P) before the tackle was calculated using the momentum formula:

$$P = m.v, \qquad \text{eq.1}$$

where *m* is mass of player *v* is average velocity over the 0.5 seconds

4.2.4 Kinetic Energy

Assuming all external forces acting on the ball-carrier and tackler are zero, kinetic energy (KE) before the tackle was calculated for the ball-carrier and tackler using the formula:

$$KE = \frac{1}{2}m.v^2, \qquad \text{eq. 2}$$

where *m* is mass of player *v* is average velocity over the 0.5 seconds

4.2.5 Tackle locations relative to set piece/breakdown

The horizontal distance (from touch-line to touch-line) from the analysed tackle to the preceding set piece/breakdown was estimated using the 2D-axis system. These were categorized into less than 10 metres from the set piece/breakdown (<10), between 10 metres and 20 metres from the set piece/breakdown (10<20), and more than 20 metres from the set piece/breakdown (>20). If no set piece or breakdown preceded the tackle, the tackle was considered to be in open play.

4.2.6 Tackle Outcome

The outcome of the tackle for this study was indicated by the direction of progression the tackler and ball-carrier made (as one unit) towards the opposition try-line from the point of contact to the point where both players went to ground. This signified the dominance of the tackler or ball-carrier in the contact.

4.2.7 Energy lost in contact

Energy lost was calculated by subtracting the KE before the collision ($KE_{before)}$ from the KE after the collision (KE_{after}). KE_{before} was calculated by adding the $KE_{ball\text{-}carrier}$ and $KE_{tackler.}$ KE_{after} was calculated using the following formula:

$$KE = \frac{1}{2}(m_{ball\ carrier} + m_{tackler})v^2_{after\ collision}, \qquad \text{eq. 3}$$

where $v^2_{\text{after collision}}$ is velocity after contact, calculated from conservation of momentum. Given that all tackles analysed in this study were complete tackles where the ball-carrier and tackler became one system and moved in the same direction after contact, it was assumed that momentum after the collision was conserved[181].

4.2.8 Statistical Analysis

Analysis of variance (ANOVA) was used to compare mean momentum and mean kinetic energy of the ball-carrier and tackler for front-on and side-on tackles in all three competitions. Furthermore, momentum and kinetic energy of the ball-carrier and tackler were compared between competitions (for both front-on and side on tackles). An independent t-test was used to compare momentum and kinetic energy between the ball-carrier and tackler during front-on and side tackles for all competitions and within each competition. Simple logistic regression analysis was used to determine the relationship between momentum and kinetic energy and tackle outcome. The sign (positive or negative) of the sum total between ball-carrier (positive) and tackler (negative) momentum and kinetic energy were used as predictors of tackle outcome (ball-carrier success vs. tackler success). An additional logistic regression was performed considering factors such as level of play, type of tackle, playing position and distance from set-piece. Analysis of variance was also used to compare energy lost in the different tackle locations. A two-tailed p-value was used for all tests, with the *a priori* alpha level of significance set at $p<0.05$. All analyses were conducted using STATA 11.1 (StataCorp LP, USA). Data reported as mean±SD or odds ratio (OR) with 95% confidence intervals.

4.3 Results

The average body mass of the ball-carrier for each respective competition was Super 14 105±10kg, Varsity Cup 97±16kg and Under 19 98±14kg. The average mass of the tackler for each respective competition were Super 14 96±12kg, Varsity Cup 94±13, and Under 19 90±8. There was an overall significant difference between ball-carrier and tackler mass ($p=0.0041$). More specifically, the ball-carriers were heavier than the tacklers in Super 14 ($p=0.0089$) and Under 19($p=0.0510$) competitions.

Table 4.1 Momentum ($Kg.ms^{-1}$) before contact for ball-carrier and tackler for front-on and side-on tackles for Super 14, Varsity Cup and Under 19. Data reported as mean±SD.

Momentum before Front-on Tackle ($Kg \cdot m \cdot s^{-1}$)						
	Ball-carrier (in the opposite direction to the tackler)			Tackler (in the opposite direction to the ball-carrier)		
	n	Mean	SD	n	Mean	SD
Super 14	10	508	±321	10	471	±212
Varsity Cup	10	529	±80	10	620	±268
Under 19	10	479	±174	10	517*	±148
All Forwards	16	523	±266	13	566	±222
All Backs	14	486	±125	17	513	±217
All Positions and Levels	30	505	±209	30	536	±217
Momentum before Side-on Tackle ($Kg \cdot m \cdot s^{-1}$)						
	Ball-carrier (approximately perpendicular to the direction of tackler)			Tackler (approximately perpendicular to the direction of ball-carrier)		
Super 14	10	519	±241	10	523	±209
Varsity Cup	10	522	±162	10	503	±181
Under 19	10	459	±156	10	347*	±106
All Forwards	16	523	±210	10	384	±133
All Backs	14	473	±158	20	494	±197
All Positions	30	500	±186	30	458	±183

*- significant difference between front-on and side-on tackles (p=0.0086).

The average velocity of the ball-carrier for each respective competition was Super 14 4.8±2.5$m \cdot s^{-1}$, Varsity Cup 5.5±1.4 $m \cdot s^{-1}$ and under 19 4.8±1.5$m \cdot s^{-1}$. The average velocity of the tackler for each respective competition was Super 14 5.2±2.0$m \cdot s^{-1}$, Varsity Cup 6.0±2.3$m \cdot s^{-1}$ and Under 19 4.8±1.8$m \cdot s^{-1}$. The velocity of the ball-carrier and the velocity of the tackler were not different. Furthermore, there were no significant differences between competitions for the velocities of the ball-carriers and tacklers.

Table 4.2 Kinetic Energy (Joules) before contact for the ball-carrier and tackler for front-on and side-on tackles for Super 14, Varsity Cup and Under 19. Data reported as mean±SD

Kinetic Energy before Front-on Tackle (Joules)						
	Ball-carrier			Tackler		
	n	Mean	SD	n	Mean	SD
Super 14	10	1635	±2291	10	1325	±1028
Varsity Cup	10	1395	±400	10	2297	±1610
Under 19	10	1300	±952	10	1601*	±964
All Forwards	16	1633	±1849	13	1761	±1126
All Backs	14	1227	±614	17	1726	±1392
All Positions and Levels	30	1443	±1407	30	1741	±1262
Kinetic Energy before Side-on Tackle (Joules)						
Super 14	10	1481	±1358	10	1612	±1137
Varsity Cup	10	1623	±920	10	1550	±1225
Under 19	10	1164	±681	10	719*	±397
All Forwards	16	1596	±1198	10	783	±540
All Backs	14	1224	±730	20	1549	±1147
All Positions	30	1422	±1009	30	1294	±1043

* - significant difference between front-on and side-on tackles (p=0.0154).

Momenta before front-on and side-on tackles were not different between the ball-carrier and tackler for all three competitions and within each competition (Table 4.1). There was a significant difference momentum between front-on and side-on tackles for the tackler at the Under 19 level (p=0.0086).

There were no significant differences in kinetic energy between the different competitions for both front-on and side-on tackles (Table 4.2). No significant differences were also found between the ball-carrier and tackler for all three competitions and within each competition for front-on and side-on tackles. There was a significant difference in kinetic energy between front-on and side-on tackles for the tackler at the Under 19 level (p=0.0154).

Without considering other factors, the odds of a player (ball-carrier or tackler) succeeding in the tackle is increased by 50% (OR 1.49, 95%Cl 0.51-4.39) when the player enters the contact at a higher momentum or kinetic energy than the opponent (Table 4.3). However, when considering the level of play, type of tackle, position and distance from set piece, this odds ratio decreased to OR 0.92 (95Cl% 0.25-3.38). The odds of the ball-carrier succeeding in contact were significantly increased when tackled from the side compared to being tackled from the front (OR 0.09, 95Cl% 0.02-0.39 p=0.001).

Table 4.3 Logistic regression analyses for tackle success (ball-carrier) and positive P and KE in isolation, and including other factors (level of play, type of tackle, position and distance from set piece).

Tackle success	**OR**	**95%Cl**
Momentum or Kinetic Energy	1.49	0.51-4.39
Tackle success (other factors included)		
Momentum or Kinetic Energy	0.92	0.25-3.38
Level of play	0.95	0.42-2.18
Type of tackle	0.09	0.02-0.39*
Position	1.00	0.71-1.41
Distance from set piece	0.86	0.47-1.58

*p=0.001

Of the 60 tackles analysed in this study, 30% of tackles occurred within 10 metres from the set piece/breakdown (energy lost range 7608J-826J), 23% between 10 metres and 20 metres (energy lost range 5762J-1002J), 35% occured beyond 20 metres (energy lost range 6209J-596J), and 12% in open play (4553J-1169J). No relationship was evident between the amount of energy lost in contact and the tackle location relative to set piece (Figure 4.1).

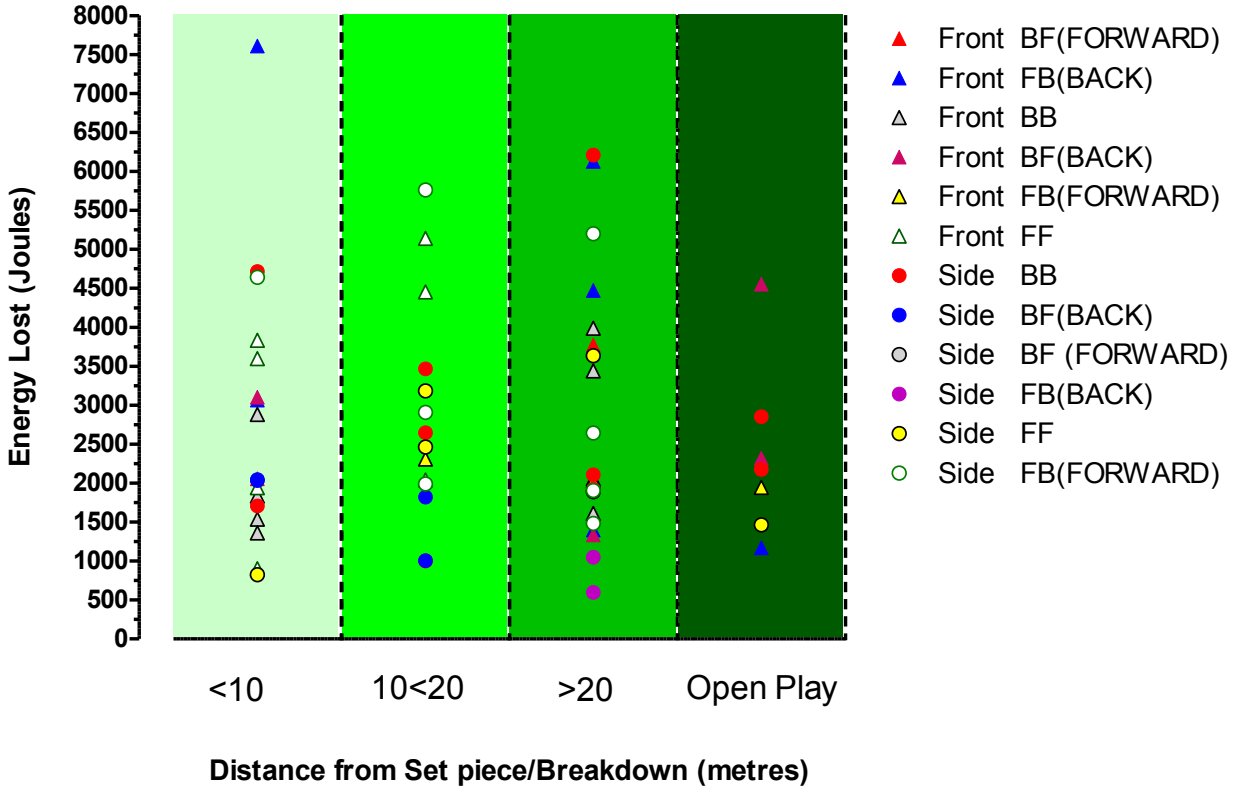

Figure 4.1 Energy lost in contact and tackle locations and tackle locations relative to set piece/breakdown (10m, 10<20m, >20m and open play) for backs (B) and forwards (F) during the front-on and side-on tackles. Player position winning the tackle indicated with brackets ().

4.4 Discussion

The purpose of this study was to quantify momentum and kinetic energy before contact in the tackle during real match situations for the ball-carrier and tackler in three different competitions. Large differences in momentum and kinetic energy are considered risk factors for injury, and may also contribute to the effectiveness of the tackle [36;40;57;118;141;168;169]. Without knowledge of the physical components and demands of the tackle in real match conditions, designing and developing training strategies to reduce the risk of injury, improve performance and developing skill would be difficult. In McIntosh's multifactorial model of injury prevention in team sports, he proposed that the biomechanics of injury risk can be explained by the event either resulting from an overload of the system's tolerance levels, or a reduction in the system's tolerance levels through microtrauma to a point where normal loads cannot be tolerated[111]. Indeed, studies have shown a positive relationship between the number of tackles made during matches and markers of muscle damage[7;36]. Also, in a laboratory based study of tackle forces, Usman et al. found that repeated tackling decreased the amount of force produced by the tackler[180]. The authors attributed this decrease in force to fatigue, and proposed fatigue be an important injury risk factor for tackling, and tackle effectiveness [180]. Similarly in rugby league, Gabbett et al. has showed a decrease in tackling technique as fatigue levels increase [35]. Given the impact measurements of the tackles analysed in this study, and considering all tackles were injury-free, the current study may be an indication of the players tolerance to impacts during the tackle. In view of aforementioned injury model [111] and studies [7;35;36;180], and the momentum, kinetic energy and magnitude of energy transfer values presented in this study, it is theorised that players' capacity to endure repeated high energy impact tackle situations has an upper limit where beyond this point, the risk of injury is substantially increased, and tackle performance is noticeably decreased (Figure 4.2). This upper limit is reached either through one or two very high-energy impact contact situations or, accumulates over a match or season. However, this upper limit can be offset by effective tackle skill training, proper physical

conditioning, strength, power, equipment and attitude/motivation [111]. For example, physically conditioned players with a high level of tackle skill may have the technical ability to distribute energy loads efficiently, dissipating the energy throughout the body instead of the energy overloading or accumulating in one region. Also, these highly skilled conditioned players may have a high tolerance level for physical loads. This theory is supported by findings in rugby league where players with greater tackling technique attempted more tackles than players with lower tackle skill [77]. Of these attempted tackles, the higher tackle skilled players also executed more dominant tackles, and missed fewer tackles [77]. Admittedly, the present study did not record any injury or the number of tackles contested. Nonetheless, building on previous work in conjunction with our findings, a theoretical model for the relationship between the number of tackles a player competes in (acute or chronic fatigue), energy lost (magnitude of impact), markers of muscle damage and how this relationship interacts with injury risk (tolerance overload or reduction) and performance is presented (Figure 4.2). Other factors such as position on the field (relative to set piece/breakdown), level of play, and environmental conditions may also influence these relationships.

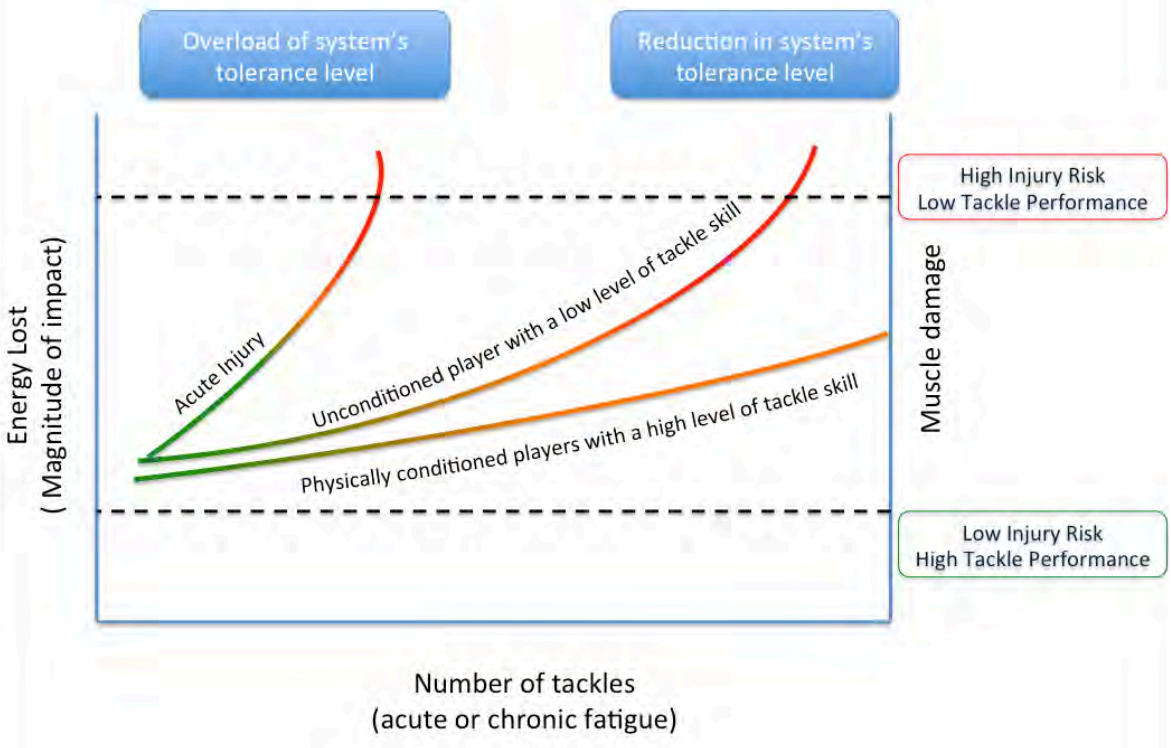

Figure 4.2 Theoretical model of the relationship between the number of tackles a player competes in (acute or chronic fatigue), energy lost (magnitude of impact), markers of muscle damage and how this relationship interacts with injury risk (tolerance overload or reduction) and performance.

From basic physical principles applied to sport, we learn that when two bodies collide (assuming no external forces are acting on these bodies), the body with the higher momentum or kinetic energy is most likely to win the collision [181;182]. This was echoed by our findings as the odds of a player succeeding in contact increased when the player entered the contact with a higher momentum or kinetic energy than the opponent. These odds however, decreased when factors such as level of play, type of tackle, position, and distance from set-piece were taken into account. This suggests that using player's physical components alone is not sufficient to predict success in real match tackle contact situations. The logistic regression analysis also revealed that the odds of a ball-carrier succeeding in contact significantly increased by 91% when being tackled from the side compared to the front. This is not surprising since previous work has shown that avoiding direct front on contact with the tackler increases the chances of the ball-carrier succeeding in contact [87]. Furthermore, coaching manuals usually instruct players to use evasive manoeuvres before contact and run at the tackler's arms [118]. Of course, from a tackler perspective, the inverse i.e. executing front-on tackle increases the odds of succeeding in contact.

No relationship was evident between the amount of energy lost in contact and the tackle location relative to set-piece/breakdown within the 60 tackles analysed for this study. This finding contends with popular belief that high impact contact situations are more likely to occur further away from the breakdown/set-piece. Despite the availability of space further away from the breakdown/set-piece, the energy lost ranges are similar across the playing field. Furthermore, it is likely that within a given match situation players are able to tolerate a range of impacts.

For the purpose of our analysis, instead of using the momentum and kinetic energy values as predictors, momentum, and kinetic energy were dichotomized into positive for ball-carrier and negative for

tackler. The disadvantage of this is that the actual amount or range of momentum or kinetic energy required for success in contact relative to the opponent is yet to be revealed for real match situations (assuming such values exist). Our analysis represented a highly simplified, but ultimately practical measure of momentum and kinetic energy involved in the collision of two bodies during rugby union. Finer details, not yet measurable would be needed to gain a more comprehensive understanding of the physical demands of the tackle contact situation and impact dynamics in rugby union. This approach has been used before to study head impacts during concussion in collision sports [163]. Although the current study reported the amount of energy lost in contact and indicated the player position winning the contact, further insight into how this energy loss is dispersed between the players during successful contact situations and injury is needed. In this regard, the duration and area over which opponents dissipate these energies may support or refute our proposed model. This concern was highlighted recently by Good et al. who report two case studies of acetabular fractures during the tackle [183]. An extremely rare injury in sport, acetubalar fractures are caused by high-energy collisions. Despite its paucity, the authors speculate that given the increased physical capabilities of the modern rugby player, the incidence of such high impact injuries will only increase if not addressed [183].

In accordance with the objectives of this study, momentum and kinetic energy before contact in the tackle during real match situations for the ball-carrier and tackler have now been quantified. Expectedly, the player with the higher momentum or kinetic energy was more likely to succeed in contact. However, when other factors were accounted for, this odds ratio decreased. Of these factors, the manner in which contact was made (i.e. front-on or side-on) was a significant predictor. Furthermore, it appears that there is an increased risk of entering a high impact collision further away from contact. Based on previous work in conjunction with our findings, a theoretical model for the relationship between the number of tackles a player competes in (acute or chronic fatigue), energy lost

(magnitude of impact), markers of muscle damage and how this relationship interacts with injury risk (tolerance overload or reduction) and performance is offered.

Chapter 5 Tackler characteristics that may increase the likelihood of a successful tackle outcome in Rugby Union

S Hendricks, B Matthews, B Roode, M Lambert. Tackle characteristics that may increase the likelihood of a successful tackle outcome in rugby union. Provisionally accepted in *European Journal of Sport Science.*

5.1 Introduction

In rugby union, when in possession of the ball (attacking), the main objective is to advance the ball down the field towards and over the opposition the try-line. For the team without the ball (defending), the main objective is to prevent the attacking team from achieving their objective of advancing forward, while also trying to regain possession of the ball. To achieve this goal, players in the defending team attempt to stop or impede the player in possession of the ball (ball-carrier). The player(s) stopping or impeding the ball-carrier are referred to as the tackler(s), and the situation where contact between the ball-carrier and tackler is made is known as the tackle.

The tackle is a dynamic and high impact contact situation between two or more colliding bodies [118]. Players' (whether ball-carrier or tackler) are exposed to this contact situation 10 to 25 times per match depending on their positional role in the team [5;176]. This frequent exposure to contact places players at high risk of injury and muscle damage [118]. Given the nature and frequency of the tackle situation, tackle contact skills are a pre requisite for participation in rugby union. Furthermore, the ability of a player to effectively carry the ball into contact or execute a tackle has an effect on the outcome of the match and also reduces the risk of injury [1;5;13;77;87;88;141].

Tackle contact skills have been described for both the ball-carrier and tackler in training [1;5;13;35;38;57;76;77;87;88;118;141]. The assumption is that these contact skills are coached during training and implemented during match play, and as a result, reduce the risk of injury and increase the possibility of a successful outcome. Undoubtedly, this concept has proven to be effective with regards to the tackle contact skills [66]. However, most techniques described in training manuals and injury prevention programs are based on anecdotal evidence. Furthermore, the dynamic nature of a rugby match, and

more specifically the tackle, does not always allow players to execute the skills they developed in training particularly if they do not adapt to the changing situation. Based on this, the tackle has been analysed retrospectively to characterize common injury mechanisms for both the ball-carrier and tackler [5;13;141]. Furthermore, retrospective analysis of the tackle has also characterised effective ball-carrier techniques and their association with successful tackle outcomes and team success [87;88]. However, to date there is no retrospective analysis from a tackler perspective, particularly examining factors associated with successful tackle outcomes and team success.

To analyse and characterise the highly complex skill of tackling, previous studies and coaching manuals have divided tackling into three phases. These three phases are i) the pre-tackle phase, ii) the tackle phase, and iii) post-tackle phase. Furthermore, retrospective analysis of tackle injury epidemiology has characterised the tackle by the manner in which contact is made, the direction by which the tackler enters the contact, the speed of the tackler, body region first contacted, the tackler's head position and the tackler's posture [5;13;141]. These types of retrospective analyses of tackle injuries have proved valuable in identifying risk factors for injury and possible weaknesses in current training strategies [118]. Nonetheless, further understanding of the techniques used during matches and their effect on performance is warranted.

Given the importance of tackling in rugby union, the nature and frequency of the tackle during matches, and high risk of injury during the tackle, more information with regards to tackler demands and techniques during the different phases of tackling and its association with performance is needed. This information will improve current tackle training strategies by identifying disparities between the techniques used in matches and techniques coached during training. With this in mind, the purpose of

this study was to identify tackler characteristics that may increase the likelihood of a successful tackle outcome in rugby union.

5.2 Methods

5.2.1 Experimental Approach to the Problem

Video footage was analyzed using Sports Code elite version 6.5.1 (Sportstec, Australia), using an Apple iMac (Apple, USA) positioned at eyelevel. The analysis software allowed control over the time lapse during each movement, and the recording and saving of each coded instance into a database. Instances were coded using characteristics and definitions described in previous research, and characteristics and definitions developed specifically for this study. Characteristics were divided into the three tackles phases [13;118] i.e. pre-contact (0.5s preceding contact), contact (first instance of contact) and post contact. The outcomes of the contact event were divided into tackle outcome, possession, territorial change and result.

5.2.2 Subjects

Due to time constraints, 18 matches were analysed of the 2010 Super 14 competition, which amounted to 2092 coded instances. Although each game was randomly selected, quota sampling was used to ensure relatively equal distribution between playing teams and competition week. This was to avoid a bias towards a playing team or time in the competition.

5.2.3 Procedures

The characteristics and definitions/defined criteria of each event consisted of the following:

5.2.3.1 Pre-contact (0.5s preceding contact)

Body position:

- Upright - tackler displayed high body height with knees extended and hips extended
- Medium - tackler displayed moderate flexion at knees and hips

- Low - tackler displayed low body height
- Upright to medium – tackler moves from an upright to a medium body position
- Upright to low – tackler moves from an upright to a low body position
- Medium to upright – tackler moves from a medium to an upright body position
- Medium to low – tackler moves from a medium to a low body position
- Low to upright – tackler moves from a low to an upright body position
- Low to medium – tackler moves from a low to a medium body position

Stance:

- Flat footed – tackler standing square with feet aligned and flat on the ground
- Back foot – tackler stepping backwards as ball-carrier approaches
- Split forward – tackler standing with a staggered stance
- No stance – tackler diving or sliding into contact

Direction of movement of tackler:

- Forward – towards the ball-carrier
- Backwards – back pedalling (i.e.) away the ball-carrier
- Lateral – towards the touch-line

Head position:

- Up and forward – toward ball-carrier
- Away – away from ball-carrier
- Down – towards the ground
- Tracking – tackler follows (tracks) the ball-carrier through the field of play

Arm position:

- Hands above shoulders
- Hands dropped

- Elbows bent with hands raised

Distance from ball-carrier (0.5 seconds before contact): [13;87]

- Near – within one body length of the ball-carrier
- Moderate – within one to two body lengths of the ball-carrier
- Distant – greater than two body lengths from ball-carrier

Speed of tackler: [184]

- Fast – running or sprinting – purposeful running with maximal effort, with high knee lift
- Moderate – jogging – non-purposeful slow running with low knee lift
- Slow – stationary or walking – no visible foot movement

Speed of ball-carrier: [184]

- Fast – running or sprinting – purposeful running with maximal effort, with high knee lift
- Moderate – jogging – non-purposeful slow running with low knee lift
- Slow – stationary or walking – no visible foot movement

Evasive manoeuvre performed by ball-carrier: [87]

- Straight – ball-carrier ran straight at the defence
- Side Step – ball-carrier performed an evasive step initiated by either leg
- Running line –

    Arcing run – ball-carrier performed arcing run

    Lateral run – ball-carrier performed a run from touchline to touchline

    Diagonal run – ball-carrier runs at an angle, instead of straight at the tackler

- Orientation of tackler in relation to ball-carrier -

    In front – tackler and ball-carrier moving head on toward each other

    Side – tackler moving in from the ball-carrier's side

    Oblique – tackler moving into ball-carrier at an angle

Behind – tackler chasing ball-carrier toward own try-line

Position of tackler: [88]

- Tight forwards – loosehead and tighthead prop, hooker and second row
- Loose forwards – open-side and blind-side flankers and number 8
- Inside backs – scrum-half, fly-half, and inside centre
- Outside backs – outside centre, both wings and fullback

Position of ball-carrier: [88]

- Tight forwards – loosehead and tighthead prop, hooker and second row
- Loose forwards – open-side and blind-side flankers and number 8
- Inside backs – scrum-half, fly-half, and inside centre
- Outside backs – outside centre, both wings and fullback

5.2.3.2 Contact

Type of tackle: [13]

- Arm tackle – tackler impedes ball-carrier with upper limbs
- Collision tackle – tackler impedes ball-carrier without the use of arms
- Jersey tackle – tackler holds ball-carrier's jersey
- Lift tackle – tackler raises ball-carrier's hips above ball-carrier's head
- Shoulder Tackle: tackler contacts the ball-carrier with the shoulder as the first point of contact further subdivided into:

  Same shoulder as leading leg

  Opposite shoulder to leading leg

  Dive

  Aligned

- Smother tackle – tackler uses chest and wraps both arms around ball-carrier

- Tap tackle – tackler trips ball-carrier with hand on lower limb below the knee

Direction of tackle:

- Front – tackler makes contact in front of ball-carrier
- Side – tackler makes contact with the ball-carrier's side
- Oblique – tackler makes contact with ball-carrier at an angle
- Behind – tackler makes contact with ball-carrier from behind

Body region of ball-carrier struck during contact: [13]

- Lower legs – area between ball-carrier's hips and toes
- Mid-torso – above the ball-carrier's hip level to the level of the ball-carrier's arm pit
- Shoulder – from the ball-carrier's arm pit level to the shoulder level, including the arm
- Head and neck – above the shoulder with any connection with the head/neck during the course of the tackle

Head placement: [13]

- Above – tackler's head higher than ball-carrier's body during contact
- Beside – tackler's next to ball-carrier's body during contact
- In front – tackler's head in front of ball-carrier's body during contact
- Behind – tackler's head at the back of ball-carrier's body during contact

Fend: [87]

- Absent – ball-carrier provided no fend
- Moderate – ball-carrier provided a light to moderate fend (e.g. Swat or slap technique)
- Strong – ball-carrier provided strong fend (e.g. Push technique)

5.2.3.3 Post-Contact

Leg drive by tackler:

- Absent – no leg drive

- Moderate – moderate knee movement, with no high lift
- Strong – high, rapid knee lift

Leg drive by ball-carrier:

- Absent – no leg drive
- Moderate – moderate knee movement, with no high lift
- Strong – high, rapid knee lift

Assisted – additional tacklers entered the tackle contest

Lift: tackler raises ball-carrier's hips above ball-carrier's head

Arm usage – tackler uses arms after initial contact is made.

- Yes -

  Pulling – Tackler uses arms to bring ball-carrier toward his body

  Region of Pulling: legs

  mid-torso

  shoulder

  head and neck

  Wrapping – Tackler uses arms to enclose region of ball-carrier's body

  Region of wrapping: legs

  mid-Torso

  shoulder

  head and neck

- No – No arm usage after initial contact was made

Shoulder Usage – Tackler uses shoulder after initial contact is made

- Yes - Region of shoulder usage: legs
  mid-torso
  shoulder
  head and neck
- No

Tackler competes for the ball

- Yes
- No

5.2.3.4 Outcomes

Tackle Outcomes

Offload – the ball-carrier is able to pass the ball to a team-mate during the tackle

Tackle Break – the ball-carrier successfully penetrates the attempted tackle and continues to advance

Tackle completed – when an offload or tackle break does not occur. Further subdivided into:

going to ground

held/standing - situation where ball-carrier is held up by tackler and cannot progress further, i.e. upright

ball-carrier goes to ground

tackler goes to ground

both go to ground

Others

Infringement – the ball-carrier is awarded a penalty as a result of a dangerous tackle

Knock-on – when the ball-carrier loses possession of the ball and in the direction of tackler's try-line

Try – the grounding of the ball by the ball-carrier in the tackler's in-goal area

Tackled in to touch – ball-carrier is tackled out of the field of play

Possession

- Ball carrier maintains possession
- Tackler gains possession

Territorial change

- Gained by tackler: further subdivided into:
  - Little – identified when the tackler made less than a body lengths progression towards the opposition try-line
  - Fair amount – identified when the tackler made one to two body lengths progression towards the opposition try-line
  - Much – identified when the tackler progressed more than two body lengths towards the opposition try-line
- Lost by Tackler: further subdivided into:
  - Little – identified when the ball-carrier made less than a body lengths progression towards the opposition try-line
  - Fair amount – identified when the ball-carrier made one to two body lengths progression towards the opposition try-line
  - Much – identified when the ball-carrier progressed more than two body lengths towards the opposition try-line

Result

- Unsuccessful – identified when the ball-carrier was able to offload the ball, or break an attempted tackle, or an infringement was committed, or when a try was scored.

- Successful– After contact, the tackler prevents the ball-carrier and ball from progressing towards his try-line and does not concede a penalty

5.2.4 Statistical Analyses

The objective of the analysis was to determine which tackler characteristics increase the likelihood of a successful outcome. To determine this, multinomial logistic regression (mlogit) analysis was computed using STATA 11.1 (StataCorp LP, USA). Before the mlogit analysis, descriptive statistics (frequency %) were calculated. Characteristics that had a percentage frequency of 0% were excluded from mlogit analysis. Main effect mlogit models for each outcome (except possession) were conducted for the three tackle phases. Thereafter likelihood ratio tests were conducted to test the overall effect of each characteristic on the outcome. Characteristics that had an overall significant effect ($p<0.05$) on the outcome were then expanded upon and reported (specific effects model). Relative risk ratio's (RRR) and 95% confidence intervals are reported for the main effects models and the characteristics of the specific effects model. Significant characteristics were also disclosed, with the alpha p value set at $p<0.05$.The standard interpretation of the multinomial logistic regression is that for a unit change in the predictor variable (the tackle characteristics), the logistic of outcome relative to the referent group (base outcome) is expected to change by its respective parameter estimate (RRR) given that the characteristics in the model are held constant.

5.2.4.1 Reliability

For intra-coder reliability, two matches were coded on two separate occasions using the variables and definitions described previously. Coding of the same match was separated by at least one week[87]. Pearson correlation (*r*) and standard error of the mean (SEE) were used to compare the number of instances coded for the same match on the two different occasions. Acceptable intra-code reliability

was shown between the matches coded on the two different (match 1 r=0.99, *SEE*= 0.63 and match 2 r=0.99, *SEE* = 1.00)

5.3 Results

5.3.1 Descriptive Statistics

Table 5.1 reports the frequency percentages for each characteristic during each phase of the tackle. Included in the table are the frequency percentages for the different outcomes of the tackle. Ball-carrier positions were distributed as follows, 25% tight forwards, 22% loose forwards, 29% inside backs and 24% outside backs. Tackler positions were apportioned as follows, 31% tight forwards, 26% loose forwards, 25% inside backs and 28% outside backs.

5.3.2 Pre contact and tackle outcomes

The relative risk of an offload occurring compared to being tackled (base outcome) was 2.41 times greater (RRR 2.41, 95% CI, 1.75-3.33, p<0.001) when the tackler was tracking compared to an up and forward head position (Table 5.2). Similarly, there was a 2.30 times greater chance of a tackle break when a tackler was identified as tracking (RRR 2.30, 95% CI, 1.56-3.39, p<0.001). When taking the ball into contact, inside backs (RRR 2.78, 95% CI, 1.62-4.78, p<0.001) and outside backs (RRR 3.07, 95% CI, 1.77-5.32, p<0.001) were more likely to break the tackle compared to tight forwards. The chance of breaking the tackle however decreased when the tackler was a loose forward (RRR 0.43, 95% CI, 0.26-0.71, p<0.001).

Table 5.1 Frequency percentages for all characteristics during each phase of the tackle and for the different outcomes of the tackle (n=2092).

Pre Contact			**Contact**			**Post Contact**			**Outcomes**		
	n	%		n	%		n	%		n	%
Body Position			Type of Tackle			Leg Drive by Tackler			Tackle Outcomes		
Medium to upright	179	8	Shoulder Tackle	1200	57	Moderate	485	23	Tackle Completed	1538	73
Medium to low	343	16	Smother Tackle	372	17	Absent	1576	75	Tackle Break	183	8
Medium	237	11	Jersey Tackle	301	14	Strong	31	1	Offload	274	13
Upright	588	28	Arm Tackle	178	8				Knock on	25	1
Low	59	2	Collision Tackle	28	1				Try	26	1
Upright to low	237	11	Tap Tackle	12	0				Into Touch	33	1
Upright to medium	438	20	Lift Tackle	1	0				Infringement	7	0
Low to upright	6	0									
Low to medium	5	0									
Stance			Shoulder Tackle			Leg Drive by BC			Going to Ground		
Flat Footed	208	9	Aligned	120	5	Absent	764	36	Both go to ground	1813	86
Split Forward	1756	83	Dive	186	8	Strong	184	8	Tackler goes to ground	118	5
No Stance	9	0	Same shoulder	730	34	Moderate	1144	54	Held/standing	118	5
Back Foot	119	5	No Shoulder	892	42				BC goes to ground	43	2
			Opposite shoulder	164	7						
Direction of Movement			Direction of Tackle			Assisted			Possession		
Forward	1461	69	Front	969	46	Yes	1087	51	BC maintains possession	2054	98
Lateral	476	22	Oblique	299	14	No	1005	48	Tackler Gains Possession	38	2
Backward	155	7	Side	632	30						
			Behind	192	9						
Head Position			Body Region			Lift			Territory Change		
Up and Forward	1402	67	Shoulder	800	38	No	2064	98	Gained by Tackler	226	10
Down	28	1	Mid-Torso	1019	48	Yes	28	1	Lost by Tackler	1866	89
Tracking	661	31	Legs	263	12						
Away	1	0	Head and Neck	10	0						
Arm Position			Head Placement			Arm Usage			Territorial Amount		
Elbows Bent	735	35	Beside	1424	68	Pulling	592	28	Little	1356	64
Hands Dropped	1324	63	Above	222	10	No Arms	200	9	A lot	204	9
Hands Above	33	1	Behind	15	314	Wrapping	1300	62	Fair amount	532	25
			In front	132	6						
Distance from BC			Fend			Region of Arm Usage			Result		
Near	205	98	Absent	1883	90	Mid-Torso	991	47	Successful	1585	75
Moderate	34	2	Strong	43	2	No Arms	197	9	Unsuccessful	507	25
			Moderate	166	7	Legs	689	33			
						Shoulder	208	9			
						Head and Neck	6	0			
Speed Tackler						Shoulder Usage					
Slow	613	29				Yes	1246	59			
Moderate	1412	67				No	846	40			
Fast	67	3									
Speed of BC						Region of Shoulder Usage					
Slow	113	5				Shoulder	332	15			
Moderate	1909	91				Mid-Torso	72	34			
Fast	70	3				Legs	211	10			
						No Shoulder	820	39			
						Head and Neck	1	0			
Evasive Manoeuvre						Tackler Competes for the ball					
Side Step	384	18				No	2082	99			
Diagonal run	134	6				Yes	10	1			
Straight	1079	51									
Lateral run	82	3									
Arcing run	411	19									
Orientation of Tackler											
Front	984	47									
Oblique	648	30									
Side	315	15									
Behind	145	6									

5.3.3 Contact and tackle outcomes

As seen in Table 5.2, jersey tackling increased the likelihood of a ball-carrier offloading by 2.17 times (RRR 2.17, 95% CI, 1.50-3.13, p<0.001), and breaking a tackle by 4.3 times (RRR 4.28, 95% CI, 2.64-6.93, p<0.001) compared to a shoulder tackle. A moderate fend increased the likelihood of an offload occurring compared to no fend (RRR 1.82, 95% CI, 1.12-2.95, p<0.05), whereas a strong fend decreased the chances of an offload occurring (RRR 0.67, 95% CI, 0.08-5.39). The likelihood of breaking an attempted tackle increased by 1.6 times when tacklers contacted the ball-carriers' legs (RRR 1.59, 95% CI, 0.94-2.68). Also, the probability of breaking a tackle increased significantly when ball-carriers used a moderate (RRR 5.78, 95% CI, 3.60-9.29, p<0.001) or strong fend (RRR 42.01, 95% CI, 18.18-97.08, p<0.001).

5.3.4 Post contact and tackle outcomes

A moderate (RRR 0.46, 95%CI, 0.32-0.66, p<0.001) or strong (RRR 0.68, 95% CI, 0.20-2.31) leg drive performed by the tackler decreased the probability of an offload occurring relative to no leg drive (Table 5.2). Likewise, a moderate (RRR 0.59, 95% CI, 0.45-0.77, p<0.001) or strong (RRR 0.12, 95% CI, 0.04-0.38, p<0.001) leg drive performed by the ball-carrier increased the probability of an offload occurring. The chances of a ball-carrier breaking the tackle decreased by 80% when the tackler performed a moderate leg drive (RRR 0.20, 95% CI, 0.10-0.38, p<0.001). In contrast, the chances of the ball-carrier breaking the tackle increased when using a moderate (RRR 6.71, 95% CI, 3.07-14.68, p<0.001) or strong (RRR 24.48 95% CI, 10.19-58.76, p<0.001) leg drive compared to no leg drive. Wrapping (RRR 1.87, 95% CI, 0.88-3.95) or pulling after contact (RRR 2.06, 95% CI, 0.95-4.47) increased the likelihood of an offload. Whereas arm usage, either wrapping (RRR 0.13, 95% CI, 0.09-0.21, p<0.001) or pulling (RRR 0.01, 95%CI, 0.01-0.02,p<0.001), decreased the chances of a ball-

carrier breaking the tackle. Shoulder usage by the tackler, decreased the chances of an offload (RRR 0.84, 95% CI, 0.64-1.12) and tackle break (RRR 0.42, 95% CI, 0.27-0.64, p<0.001).

5.3.5 Pre Contact and territory change

Following the ball-carrier before contact (tracking) as opposed to up and forward decreased the probability of the tackler gaining territory by nearly 60% (RRR 0.43, 95% CI, 0.27-0.68,p<0.001) (Table 5.3). In addition, ball-carriers entering the contact at a moderate (RRR 0.25, 95% CI, 0.16-0.41, p<0.001) or fast (RRR 0.10, 95% CI, 0.02-0.44, p<0.05) speed decreased the chances of the tackler gaining territory, provided all the other characteristics in the model remained constant.

5.3.6 Contact and territory change

Shoulder tacklers significantly increased the likelihood of gaining territory compared to arm (RRR 0.36, 95% CI, 0.16-0.80, p<0.05) or jersey (RRR 0.36, 95% CI, 0.19-0.70,p<0.01) tackles (Table 5.3). Contacting the ball-carrier obliquely (RRR 0.58, 95% CI, 0.36-0.93, p<0.05) or from the side (RRR 0.40, 95% CI, 0.40-0.91, p<0.05) decreased the probability of gaining territory. Moreover, contacting the legs of ball-carriers significantly reduced the tackler's probability of gaining territory (RRR 0.25, 95% CI, 0.12-0.53, p<0.001).

5.3.7 Post Contact and territory change

Leg driving after contact significantly increased the probability of the tackler gaining territory (moderate leg drive RRR 10.41, 95% CI 7.33-14.78, p<0.001; strong leg drive RRR 201.78, 95% CI 60.04-678.06, p<0.001) (Table 5.3). Conversely, a moderate (RRR 0.15, 95% CI 0.10-0.22, p<0.001) or strong (RRR 0.01, 95% CI 0.00-0.07, p<0.001) leg drive by the ball-carrier significantly decreased the probability of the tackler gaining territory.

Table 5.2 Multinomial logistic regression for pre contact, contact, post contact and tackle outcomes. Data reported as relative risk ratios (RRR) and 95% confidence intervals (95% Cl).

	RRR		95% CI		P value
	Main	Specific	Main	Specific	Main
Pre contact					
Offload (vs. Tackle Completed)					
Body Position	0.98		0.92 - 1.06		0.68
Stance	1.26		1.03 - 1.54		0.02
Direction of Movement	0.88		0.67 - 1.15		0.36
Head Position (Up and Forward)	0.52		0.39 - 0.68		0.00
Down		1.01		0.30 - 3.47	
Tracking		2.41		1.75 - 3.33***	
Arm Position	1.15		0.99 - 1.33		0.07
Distance from Ball Carrier	0.79		0.29 - 2.19		0.66
Speed of Tackler	0.87		0.63 - 1.19		0.37
Speed of Ball Carrier	1.03		0.64 - 1.64		0.91
Evasive Manoeuvre	0.96		0.90 - 1.03		0.28
Orientation of Tackler	1.00		0.83 - 1.20		0.97
Tackler Position (Tight Forwards)	1.18		1.03 - 1.34		0.01
Loose Forwards		1.01		0.69 - 1.48	
Inside Backs		1.33		0.90 - 1.94	
Outside Backs		1.60		1.06 - 2.41*	
Ball-carrier Position (Tight Forwards)	1.11		0.97 - 1.26		0.12
Loose Forwards		1.19		0.77 - 1.83	
Inside Backs		1.68		1.14 - 2.47	
Outside Backs		1.23		0.81 - 1.87**	
Tackle Break (vs. Tackle Completed)					
Body Position	0.91		0.84 - 0.99		0.04
Stance	1.01		0.82 - 1.25		0.90
Direction of Movement	1.18		0.85 - 1.63		0.33
Head Position (Up and Forward)	0.59		0.42 - 0.83		0.00
Down		-		-	
Tracking		2.30		1.56 - 3.39***	
Arm Position	0.97		0.81 - 1.15		0.72
Distance from Ball Carrier	0.63		0.22 - 1.81		0.39
Speed of Tackler	0.94		0.65 - 1.36		0.75
Speed of Ball Carrier	0.65		0.36 - 1.15		0.14
Evasive Manoeuvre	0.96		0.88 - 1.04		0.28
Orientation of Tackler	1.09		0.87 - 1.36		0.46
Tackler Position (Tight Forwards)	1.07		0.92 - 1.25		0.37
Loose Forwards		0.43		0.26 - 0.71***	
Inside Backs		0.87		0.57 - 1.35	
Outside Backs		1.12		0.71 - 1.77	
Ball-carrier Position (Tight Forwards)	1.47		1.25 - 1.73		0.00
Loose Forwards		1.73		0.95 - 3.14	
Inside Backs		2.78		1.62 - 4.78***	
Outside Backs		3.07		1.77 - 5.32***	
Contact					
Offload (vs. Tackle Completed)					
Type (Shoulder Tackle)	0.85		0.77 - 0.93		0.00
Arm Tackle		1.00		0.60 - 1.66	
Collision Tackle		2.55		0.70 - 9.26	
Jersey Tackle		2.17		1.50 - 3.13***	
Smother Tackle		0.81		0.45 - 1.43	
Direction	1.08		0.95 - 1.23		0.24
Body Region (Mid-Torso)	0.62		0.51 - 0.76		0.00
Legs		0.61		0.40 - 0.94*	
Shoulder		0.29		0.20 - 0.42	
Head Placement	0.93		0.76 - 1.14		0.49

Table 5.2 Continue					
Fend (Absent)	1.64		1.11 - 2.43		0.01
Moderate		1.82		1.12 - 2.95*	
Strong		0.67		0.08 - 5.39	
Tackle Break (vs. Tackle Completed)					
Type (Shoulder Tackle)	0.59		0.53 - 0.66		0.00
Arm Tackle		6.24		3.81 - 10.23***	
Collision Tackle		11.52		4.22 - 31.45***	
Jersey Tackle		4.28		2.64 - 6.93***	
Smother Tackle		0.51		0.20 - 1.30	
Direction	1.12		0.94 - 1.35		0.20
Body Region (Mid-Torso)	0.74		0.56 - 0.99		0.04
Legs		1.59		0.94 - 2.68	
Shoulder		0.75		0.47 - 1.19	
Head Placement	0.98		0.73 - 1.33		0.91
Fend (Absent)	7.01		5.04 - 9.75		0.00
Moderate		5.78		3.60 - 9.29***	
Strong		42.01		18.18 - 97.08***	
Post Contact					
Offload (vs. Tackle Completed)					
Leg drive by Tackler (Absent)	0.50		0.36 - 0.70		0.00
Moderate		0.46		0.32 - 0.66***	
Strong		0.68		0.20 - 2.31	
Leg Drive by Ball-carrier (Absent)	0.54		0.43 - 0.69		0.00
Moderate		0.59		0.45 - 0.77***	
Strong		0.12		0.04 - 0.38***	
Arm Usage (No arms used)	1.08		0.85 - 1.38		0.51
Pulling		2.06		0.95 - 4.47	
Wrapping		1.87		0.88 - 3.95	
Shoulder Usage (No Shoulder usage)	0.82		0.62 - 1.08		0.15
Shoulder usage		0.84		0.64 - 1.12	
Tackle Break (vs. Tackle Completed)					
Leg drive by Tackler (Absent)	0.19		0.10 - 0.36		0.00
Moderate		0.20		0.10 - 0.38***	
Strong		-		-	
Leg Drive by Ball-carrier (Absent)	4.68		3.20 - 6.85		0.00
Moderate		6.71		3.07 - 14.68***	
Strong		24.48		10.19 - 58.76***	
Arm Usage (No arms used)	0.11		0.08 - 0.15		0.00
Pulling		0.13		0.09 - 0.21***	
Wrapping		0.01		0.01 - 0.02***	
Shoulder Usage (No Shoulder usage)	0.40		0.26 - 0.61		0.00
Shoulder usage		0.42		0.27 - 0.64***	

* ≤ 0.05 ** ≤ 0.01 *** ≤ 0.001
- No events occurred
Main – main effects model
Specific – specific effects model
Base outcome in brackets()

Table 5.3 Multinomial logistic regression for pre contact, contact, post contact and territory change. Data reported as relative risk ratios (RRR) and 95% confidence intervals (95% Cl).

	RRR		95% CI		P value
	Main	Specific	Main	Specific	Main
Precontact					
Gained by Tackler (vs. Lost by Tackler)					
Body Position	1.04		0.96 - 1.13		0.33
Stance	1.13		0.92 - 1.38		0.25
Direction of Movement	0.95		0.66 - 1.36		0.76
Head Position (Up and Forward)	1.75		1.17 - 2.62		0.01
Down		1.45		0.48 - 4.35	
Tracking		0.43		0.27 - 0.68***	
Arm Position	0.89		0.76 - 1.03		0.13
Distance from Ball Carrier	1.05		0.33 - 3.34		0.94
Speed of Tackler	0.91		0.65 - 1.28		0.60
Speed of Ball Carrier (Slow)	3.85		2.48 - 5.99		0.00
Moderate		0.25		0.16 - 0.41***	
Fast		0.10		0.02 - 0.44**	
Evasive Manoeuvre	1.03		0.95 - 1.13		0.47
Orientation of Tackler	0.85		0.68 - 1.06		0.16
Tackler Position (Tight Forwards)	0.82		0.70 - 0.95		0.01
Loose Forwards		0.82		0.56 - 1.20	
Inside Backs		0.65		0.43 - 0.99*	
Outside Backs		0.55		0.34 - 0.91*	
Ball-carrier Position	1.08		0.94 - 1.25		0.28
Contact					
Gained by Tackler (vs. Lost by Tackler)					
Type (Shoulder Tackle)	1.20		1.05 - 1.37		0.01
Arm Tackle		0.36		0.16 - 0.80*	
Collision Tackle		1.23		0.43 - 3.55	
Jersey Tackle		0.36		0.19 - 0.70**	
Smother Tackle		0.66		0.37 - 1.17	
Direction (Front)	0.76		0.64 - 0.89		0.00
Behind		1.43		0.67 - 3.05	
Oblique		0.58		0.36 - 0.93*	
Side		0.60		0.40 - 0.91*	
Body Region (Mid-Torso)	1.30		1.03 - 1.65		0.03
Legs		0.25		0.12 - 0.53***	
Shoulder		0.94		0.66 - 1.33	
Head Placement (Beside)	1.26		1.04 - 1.54		0.02
Above		1.17		0.62 - 2.19	
Behind		0.64		0.33 - 1.24	
In front		1.21		0.64 - 2.28	
Fend (Absent)	0.50		0.28 - 0.90		0.02
Moderate		0.65		0.31 - 1.35	
Strong		0.27		0.04 - 2.02	
Post Contact					
Gained by Tackler (vs. Lost by Tackler)					
Leg drive by Tackler (Absent)	0.40		0.30 - 0.53		0.00
Moderate		0.36		0.26 - 0.50***	
Strong		0.39		0.11 - 1.35	
Leg Drive by Ball-carrier (Absent)	1.00		0.83 - 1.21		1.00
Continue		0.86		0.67 - 1.09	
Moderate		1.29		0.86 - 1.94	
Arm Usage (No arms used)	0.47		0.40 - 0.55		0.00
Pulling		0.30		0.21 - 0.43***	
Wrapping		0.19		0.13 - 0.27***	
Shoulder Usage	0.73		0.58 - 0.92		0.01

* ≤ 0.05 ** ≤ 0.01 *** ≤ 0.001

- No events occurred

Main – main effects model

Specific – specific effects model

Base outcome in brackets()

5.3.8 Pre contact and result

Tracking decreased the tacklers' chances of a successful tackle (RRR 2.24, 95% CI 1.72-2.92, p<0.001) relative to an up and forward head position (Table 5.4). Tight forwards carrying the ball into the tackle had a significantly higher probability of success compared to inside backs (RRR 1.95, 95% CI 1.41-2.70, p<0.001) or outside backs (RRR 1.77, 95% CI 1.26-2.49, p<0.001).

5.3.9 Contact and result

The type of contact made by the tackler had significant effect on the success of the tackle (p<0.0001) (Table 5.4). Arm tackles (RRR 2.32, 95% CI 1.62-3.32, p<0.001), collision tackles (RRR 4.98, 95% CI 2.17-11.42, p<0.001) and jersey tackles (RRR 2.56, 95% CI 1.87-3.49, p<0.001), significantly reduced the chances of a successful result relative to shoulder tackles. Furthermore, ball-carriers employing a fend at contact (relative to no fend) significantly decreased tacklers' probability of success in the tackle (moderate fend RRR 2.97, 95% CI 2.04-4.31, p<0.001; strong fend (RRR 15.35, 95% CI 6.89-34.21, p<0.001).

5.3.10 Post Contact and Result

A moderate (RRR 0.36, 95% CI 0.26-0.50, p<0.001) or strong (RRR 0.39, 95% CI 0.11-1.35) leg drive by the tackler after contact increased the likelihood of a successful tackle (Table 5.4). Using the arms for either pulling (RRR 0.30, 95% CI 0.21-0.43, p<0.001) or wrapping (RRR 0.19, 95% CI 0.13-0.27, p<0.001), improved tacklers' probability of success in contact.

Table 5.4 Multinomial logistic regression for pre contact, contact, post contact and result. Data reported as relative risk ratios (RRR) and 95% confidence intervals (95% Cl).

	RRR		95% CI		P value
	Main	Specific	Main	Specific	Main
Precontact					
Unsuccessful (vs. Successful)					
Body Position	0.95		0.90 - 1.01		0.09
Stance	1.14		0.98 - 1.32		0.09
Direction of Movement	0.98		0.78 - 1.22		0.83
Head Position (Up and Forward)	0.57		0.45 - 0.72		0.00
Down		0.57		0.17 - 1.94	
Tracking		2.24		1.72 - 2.92***	
Arm Position	1.09		0.96 - 1.22		0.17
Distance from Ball Carrier	0.73		0.33 - 1.63		0.45
Speed of Tackler	0.89		0.69 - 1.14		0.36
Speed of Ball Carrier	0.84		0.57 - 1.24		0.39
Evasive Manoeuvre	0.96		0.90 - 1.01		0.12
Orientation of Tackler	1.04		0.90 - 1.21		0.59
Tackler Position (Tight Forwards)	1.13		1.02 - 1.26		0.02
Loose Forwards		0.75		0.55 - 1.02	
Inside Backs		1.12		0.83 - 1.52	
Outside Backs		1.36		0.98 - 1.88	
Ball-carrier Position (Tight Forwards)	1.24		1.12-1.38		0.00
Loose Forwards		1.29		0.90 - 1.85	
Inside Backs		1.95		1.41 - 2.70***	
Outside Backs		1.77		1.26 - 2.49***	
Contact					
Unsuccessful (vs. Successful)					
Type (Shoulder Tackle)	0.74		0.68 - 0.79		0.00
Arm Tackle		2.32		1.62 - 3.32***	
Collision Tackle		4.98		2.17 - 11.42***	
Jersey Tackle		2.56		1.87 - 3.49***	
Smother Tackle		0.65		0.40 - 1.07	
Direction	1.07		0.96 - 1.20		0.22
Body Region (Mid-Torso)	0.67		0.56 - 0.80		0.00
Legs		1.25		0.88 - 1.76	
Shoulder		0.51		0.33 - 0.77***	
Head Placement	0.94		0.79 - 1.12		0.51
Fend (Absent)	3.49		2.67 - 4.57		0.00
Moderate		2.97		2.04 - 4.31***	
Strong		15.35		6.89 - 34.21***	
Post Contact					
Unsuccessful (vs. Successful)					
Leg drive by Tackler (Absent)	0.40		0.30 - 0.53		0.00
Moderate		0.36		0.26 - 0.50***	
Strong		0.39		0.11 - 1.35	
Leg Drive by Ball-carrier (Absent)	1.00		0.83 - 1.21		1.00
Moderate		0.86		0.67 - 1.09	
Strong		1.29		0.86 - 1.94	
Arm Usage (No arms used)	0.47		0.40 - 0.55		0.00
Pulling		0.30		0.21 - 0.43***	
Wrapping		0.19		0.13 - 0.27***	
Shoulder Usage (No Shoulder usage)	0.73		0.58 - 0.92		0.01

* ≤ 0.05 ** ≤ 0.01 *** ≤ 0.001
- No events occurred
Main – main effects model
Specific – specific effects model
Base outcome in brackets()

5.4 Discussion

The aim of this study was to identify tackler characteristics that would increase the likelihood of a successful tackle outcome in rugby union. For this study, the outcome of the tackle was characterised according to the progression of the ball or ball-carrier after contact. Furthermore, in accordance with previous literature, the events preceding the outcome were divided into three phases [13;118]. Each phase represented a period in the tackle and has a unique objective in contributing to the overall outcome of the tackle [118].

Tracking was consistently a significant pre contact characteristic that decreased the tackler's chances of a successful tackle. Tracking can be related to the perceptual and decision-making component of tackling, and to the reactive agility component of the tackling. The importance of perceptual and decision making factors such as visual scanning, anticipation, pattern recognition and knowledge of situation [185], and reactive agility (example change of direction and acceleration) [174;186] and its relationship to tackling proficiency has been highlighted previously in rugby league [174;186]. In this regard, tacklers still following the ball-carrier through the field of play during the pre-contact phase suggests that tackler's were uncertain whether they should commit to tackling the player in possession of the ball at that specific time. As a result, tacklers are unable to react and position themselves accordingly, and therefore unprepared for the imminent tackle. According to the Australian Rugby Union SmartRugby program, tracking is a fundamental skill required for optimum positioning to effectively execute a tackle [4]. Furthermore, in the South African Rugby Union BokSmart practical guidelines for safe and effective technique for the tackle, tracking the attacking player is specified as the first action when tackling [68]. Also, in a recent review on coaching strategies for effective technique and injury prevention in the tackle in rugby union, guidelines for coaching the tackle for injury prevention and performance recommends training tracking of the ball-carrier when the player(s)

reaches an advance level [118]. Defensive systems may also aid the tracking process of a tackler, since these systems allow players to predetermine their target ball-carrier, which allows for better preparation [118].

The type of contact made, the body region struck, and the fending action by the ball-carrier were significant predictors of tackle success in the contact phase of the tackle for all three outcomes. Specifically, arm tackles and jersey tackles decreased the likelihood of a tackler completing a tackle, gaining territory and having a positive result compared to shoulder tackles. This is not surprising since arm and jersey tackles limits the tacklers hold of the ball-carrier. Arm tackles and jersey tackles are usually the result of ball-carriers successfully evading front-on contact with the tackler, and in reaction, the tackler extends the arm in an attempt to impede the ball-carrier. Arm tackles in particular, have also been reported to account for the most number of injuries when tackling [13]. Although the mechanism of injury is not fully understood, it is generally assumed the an extended, abducted and externally rotated arm position during arm tackles or shoulder tackles, destabilizes the shoulder, and as a result increases the risk of a shoulder injury [187]. Given that arm tackles reduces the chances of succeeding in contact, and destabilizes the shoulder, it is recommended that when training tackling, coaches should focus on the footwork of the tackler, and emphasis the importance of body position and trying to stay square with the ball-carrier as long as possible in order to contact the ball-carrier with the shoulder [1;77]. Moreover, coaches need to demonstrate the arm positions that stabilize the shoulder before contact.

The ball-carriers' chances of offloading and gaining territory increased when tacklers' struck the legs as the first point of contact as opposed to contacting the mid-torso area. Contacting the legs to tackle the ball-carrier however reduced the chances of a tackle break and improved the probability of a successful tackle. These findings suggest that as a tackler, contacting the legs of the ball-carrier as the

first point of contact will afford a passive tackle where the ball-carrier is only brought to ground. However, to execute an active and more dominant tackle, tacklers should aim for the mid-torso area where the ball-carrier's centre of gravity is usually situated.

The prospect of the tackler succeeding in contact significantly decreased when the ball-carrier used a fend. From a ball-carrier perspective, the effectiveness of fending during contact has been reported. Studying contact skills that predict tackle breaks in the 2006 Super 14 competition, Wheeler and Sayers found strong fending strategies to significantly contribute to poor positioning by defenders [88]. As a result, the quality (absent, moderate, and strong) of the fend was significantly associated with breakdown wins, tackle breaks and offloading [88]. Similar results where shown in the present study, except for the relationship between fending and offloading. In the current study, a moderate fend increased the likelihood of an offload, whereas as strong fend decreased the likelihood of an offload occurring. This suggests that the function of the moderate fend by the ball-carrier is not to break the tackle, but rather to evade the tackler to afford an offload. In contrast, ball-carriers employing a strong fend makes a concerted decision not to offload, and attempts rather to break the tackle. From a tackler perspective, any form of fending strategy used by the ball-carrier seems to increase the difficulty of succeeding in contact. Despite this, little or no consideration is given on tackler counter measures in the coaching literature [118]. Future studies concentrating on developing strategies for the tackler to counter the ball-carrier's fend is therefore warranted. Ultimately, these counter fend strategies should form part of the coaching literature and be included in tackle training programs.

Not surprisingly, using the legs to drive through the tackle after contact consistently increased the likelihood of success in the tackle for both the tackler and ball-carrier. The effectiveness of leg driving subsequent to contact, for both ball-carrier [88] and tackler [77], is well reported in the coaching literature

and described in training manuals for injury prevention [4;63;64;68;118]. Furthermore, in practice, players reported that 'Using the legs to drive the tackle' was emphasised the most when training the front-on tackle [152]. Needless to say, the advantage of driving the legs beyond contact arises from players applying an added force over an extended period against their opponents [118]. Apart from offloading, tacklers using their arms to either wrap or pull ball-carriers had a higher probability of success in contact. Similar to leg driving, using the arms to either wrap or pull the ball-carrier is also a highly recommended technique described in injury prevention training manuals [4;63;64;68;118].

The present study analysed tackle situations from a cohort of Super 14 matches. Given the high-level of training and experience of Super 14 players [175;188;189], caution should be applied when generalizing these findings to other levels of play (for example, junior or amateur players). It is also recommended that future research consider the location on the field where the tackle takes place, the time period, and factors preceding the pre-contact phase (for example, defensive strategies of the team). The time period in which the tackle occurs is especially important since increased fatigue levels has been shown to contribute to poor tackling technique [35]. Recent studies in other team sports have shown that technical components, such as tackling, are influenced by situational conditions such as match location, quality of opposition, and match status [190-192].

5.5 Conclusions

Key characteristics that predicted a successful tackle were identified in the present study (Figure 1). Notably, reducing tracking time, countering the ball-carrier fend and using the arms to warp or pull the ball-carrier. Moreover, the characteristics identified in this study provide scientific evidence to support

current injury prevention training manuals for the tackler. In this regard, tackler techniques described as reducing the risk of injury, also increase the likelihood of a successful tackle.

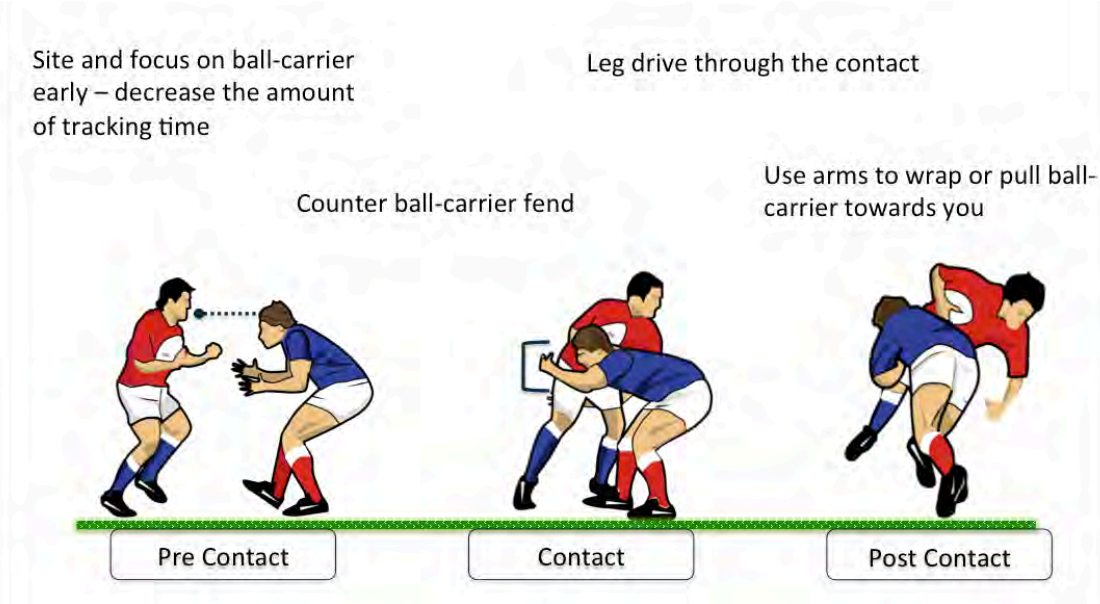

Figure 5.1 Summary of key characteristics that significantly predicted a successful tackle.

Chapter 6 Defensive Strategies in Rugby Union

S Hendricks, B Matthews, B Roode, M Lambert. Defensive Strategies in Rugby Union. *Perceptual and Motor Skills*. In review.

6.1 Introduction

Rugby union is a popular international team sport. It is played by two team teams, each consisting of 15 players, for 2 periods of 40 minutes [5]. The primary objective of the game is to score as many points as possible by advancing the ball down the field towards and over the opposition try-line or kicking the ball between the goal posts [118]. Since the game of rugby union became professional in 1995, the demand and emphasis on team success has increased substantially. In accordance with this increased demand, players, coaches and support staff have more time and resources available to study and apply various aspects to the game in an attempt to obtain a competitive advantage over the opposition [118]. Consequently, rugby has evolved into a more structured game with teams implementing a range of game strategies and tactics. This evolution of a more structured game also has filtered down into amateur rugby.

In accordance with the objective of the game, the aim of adopting these strategies and tactics is to score as many points as possible. Comparable to most team sports, this phase of the game is known as attack or offense. Teams also employ strategies and tactics to prevent the attacking team from scoring points. As in most team sports, this phase of play is known as defence. Defence in rugby union not only aims to prevent the attacking team from scoring points, but also to regain possession of the ball [193;194]. Approximately 50% of the game is spent defending [195-197]. Therefore, undoubtedly success in rugby union is dependent, in part, on the defensive strategies of a team.

Defensive strategies are structured around the shape of the defensive strategy, the spacing of the players within the defensive strategy, defensive line speed and organisation (which includes communication between the players) [193]. This structured movement of players with a common goal in a

match setting is analogous to a dynamical system [145;198;199]. In this regard, the defensive system is regulated by a number of constraints, for example, the laws of the game, the attacking strategy of the team in possession of the ball, players within the defensive behaviour system and perception of the situation, and instructions given by the coach during training or before the game [145;198;199]. An effective and efficient system should therefore have the capacity to successfully re-structure and re-organise the defensive strategy in response to these constraints [145;198;199].

To optimize training and preparation for matches (and therefore improve performance), researchers and coaches frequently study performance characteristics of successful teams and analyse strategies and tactics of opposition teams [87;200-203]. An effective method for studying and analysing team performance has been the use of video and notational analysis [204;205]. A fundamental component of notational analysis is the selection and identification of key action variables of the sport that aim to define some or all aspects of performance [204]. In rugby union, video and notational analysis has been used extensively from identifying injury mechanisms and risk factors [5;13;141;187], to quantifying match demands [175;176;189;206;207] and its relationship with physiological indicators [36;188]. In particular, video and notational analysis has been used to describe attacking strategies associated with team success [87;88]. Wheeler et al. described attacking patterns of team play during the Super 14 2006 and their association with phase outcome and team success [87]. A major finding of this study was that tackle-breaks and not line-breaks or offloading in the tackle were associated with team success in rugby union [87]. The authors proposed that this finding suggests that defensive structures at elite level may limit the space of attackers, and therefore prevent attackers from breaking the line. In spite of this proposal, this finding was difficult to substantiate since the study did not describe defensive strategies in detail. Furthermore, studies on defensive strategies in rugby union are limited.

Undoubtedly success in rugby union is dependent on both effective attacking and defensive strategies. Analysis of effective attacking and defensive strategies is therefore imperative for designing training drills and game strategies in order to prepare adequately for competition. Despite this, very little empirical evidence exists about effective defensive strategies in rugby union. Therefore, the purpose of this study is to describe defensive characteristics that would increase the likelihood of a successful phase outcome in rugby union while taking into account the game situation.

6.2 Method

6.2.1 Procedures

Commercially available video footage was analysed using Sports Code elite version 6.5.1 (Sportstec, Australia), using an Apple iMac (Apple, USA) positioned at eyelevel. The analysis software allowed control over the time lapse during each movement, and the recording and saving of each coded instance into a database. Instances were coded using characteristics and definitions described in previous research [13;87;88], and characteristics and definitions developed specifically for this study. Characteristics were divided into three categories – playing situation, defensive characteristics, and phase outcomes. Twenty-one matches were analysed of the 2010 Super 14 competition, which amounted to 2394 coded instances. Although each game was randomly selected, quota sampling was used to ensure relatively equal distribution between playing teams and competition week. This was to avoid a bias towards a playing team or time in the competition.

Defence was defined as the team not in possession of the ball, with two or more players (defenders) facing the attacking line at the phase of play or at the point of breakdown. An attacking line was

identified when the ball-carrier (attacker in possession of the ball) and potential ball-carriers (attackers in proximity) challenged the gain line [85].

6.2.2 Playing Situation

Previous Phase or Set Piece: The phase or set play preceding the attack/defence interaction. These were divided into scrums, lineouts, ruck and mauls (as defined by the International Rugby Board).

Pass Number: The number of passes from the previous phase or set piece where the attacker received the ball and makes contact with the defender [87].

- Immediate – when the attacker received possession of the ball directly from the breakdown, or set piece. i.e. no pass.
- Close – when the attacker received possession of the ball through no more than one pass from the breakdown or set piece.
- Middle – when the attacker received possession of the ball through a pass from the first receiver, i.e. second pass.
- Wide – when the attacker received possession of the ball through beyond the second pass

Attacking Strategy: Running lines and direction of the attacker or attacking line [87]

- Direct – attackers ran directly at defenders.
- Lateral – attackers ran away from defenders i.e. not direct.
- Evasive step – attacker used a side step or crossover step before contact with the defender
- Combinations of the above were also identified, i.e. Direct Lateral Evasive Step, Direct Evasive Step, Direct Lateral, Lateral Evasive Step.

Field Position: The field was divided into a 4x4 matrix (16 segments). The direction of play was from right to left, i.e. the attackers' goal line was in the A region while the defenders' goal line was in the D region.

Match Period: Each match was divided into four periods of 20 minutes (1st, 2nd ,3rd and 4th period). Thereafter the period in which each instance occurred was recorded.

6.2.3 Defensive Characteristics

Distance of Defence: Distance of the defence in relation to the attacker when the attacker receives possession of the ball [87].

- Close – attacker receives ball within one body length of defence.
- Moderate – attacker receives ball one to two body lengths from defence.
- Distant – attacker receives ball more than two body length from defence.

Defensive Speed: The speed of the defence in response to the attacking line [176;184]

- Slow – defence is stationary or walking.
- Moderate – defence is jogging or a slow run with low knee lifts.
- Fast – defence is running with high knees or sprinting at ball reception.

Defensive Direction: The direction of movement of the defence in response to the attacking line.

- Lateral – defence is approaching the ball carrier laterally.
- Backwards – defence is retreating from the ball carrier.
- Forward – defence is approaching the ball carrier front-on.
- No direction – Defence has no identifiable movement direction i.e not moving lateral, backwards or forwards.

Defensive Shape and Movement: configuration and movement pattern of defenders.

- Up and in– defenders approach the attacking line in a straight-line formation followed by the outer players (players furthest away from the ball) advancing ahead of the line towards the ball.
- Up and out – defenders approach the attacking line in a straight-line formation followed by inner players (players closest to the ball) following the movement of the ball towards the touchline.
- Push/rush – the defenders approach the attacking line at a fast speed and are in a straight and direct line.
- Lateral shift – initial movement of the defenders is towards the touchline without challenging attacking line/attacker.
- Rabbit runner – one defender shoots rapidly from the defensive line towards attacking line/attacker.
- Straight line – defenders are in a straight line while approaching the attacking line.
- Static line – defenders are in a straight line and with no movement towards the attacking line/attacker.
- Arrow head – defenders approach the attacking line in a triangle shape formation, i.e. one defender is followed by other defenders besides and behind him on each side.
- Random – defenders with no clear configuration or movement pattern.

Defender vs. Attacker Ratio: The ratio of attacker's vs. defenders of the defence line from when the phase begins.

- Man on man: same number of defenders and attackers.
- One man over lap: one more defender in the defensive line compared to the attacking line.

- Two man over lap: two more defenders in the defensive line compared to the attacking line.
- Multiple over lap: more than two defenders in the defensive line compared to the attacking line.
- One man under lap: one more attacker in the attacking line compared to the defending line.
- Two man under lap: two more attackers in the attacking line compared to the defending line.
- Multiple under lap: more than two attackers in the attacking line compared to the defending line.

6.2.4 Phase Outcomes

Gain line: an imaginary line that is drawn through the middle of the set piece/breakdown width wise dividing the field into two separate regions [193].

- Gain line not crossed: the defensive team prevented the attack ring team from crossing the gain line.
- Gain line crossed: the defending team was unsuccessful in preventing the attacking team from crossing the gain line. The gain line was crossed either by a tackle break, offload, line break or tackled after crossing the gain line [87;88].
  - Tackle break: gain line crossed by attacker penetrating the attempted tackle.
  - Offload: gain line crossed by attacker successfully off loading in the contact situation.
  - Line break: gain line crossed by attacker successfully evading contact.
  - Tackled: tackled after crossing the gain line.

Breakdown: post tackle contact situation that resulted in a ruck or maul.

- Breakdown win: defending team successfully regained possession of the ball

- Breakdown loss: defending team failed to regain possession of the ball
- Breakdown penalized: an offense, which is cause by a player during the breakdown.

The Tackle Sequence: The sequence of attacker and defenders in the contact situation [13].

- One-on-one: one defender contacts one attacker.
- Sequential: one defender contacts one attacker, followed by a second defender joining the contact situation.
- Simultaneous: two defenders contact one attacker at the same time.
- Attacking Sequential: two attackers contact one defender

Other Outcome Variables

- Handling error: incomplete passes or dropped balls.
- Handling error knock on: the attacker knocks the ball on.
- Handling Error forward pass: the attacker passes the ball in a forward direction.
- Touch: the attacker runs into touch (outside the field of play).
- Interception: a defender intercepts the ball.
- Obstruction: the attacker runs into his teammate.

Only instances with clearly identified breakdown/set piece and attack/defender lines were used. Kick and advantage plays were excluded from the analysis. Advantage plays were excluded since the outcomes of these events after the advantage is awarded is predetermined and independent of the defensive strategy of the team.

6.2.5 Statistical Analyses

The objective of the analysis was to determine which defensive characteristics increased the likelihood of a successful phase outcome. To determine this, multinomial logistic regression (mlogit) analysis was

computed using STATA 11.1 (StataCorp LP, USA). Before the mlogit analysis, descriptive statistics (frequency %) were calculated. Characteristics that had a percentage frequency of 0% were excluded from mlogit analysis. Main effect mlogit models were conducted for each phase outcome. Thereafter likelihood ratio tests were conducted to test the overall effect of each characteristic on the phase outcome. Characteristics that had an overall significant effect ($p<0.05$) on the outcome were then expanded upon and reported (specific effects model). Relative risk ratio's (RRR) and 95% confidence intervals are reported for the main effects models and the characteristics of the specific effects model. Significant characteristics in the specific effects model were also disclosed, with the alpha p value set at $p<0.05$. The standard interpretation of the multinomial logistic regression is that for a unit change in the predictor variable (the tackle characteristics), the logistic of outcome relative to the referent group (base outcome) is expected to change by its respective parameter estimate (RRR) given that the characteristics in the model are held constant.

6.2.5.1 Phase Outcomes and Match Results

Chi-squared (χ^2) analysis was used to examine whether the phase outcomes of the present study was associated with winning or losing and the amount of points scored against the defending side. Points against was grouped into five categories:

- Category 1: 0-10 points.
- Category 2: 11-20 points.
- Category 3: 21-30 points.
- Category 4: 31-40 points.
- Category 5: >40 points.

6.2.5.2 Reliability

For intra-coder reliability, two matches were coded on two separate occasions using the variables and definitions described previously. Coding of the same match was separated by at least one week [87]. Pearson correlation and standard error of the estimate (*SEE*) were used to compare the number of instances coded for the same match on the two different occasions. Acceptable intra-code reliability was shown between the matches coded on the two different occasions (match 1 r=0.99, *SEE* = 4.2 and match 2 r=0.97, *SEE* = 8.2).

6.3 Results

6.3.1 Descriptive Statistics

Table 6.1 reports the frequency percentages for all characteritics during each phase of play and for the different outcomes.

6.3.2 Phase outcome and Match Results

Winning in the Super 14 2011 was associated with a team's breakdown win/loss ratio when defending (χ^2 (1) = 5.10, P<0.05). Winning teams won more breakdowns (17%) on defence (regaining possession of the ball) compared to losing teams (13%). Teams that won more breakdowns also had less points scored against them (breakdown wins 18% in category 1 compared to 15% in category 5). Crossing the gain line was not associated with winning or losing (χ^2 (4) = 4.11, P=0.391). However, crossing the gain line was associated with the amount of points scored against a team (χ^2 (16) = 38.73, P≤0.001). Teams in category 1 had less line breaks (1%) and tackle breaks (8%) compared to teams in the other categories.

Table 6.1 Frequency percentages for all characteristics during each phase of play and for the different outcomes (n=2394)

6.3.3 Playing situation, defensive characteristics and breakdown outcome

Playing Situation	n	%	Defensive Characteristics	n	%	Outcomes	n	%
Set Piece			Defensive Distance			Gain Line		
Breakdown	2 017	8	Close	1 308	55	Not crossed	1,008	43
Lineout	26	1	Moderate	562	24	Tackled but crossed	1,007	43
Scrum	199	84	Deep	520	22	Tackle Break	196	8
Maul	152	6				Line Break	54	2
						Offload	93	4
Pass Number			Defensive Speed			Breakdown		
Immediate	497	41	Slow	903	38	Breakdown Win	329	14
Close	983	21	Moderate	1 326	56	Breakdown Win (penalized)	55	2
Middle	627	26	Fast	153	6	Breakdown Loss	1,860	78
Wide	284	12				Breakdown Loss (penalized)	147	6
Attacking Strategy			Defensive Direction			Other outcomes		
Direct	1 483	63	Forwards	1 288	54	Handling Error	176	46
Direct Evasive Step	187	8	Lateral	512	21	Knock on	137	36
Direct Lateral	6	0	Forwards Lateral	131	5	Forward Pass	19	5
Direct Lateral Evasive	10	0	No direction	450	19	Handling error in to touch	7	2
Lateral	455	19	Backwards	4	0	Interception	9	2
Lateral Evasive Step	212	9				Touch	30	8
Evasive Step	3	0				Obstruction	2	1
Match Period			Defensive shape and movement			Tackle Sequence		
1st Quarter	488	22	Straight Line	806	34	One on One	832	37
2nd Quarter	502	23	Static Line	308	13	Sequential	802	36
3rd Quarter	594	27	Rabbit	232	10	Simultaneous	464	21
4th Quarter	608	28	Up and Out	161	7	Attacking Sequential	152	7
			Up and In	233	10			
			Lateral	299	12			
			Random	218	9			
			Rush/Push	32	1			
			Arrow Head	104	4			

The period in which the play occurs ($p \leq 0.05$), the number of passes from the previous phase or set piece ($p \leq 0.001$) and speed of defence ($p \leq 0.05$) had a significant effect on the breakdown outcome (Table 6.2). The probability of the defensive side winning the breakdown and regaining possession of the ball increased as the match progressed (RRR 1.45, 95% CI 1.01-2.09, $p \leq 0.05$ in the 4th quarter). Also, the defensive team's chances of winning the breakdown significantly increased when the

attacking team played the ball further away from the previous phase or set piece (Immediate RRR 0.74, 95% CI 0.48-1.13; Middle RRR 1.52, 95% CI 1.11-2.08, p≤0.01; Wide RRR 2.29, 95% CI 1.57-3.35, p≤0.001). A moderate defensive speed (RRR 1.37, 95% CI 0.66-2.14) increased the likelihood of a breakdown win compared to a slow speed, provided all the other characteristics in the model remained constant.

6.3.4 Playing situation, defensive characteristics and crossing the gain line

Playing situation characteristics that had a significant effect on crossing the gain line were the number of passes made (p≤0.001) and the attacking strategy used by the attacking player/team (p≤0.001) (Table 6.3). In terms of defensive characteristics, speed (p≤0.001) and direction of movement (p≤0.001) were significant predictors of crossing the gain line.

Table 6.2 Multinomial logistic regression for playing situation, defensive characteristics, and breakdown outcomes. Data reported as relative risk ratios (RRR) and 95% confidence intervals (95% Cl).

Playing Situation, Defensive Characteristics and Breakdown Outcome					
	RRR		95% CI		P value
Breakdown Win (vs. Breakdown Lost)	Main	Specific	Main	Specific	Main
Playing Situation					
Period (1st quarter)	1.12		1.00-1.25		0.05
2nd quarter		1.36		0.92-1.99	
3rd quarter		1.43		0.99-2.07	
4th quarter		1.45		1.01-2.09*	
Field location	0.99		0.96-1.03		0.78
Set piece	1.11		0.91-1.35		0.29
Pass number (Close)	1.33		1.18-1.49		0.001
Immediate		0.74		0.48-1.13	
Middle		1.52		1.11-2.08**	
Wide		2.29		1.57-3.35***	
Attacking Strategy	0.92		0.81-1.04		0.17
Defensive Characteristics					
Distance	0.98		0.84-1.14		0.76
Speed (Slow)	0.78		0.84-1.14		0.05
Moderate		1.37		0.66-2.14	
Fast		1.19		0.97-1.94	
Direction	1.02		0.90-1.14		0.78
Shape and Movement	0.99		0.94-1.05		0.72

≤ 0.05 ** ≤ 0.01 *** ≤ 0.001
Main – main effects model
Specific – specific effects model
Base outcome in brackets()

Passing the ball wide significantly increased the probability of the attacking team breaking the line (*Line-Break* RRR 4.77, 95% CI 1.97-11.55, p≤0.001) or offloading (*Offload* RRR 2.97, 95% CI 1.42-6.22, p≤0.01). Whether running directly or laterally, the addition of an evasive manoeuvre before contact significantly increased the chances of an offload (*Offload* Lateral Evasive Manoeuvre RRR 2.09, 95% CI 1.06-4.10, p≤0.05) or breaking the tackle (*Tackle Break* Direct Evasive Manoeuvre RRR 2.73, 95% 1.64-4.55,p≤0.001; Lateral Evasive Manoeuvre RRR 2.63, 95% 1.59-4.34,p≤0.001) compared to running directly into contact. A moderate (*Tackled-Gain line crossed* RRR 0.44, 95% 0.34-0.57,p≤0.001) or fast (*Tackled-Gain line crossed* RRR 0.42, 95% 0.27-0.67,p≤0.001) defensive line speed significantly reduced the likelihood of the attacking team crossing the gain line. The

probability of defenders stopping the attackers from penetrating the tackle (*Tackle Break* RRR 2.19, 95% 1.11-4.34,p≤0.001), and preventing the attackers from crossing the gain line (*Tackled-Gain line crossed* RRR 1.58, 95% 1.06-2.36,p≤0.05), was significantly reduced when the defenders approached the attacker from a lateral direction. In contrast, approaching the attackers from a front-on direction significantly reduced the attackers chances of crossing the gain line (*Tackled-Gain line crossed* RRR 0.37, 95% 0.27-0.50, p≤0.001).

Playing situation characteristics that predicted the likelihood of a double tackle compared to one-on-one tackles were field position (p≤0.001), pass number (p≤0.001) and attacking strategy (p≤0.001) (data not shown in table). Taking into account the playing situation, defensive characteristics that predicted the likelihood of a double tackle compared to one-on-one tackles included defensive distance (p≤0.001), defensive speed (p≤0.001), defensive direction (p≤0.05) and defensive shape and movement (p<0.001) (data not shown in table). Having a *rabbit runner* or no clear defensive shape or movement significantly decreased the likelihood of a double tackle (Rabbit RRR 0.19, 95% CI 0.78-0.47, p≤0.001; Random RRR 0.37, 95% CI 0.19-0.74, p≤0.01).

Only 240 instances of defender vs. attacker ratios were identified due to the visual of the video footage. The defensive speed (χ^2 (32) = 59.83, P≤0.01), and defensive shape and movement (χ^2 (8) = 15.62, P≤0.05) of the defending team were significantly associated with the defender vs. attacker ratio. During a phase play where attackers had an extra player, the defensive shape and movement most frequently used by defenders were up and out (27%), and lateral shift (30%). A moderate defensive speed (77%) was most frequently used when the attacking side had an extra player during a phase play.

Table 6.3 Multinomial logistic regression for playing situation, defensive characteritics and gain line crossed. Data reported as relative risk ratios (RRR) and 95% confidence intervals (95%Cl)

Playing situation, Defensive characteristics and Gain line crossed					
	RRR		95% CI		P value
	Main	Specific	Main	Specific	Main
Line-Break (vs Tackled-Not crossed)					
Playing Situation					
Period	1.04		0.81-1.33		0.78
Field location	0.95		0.87-1.04		0.29
Set piece	1.26		0.82-1.94		0.30
Pass number (Close)	1.78		1.35-2.36		0.001
Immediate		1.83		0.59-5.69	
Middle		1.88		0.85-4.17	
Wide		4.77		1.97-11.55***	
Attacking Strategy (Direct)	1.08		0.84-1.40		0.54
Direct Evasive Manoeuvre		1.86		0.79-4.36	
Lateral		0.88		0.41-1.90	
Lateral Evasive Manoeuvre		1.29		0.52-3.22	
Defensive Characteristics					
Distance	1.11		0.79-1.56		0.56
Speed (Slow)	0.84		0.47-1.51		0.56
Moderate		1.53		0.51-4.55	
Fast		1.32		0.30-5.78	
Direction (No direction)	1.31		0.98-1.75		0.07
Forwards		0.58		0.14-2.43	
Forwards Lateral		1.99		0.35-11.35	
Lateral		1.24		0.27-5.76	
Shape and Movement	0.92		0.82-1.03		0.16
Offload (vs Tackled-Not crossed)					
Playing Situation					
Period	0.99		0.81-1.20		0.89
Field location	0.92		0.86-0.98		0.01
Set piece	1.28		0.88-1.87		0.20
Pass number (Close)	1.50		1.20-1.87		0.001
Immediate		0.82		0.37-1.83	
Middle		2.08		1.16-3.74**	
Wide		2.97		1.42-6.22**	
Attacking Strategy (Direct)	1.28		1.05-1.56		0.01
Direct Evasive Manoeuvre		1.44		0.65-3.16	
Lateral		1.44		0.81-2.55	
Lateral Evasive Manoeuvre		2.09		1.06-4.10*	
Defensive Characteristics					
Distance	1.09		0.83-1.44		0.52
Speed (Slow)	1.20		0.74-1.93		0.47
Moderate		1.05		0.46-2.37	
Fast		0.45		0.11-1.84	
Direction (No direction)	1.83		1.46-2.28		0.001
Forwards		0.14		0.06-0.35***	
Forwards Lateral		0.35		0.10-1.26	
Lateral		0.56		0.21-1.52	
Shape and Movement	0.96		0.88-1.06		0.43
Tackle Break (vs Tackled-Not crossed)					
Playing Situation					
Period	1.07		0.93-1.23		0.35
Field location	0.97		0.92-1.02		0.22
Set piece	1.04		0.81-1.33		0.75
Pass number (Close)	1.02		0.87-1.19		0.81
Immediate		1.08		0.64-1.81	

Table 6.2 Continue					
Middle		0.87		0.58-1.30	
Wide		1.02		0.57-1.81	
Attacking Strategy (Direct)	1.33		1.16-1.54		0.001
Direct Evasive Manoeuvre		2.73		1.64-4.55***	
Lateral		1.31		0.85-2.02	
Lateral Evasive Manoeuvre		2.63		1.59-4.34***	
Defensive Characteristics					
Distance	1.00		0.82-1.22		0.99
Speed (Slow)	1.00		0.73-1.38		0.99
Moderate		0.65		0.41-1.02	
Fast		0.94		0.48-1.85	
Direction (No direction)	1.37		1.17-1.60		0.001
Forwards		0.74		0.41-1.35	
Forwards Lateral		1.63		0.62-4.29	
Lateral		2.19		1.11-4.34*	
Shape and Movement	0.95		0.89-1.02		0.19
Tackled – Gain line crossed (vs Tackled-Not crossed)					
Playing Situation					
Period	1.01		0.93-1.10		0.74
Field location	0.97		0.94-1.00		0.04
Set piece	1.07		0.92-1.26		0.37
Pass number (Close)	1.01		0.92-1.11		0.85
Immediate		1.24		0.92-1.66	
Middle		0.70		0.54-0.91**	
Wide		1.18		0.82-1.70	
Attacking Strategy (Direct)	1.02		0.92-1.12		0.75
Direct Evasive Manoeuvre		1.01		0.69-1.48	
Lateral		0.86		0.66-1.11	
Lateral Evasive Manoeuvre		1.03		0.71-1.49	
Defensive Characteristics					
Distance	1.12		1.00-1.26		0.05
Speed (Slow)	1.66		1.37-2.01		0.001
Moderate		0.44		0.34-0.57***	
Fast		0.42		0.27-0.67***	
Direction (No direction)	1.68		1.54-1.84		0.001
Forwards		0.37		0.27-0.50***	
Forwards Lateral		1.12		0.63-2.02	
Lateral		1.58		1.06-2.36*	
Shape and Movement	1.02		0.97-1.06		0.49

6.4 Discussion

The aim of this study was to describe, the defensive characteristics that would increase the likelihood of the defending team winning the breakdown or preventing the attacking team from crossing the gain line while considering the playing situation of the playing phase. The study found that the likelihood of the defending team winning the breakdown increased as the match progressed, and when the attacking team moved the ball further away from the previous phase or set piece. Moreover, defensive speed was

the only significant defensive characteristic that predicted breakdown wins, where defenders approaching attackers at a moderate or fast speed increased the probability of a breakdown win. Undoubtedly, approaching the attacking line at a set speed affords less time and space for the attackers to decide and execute their play [1;193;208]. From an attacking perspective, this is worsened when the attack was out wide, as indecision and poor execution may result in a player getting isolated and as a consequence not have enough supporting players at the breakdown to maintain possession of the ball. These findings are in accordance with studies describing effective attacking strategies where attacking wide was associated with losing the breakdown. The definition of breakdown success used in this study was based on previous research in this area [87;205], and was defined according to the defensive teams regaining of possession of the ball. The ability to win the breakdown is however, not only dependent on tactical proficiency as measured in this study, but also technical proficiency [188]; therefore tackle and breakdown technique may have influenced the outcome of the event.

In contrast to breakdown wins, passing the ball wide increased the probability of line-breaks and offloads. Considering that playing wide increases the chances of a breakdown win, this finding suggests that when contact is avoided out wide, defensive lines are vulnerable, and as a result, the gain line is crossed. For defenders, preventing line-breaks and offloads is key to success in rugby union as the present study and others have shown a positive association between the number of line-breaks and offloads and the amount of points scored against a team [87]. The addition of an evasive manoeuvre by the attacker, regardless of the running line, further increased the vulnerability of the defensive line as this increased their chances to offload or break the tackle. These findings lend support to previous research in this area where an evasive manoeuvre represented the most effective attacking strategy in achieving tackle breaks [85;87]. An attacker utilizing an evasive manoeuvre to avoid front on contact is likely to put the defender in a weak position resulting in a poor and ineffective attempted tackle, and

consequently, the attacker is able to break the tackle or free his arms to offload the ball. Comparable to breakdown wins, a moderate or fast speed prevented attackers crossing the gain line. This provides further evidence for the effectiveness of line speed during defence in rugby union [1;193;208]. In addition, approaching attackers front-on as opposed to lateral reduced the likelihood of the attackers crossing the gain line. This highlights the importance of the defender getting into an advantageous position in preparation for executing an effective tackle [118;152].

In the present study, tackle sequence was also used as an outcome variable even though the sequence of attackers and defenders in the contact situation may not have a direct effect on the amount of points scored against a team. However, when defenders executed a double tackle or sequential tackle, it is usually an indication of a good defensive strategy. The ability to execute doubles tackles in the present study was predicted by most of the variables, suggesting there are several factors that contribute to executing a double tackle. Nonetheless, the strongest indicator for the unlikelihood of doubles tackles in our analysis was having a rabbit runner or no clear defensive shape. The defenders vs. attackers ratio is critical when deciding on which defensive strategy to employ since it is reliant on game situation [145;193;198;199]. To analyse the defenders vs. attackers ratio accurately, wide screenshots are needed to identify all the players in the defensive and attacking lines. Since our study only used commercially available video footage, our analysis was limited to only 240 instances where these criteria were fulfilled. Given this limitation, chi-squared analysis instead of multiple regression analysis was used to find associations between the ratio and defensive characteristics. The defensive speed and the defensive shape and movement were significantly associated with the defender vs. attacker ratio. When the attacking side had one extra player during a phase play, , the strategy applied was up and out or lateral shift with a moderate defensive speed. These defensive characteristics are synonymous when the defending side is at a number disadvantage, as defenders will try to limit the attacking side space by

ushering the attackers towards the touchline [193;208]. Further analysis, with more instances and accounting for the playing situation is needed to make any additional conclusive remarks.

The purpose of this study was to describe the defensive characteristics of Super 14 teams that would lead to a successful outcome. However, we do acknowledge that tactical proficiency alone is not enough to succeed in the outcome variables chosen for this study [188]. In this regard, using this study as a basis, it is recommended that future research in this area analyse the relationship between the playing situation, the defensive characteristics of a team and characteristics of the defenders tackle technique.

Furthermore, future research should investigate how this relationship influences the chances of the defending team winning the breakdown and gaining possession of the ball or prevents the attacking team from crossing the gain line. Prospective studies should also account for factors such match location (i.e. playing at home or away), quality of opposition, and match status as recent studies in other team sports have shown that these factors can influence a team's strategy and tactics [190-192;203]. Nonetheless, the defensive strategies executed during matches should be governed by the playing situation. For this reason, defensive training drills should simulate match conditions to improve defenders adaptability to the playing situations. From a practical perspective, the defensive strategies executed during matches should be governed by the playing situation. For this reason, defensive training drills should simulate match conditions to improve defenders adaptability to the playing situation.

In conclusion, understanding match behaviour and dynamics is substantive for the organisation, design, teaching, and training of team sports [145;193;198;199]. Indeed, this methodology has been successfully demonstrated in rugby union [87;88;143;145;155;198;201]. In our analysis, a moderate or fast defensive line

speed increased the likelihood of both breakdown success and preventing the attacking team from crossing the gain line. This finding supports current coaching literature on the importance of approaching line speed during defence [1;193;208].

Chapter 7 Summary and Conclusions

Introduction

This thesis investigated current training methods, and proposed to understand the demands of the tackle in real match situations to identify and develop better coaching and training strategies. The thesis was divided into 5 studies, each designed to answer specific questions (bold), which contributed to fulfilling the overall objectives of the thesis. In an attempt to synthesise the data a succinct answer to each research question is provided below.

Chapter 2

Question

What are the current attitudes and behaviours of rugby union players in training and match play with regards to injury prevention and improving performance in the tackle?

Answer

When executing a tackle the aim is to dominate the contact situation and prevent the ball-carrier from gaining territory and retaining the ball. During training and match play, the mean ratings of players were marginally higher for improving performance than for injury prevention. Players, coaches, and administrators need to find the most suitable balance between injury prevention and performance during training within their team setting. Modifying the current equipment and training drills used to train the tackle, and the time of season during which tackle technique training occurs may facilitate this process. Equally important, players should learn proper tackle technique at a younger age, with the importance of safety emphasised from all information sources.

Chapter 3

Question

What are the ball-carrier and tackler velocities and acceleration values before contact in real match situations at different levels of play?

Answer

Using an innovative video analysis method, the velocities at which ball-carriers and tacklers in Super 14, Varsity Cup and Under 19 competitions enter front-on and side-on tackles in real match situations is now known. This study suggested that when tacklers enter the pre-tackle phase at a velocity considerably different to that of the ball-carrier (whether higher or lower), tacklers adjust their velocity accordingly to reach a suitable relative velocity before making contact with the ball-carrier. This knowledge of the interaction between ball-carrier and tackler before the tackle in real match situations, which arguably governs the dynamics of the tackle, provides a basis for future studies.

Chapter 4

Questions

- **Quantify momentum and kinetic energy before contact in the tackle during real match situations for the ball-carrier and tackler in 3 different levels of competition.**
- **Estimate the magnitude of energy transfer during tackle situations and relate this magnitude to distance from set piece/breakdown and position.**
- **What is the relationship between the physical components before contact in the tackle and level of play, type of tackle, playing position, distance relative to set piece and the outcome of tackle?**

Answer

In accordance with the objectives of this study, momentum and kinetic energy before contact in the tackle during real match situations for the ball-carrier and tackler have now been quantified. As expected, the player with the higher momentum or kinetic energy was more likely to succeed in contact. However, when other factors were accounted for, this odds ratio decreased. Of these factors, the manner in which contact was made (i.e. front-on or side-on) was a significant predictor. Furthermore, it appears that there is an increased risk of entering a high impact collision further away from contact. Based on previous work in conjunction with our findings, a theoretical model for the relationship between the number of tackles a player competes in (acute or chronic fatigue), energy lost (magnitude of impact), markers of muscle damage and how this relationship interacts with injury risk (tolerance overload or reduction) and performance is offered.

Chapter 5

Question

What are the tackler characteristics that may increase the likelihood of a successful tackle outcome in rugby union?

Answer

Tracking was a key pre contact characteristic that decreased the tackler's chances of a successful tackle. Arm tackles and jersey tackles decreased the likelihood of a tackler completing a tackle, gaining territory and having a positive result compared to shoulder tackles. Contacting the legs to tackle the ball-carrier reduced the chances of a tackle break and improved the probability of a successful tackle. However, contacting the legs as the first point of contact as opposed to contacting the mid-torso area increased the ball-carriers chances of offloading and gaining territory. Furthermore, the prospect of the tackler succeeding in contact decreased significantly when the ball-carrier used a fend. Not surprisingly, using the legs to drive through the tackle after contact consistently increased the likelihood of success in the tackle for both the tackler and ball-carrier. Most of the key characteristics identified in this study are in accordance with training manuals from injury prevention programs such SmartRugby or BokSmart. Nonetheless, areas that can be improved in training for the tackle were also identified.

Chapter 6

Question

What are the defensive strategies in rugby union that may increase likelihood of a successful phase outcome?

Answer

The study found that the likelihood of the defending team winning the breakdown increased as the match progressed, and when the attacking team moved the ball further away from the previous phase or set piece. Moreover, defensive speed was the only significant defensive characteristic that predicted breakdown wins, where defenders approaching attackers at a moderate or fast speed increased the probability of a breakdown win. In contrast to breakdown wins, passing the ball wide increased the probability of line-breaks and offloads. Considering that playing wide increases the chances of a breakdown win, this finding suggests that when contact is avoided out wide, defensive lines are vulnerable, and as a result, the gain line is crossed. Comparable to breakdown wins, a moderate or fast speed prevented attackers crossing the gain line. This provides further evidence for the effectiveness of line speed during defence in rugby union.

7.1 Practical Implications

The aspects of the tackle studied in this thesis have indeed furthered our knowledge and understanding of the tackle in both training and match play. Execution of the correct techniques (for ball-carrier and tackler) during a tackle in rugby union will not only reduce the player's risk of injury, but also increase the player's chances of succeeding in contact. Furthermore, this thesis shows that technical training alone is not sufficient to fully prepare a player for the tackle contest in real match situations. Before contact in the tackle, the player's assessment and processing of the playing situation, and his/her ability to adapt and respond with the appropriate technical skills set is crucial to the outcome of the tackle.

Based on the findings of this thesis and concepts of motor control and sport performance [136] a chart that coaches and players can use as a guideline when developing skills for the tackle has been developed (Table 7.1). The guidelines begin with an assessment of the player(s); thereafter the coach prepares training accordingly by setting the difficulty of the task and environment. The coach will then evaluate the training by measuring the process as a performance indicator or the outcome as a performance indicator. As the player develops, the difficulty increases with the task becoming more complicated with addition of variables and the training environment approaching more match-like situations. The chart also allows coaches to modify the training specific to the player(s) or team needs. At the same time, refinement of the basic skills needs to be included in all sessions (perhaps as a warm-up to the harder tasks). When using the guidelines, coaches need to consider other factors such as physical condition [35] and psychological (motivation, attitude, experience) and previous injury of the player.

Table 7.1 Guidelines for Developing Tackling Skills

Player Level of play, age, skill level, experience, size of player, playing position, etc.	**Task** Basic principles and added variables	**Environment** Control vs. semi control vs. uncontrolled/ match simulating	**Measure of Performance** Indication of progress
Beginner, Junior	• General front on tackle instructions • Repetition of proper technique until it becomes implicit and autonomous. • Instruct on relevant cues when approaching the ball-carrier	• Controlled – against a stationary person or bag.	• Process measure – execution of proper technique • Efficiency
Intermediate	• Add reaction time and decision making [1] • Include physical contact • Add tackles from various directions, situations, and tackle types. • Add physical conditioning[35]	• Semi – controlled –tackler has 2 or 3 options to choose from, using a stationary person or bag, or slow moving person or bag. • Speed of movement of person or bag increases. • First in a controlled setting then progress to semi-control.	• Execution of proper technique, efficiency, decreased reaction time and speed.
Advance	• Train tackling technique according to defensive structures • Tracking of ball-carriers[4] • Individualize training for player (s), according to position, size, and team. • Refinement of basic skills.	• Semi-control • Match simulating conditions	• Outcome measure -Prevent ball-carrier from gaining territory and minimise the chance of the ball-carrier from retaining position of the ball [4]

7.2 Future Research

This thesis has not only furthered our understanding of the tackle, but also serves as a basis for future studies. In chapter 2, players' attitudes and behaviours were assessed and considered an indirect indication of the coaches' perspective. Prospective studies in this area should therefore focus on directly assessing coaches' attitudes and behaviours with regards to injury prevention and performance in the tackle, and quantitatively record training behviour. Undeniably, a natural progression from the studies in real match situations would be to understand the relationship between the physical components of the tackle, the governing dynamics in contact/non contact situations, the technical and tactical components of the tackle and defence, as well as situational factors such as home advanatage. Moreover, studying these aspects and relationships of the tackle in both the injured population and tackles that resulted in an injury will prove invaluable in our quest to improve tackle skill acquisition, performance, and injury prevention. Furthermore, as mentioned earlier, the pre tackle period is crucial for a successful tackle outcome. In this regard, perceptual, anticipatory, and decision-making components of tackle need to be explored further.

~oOo~

Appendices

Department of Human Biology
UCT/MRC RESEARCH UNIT FOR EXERCISE SCIENCE & SPORTS MEDICINE
Faculty of Health Sciences, University of Cape Town
Private Bag, Rondebosch 7700, South Africa
Tel: + 27-21-650-4569 Fax: + 27-21-686-7530

Investigation into Tackling Technique from the Perspective of Junior Rugby Players

Tackling in rugby is a fundamental component of the game. The ability to execute an effective tackle could be the difference between winning and losing, and more importantly getting injured or not. The purpose of this questionnaire is to gain insight into the:

I. Knowledge and opinions of South African rugby players around the tackle in training and match situations
II. Training and match behavior around the tackle situation among South African rugby players

This information will prove invaluable in our understanding and development of a safe and effective tackle which will allow for a more exciting and safe game of rugby for all.

Player Information			**Date: yyyy /mm/ dd**
Surname			
First Names			
Club/School Name			
Province			
Date of Birth	*y y y y m m d d*		
Height (cm)			
Weight (kg)			
Position (Indicate by marking an **X** on the position you mostly play)	*1 2 3 4 5 6 7 8 9 10 11 12 13 14 15*		
What is the highest level you have played?	**Team** (e.g. 1st XV, 2nd XV, under 20A, under 19 etc)	**Competition**(e.g Provincial, Varsity Cup, Super A/B, school etc	
What is the current level you playing(i.e this season)?	**Team** (e.g. 1st XV, 2nd XV, under 20A, under 19 etc)	**Competition** (e.g Provincial, Varsity Cup, Super A/B, school etc	
What was your age when you started playing rugby?	*<5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20>*		

Instructions:

All questions should be answered based on your current or most recent season's training and matches unless stated otherwise.

The questionnaire is divided into 2 sections: A. Training Questions
B. Match Questions

1. The questions are set out so that you may answer on a rating scale of 1 to 5 (except for Questions 1 were an exact amount is needed). The meaning of each of the numbers will be given on top of the answer table unless stated otherwise.
2. A *"not familiar (NF)"* option in certain questions will also be provided if you do not know what we are talking about.
3. To indicate your answers make an **X** in the desired block.

Example:

E.g Which type of tackle do you focus on during training?
To indicate your answers make an X in the desired block

	Not Familiar (NF)	Never	Rarely	Sometimes	Frequently	Always
Front-On Tackle	NF	1	X	3	4	5

A. Training Questions

1. How often do you train per week (includes gym, running, field sessions) during the different periods in the last season?
To indicate your answers make an X on the number of sessions you train per week.

Off-Season (Sep-Jan)	1	2	3	4	5	6	7	8	9	10 or more
Pre-Season (Jan-April)	1	2	3	4	5	6	7	8	9	10 or more
In-Season (April-Sep)	1	2	3	4	5	6	7	8	9	10 or more

2. How important is proper technique to you for the following?
To indicate your answers make an X in the desired block

	Not all important	Not too important	Undecided	Somewhat important	Very important
Injury prevention *(lowering the risk of getting injured during the tackle)*	1	2	3	4	5
Improved tackling performance *(Preventing the ball-carrier from gaining territory and the ball-carriers team from retaining the ball)*	1	2	3	4	5

3. How important is training tackling to you for the following?
To indicate your answers make an X in the desired block

	Not all important	Not too important	Undecided	Somewhat important	Very important
Injury prevention *(lowering the risk of getting injured during the tackle)*	1	2	3	4	5
Improved tackling performance *(Preventing the ball-carrier from gaining territory and the ball-carrier's team from retaining the ball)*	1	2	3	4	5

4. When having a team/squad field training session, how often did your team/squad train tackling technique in different periods of the last season?
To indicate your answers make an X in the desired block

	Never	Rarely	Sometimes	Frequently	Always
Off-Season (Sep-Jan)	1	2	3	4	5
Pre-Season (Jan-April)	1	2	3	4	5
In-Season (April-Sep)	1	2	3	4	5

5. When having a team/squad field training session, how often do you train the following different types tackles?
To indicate your answers make an X in the desired block

	Not Familiar (NF)	Never	Rarely	Sometimes	Frequently	Always
Front-On Tackle	NF	1	2	3	4	5
Side-On Tackle	NF	1	2	3	4	5
Smother Tackle	NF	1	2	3	4	5
Tackling from behind	NF	1	2	3	4	5
Double Tackle	NF	1	2	3	4	5

6. Coaches use various drills to train tackling and may spend more time on different aspects of the tackle. Please rate what method of coaching is important to you for a) Injury prevention *(lowering the risk of getting injured during the tackle)* and b) Improving tackle performance *(preventing the ball-carrier from gaining territory and the ball-carriers team from retaining the ball)*
To indicate your answers make an X in the desired block

a) Injury Prevention	Not Familiar (NF)	Not all important	Not too important	Undecided	Somewhat important	Very important
Live tackling in a 1 player vs. 1 player grid	NF	1	2	3	4	5
Using tackling bag	NF	1	2	3	4	5
Given verbal instruction	NF	1	2	3	4	5
Using shield	NF	1	2	3	4	5
Using a body armour	NF	1	2	3	4	5
A full contact practice match	NF	1	2	3	4	5
Demonstration	NF	1	2	3	4	5
Tackling Drill combined with ball skill exercise	NF	1	2	3	4	5
Tackling Drill combined with a vision exercise	NF	1	2	3	4	5
Tackling Drill combined with reaction exercise	NF	1	2	3	4	5
Tackling Drill combined with fitness conditioning	NF	1	2	3	4	5
b) Improving Tackle Performance						
Live tackling in a 1 player vs. 1 player grid	NF	1	2	3	4	5
Using tackling bag	NF	1	2	3	4	5
Given verbal instruction	NF	1	2	3	4	5
Using shield	NF	1	2	3	4	5
Using a body armour	NF	1	2	3	4	5
A full contact practice match	NF	1	2	3	4	5
Demonstration	NF	1	2	3	4	5
Tackling Drill combined with ball skill exercise	NF	1	2	3	4	5
Tackling Drill combined with a vision exercise	NF	1	2	3	4	5
Tackling Drill combined with reaction exercise	NF	1	2	3	4	5
Tackling Drill combined with fitness conditioning	NF	1	2	3	4	5

7. Continuing from the previous question (Question 6), what method have you been coached in the last season?
To indicate your answers make an X in the desired block

	Not Familiar (NF)	Never	Rarely	Sometimes	Frequently	Always
Live tackling in a 1 player vs. 1 player grid	NF	1	2	3	4	5
Using tackling bag	NF	1	2	3	4	5
Given verbal instruction	NF	1	2	3	4	5
Using shield	NF	1	2	3	4	5
Using a body armour	NF	1	2	3	4	5
A full contact practice match	NF	1	2	3	4	5
Demonstration	NF	1	2	3	4	5
Tackling Drill combined with ball skill exercise	NF	1	2	3	4	5
Tackling Drill combined with a vision exercise	NF	1	2	3	4	5
Tackling Drill combined with reaction exercise	NF	1	2	3	4	5
Tackling Drill combined with fitness conditioning	NF	1	2	3	4	5

8. When training 1 vs. 1 live tackling, coaches commonly use a small grid (less than 10x10m) or a larger grid (more than 10x10m) to simulate match conditions. Also, some coaches may prefer to control the conditions in the grid by letting the tackler know what the ball-carrier is going to do or some coaches may prefer to have a less controllable grid where the tackler does not know what the ball-carrier is going to do. What 1vs 1 live tackling grid have you been training most frequently in the last season?
To indicate your answers make an X in the desired block

	Not Familiar (NF)	Never	Rarely	Sometimes	Frequently	Always
Small grid (less than 10x10m) + controlled conditions	NF	1	2	3	4	5
Small grid (less than 10x10m) + less controlled conditions	NF	1	2	3	4	5
Large grid (more than 10x10m) + controlled conditions	NF	1	2	3	4	5
Large grid (more than 10x10m) + less controlled conditions	NF	1	2	3	4	5

Further Comment (Any additional information regarding this question):

9. When doing a tackle drill during a team/squad field session, how much time is spent on the following? Answer according to the last season.
To indicate your answers make an X in the desired block

	Not at all	A little	A fair amount	Much	Very Much
Emphasising proper technique to prevent injuries *(lowering the risk of getting injured during the tackle)*	1	2	3	4	5
Emphasising proper technique to improve tackle performance *(Preventing the ball-carrier from gaining territory and the ball-carriers team from retaining the ball)*	1	2	3	4	5

Further Comment (Any additional information regarding this question):

10. How much influence have the following factors had on your tackle technique to prevent you from injuries *(i.e lowering the risk of getting injured during the tackle)* and improve your tackling performance *(i.e preventing the ball-carrier from gaining territory and the ball-carriers team from retaining the ball)* in the last season.
To indicate your answers make an X in the desired block

Your coach from last season	Not at all	A little	A fair amount	Much	Very Much
Individual one-one verbal instruction from the coach	1	2	3	4	5
Verbal instruction to the entire team	1	2	3	4	5
Individual one-one demonstration	1	2	3	4	5
Demonstration to the entire team	1	2	3	4	5
Identifying a problem in your tackle technique and fixing it	1	2	3	4	5
Identifying a team problem in tackle technique and fixing it	1	2	3	4	5
Media and books					
Newspapers	1	2	3	4	5
Rugby Magazines	1	2	3	4	5
Internet	1	2	3	4	5
Televised rugby matches	1	2	3	4	5
Sport/Rugby shows on TV	1	2	3	4	5
Rugby training videos	1	2	3	4	5
Rugby training books	1	2	3	4	5
Other					
Relatives	1	2	3	4	5
Friends	1	2	3	4	5
Teammates	1	2	3	4	5
Experience	1	2	3	4	5
Attending live rugby matches	1	2	3	4	5
Coaching clinics	1	2	3	4	5
Your rugby Icon	1	2	3	4	5

11. How much did you learn about tackling technique in the different age categories?
To indicate your answers make an X in the desired block

Age Category	Not at all	A little	A fair amount	Much	Very Much
Under 10	1	2	3	4	5
Under 13	1	2	3	4	5
Under 15	1	2	3	4	5
Under 19	1	2	3	4	5
Seniors	1	2	3	4	5

12. During a front-on tackle drill in the last season, how much emphasis was placed on the following pointers?
To indicate your answers make an X in the desired block

Pointers before the tackle	Not Familiar (NF)	Never	Rarely	Sometimes	Frequently	Always
Approach	NF	1	2	3	4	5
Body position before the tackle	NF	1	2	3	4	5
Where your eyes should focus	NF	1	2	3	4	5
Position of the arms	NF	1	2	3	4	5
Lowering your centre of gravity	NF	1	2	3	4	5
Footwork before the tackle	NF	1	2	3	4	5
Aim for the legs	NF	1	2	3	4	5
Aim for the waist	NF	1	2	3	4	5
Aim for the upper body	NF	1	2	3	4	5
Aim for the ball only	NF	1	2	3	4	5
No target – just bring the opposition player down	NF	1	2	3	4	5
Pointers for contact in the tackle						
Importance of safety	NF	1	2	3	4	5
Head placement	NF	1	2	3	4	5
Eyes being open	NF	1	2	3	4	5
Position of your neck and spine	NF	1	2	3	4	5
Direction from which to enter contact in the tackle	NF	1	2	3	4	5
Shoulder and chest placement	NF	1	2	3	4	5
Arm placement	NF	1	2	3	4	5
Staying on feet	NF	1	2	3	4	5
Accelerate into contact with the same shoulder as the front leg	NF	1	2	3	4	5
Accelerate into contact with the opposite shoulder to the front leg	NF	1	2	3	4	5
Diving into the tackle	NF	1	2	3	4	5
Using the legs to drive the tackle	NF	1	2	3	4	5
Lifting the opposition player	NF	1	2	3	4	5
Using your own bodyweight to bring the opposition player down	NF	1	2	3	4	5
Pointers for after contact						
Following through with the tackle	NF	1	2	3	4	5
Staying on feet	NF	1	2	3	4	5
Lift off and dive through the tackle	NF	1	2	3	4	5
Use your bodyweight to bring the opponent down	NF	1	2	3	4	5
Prepare body position for going to ground after the tackle	NF	1	2	3	4	5

B. Match Questions

1. In the last season of matches you played (friendlies and league) from which direction do you think you tackled the most?
To indicate your answers make an X in the desired block

	Not at all	A little	A fair amount	Much	Very Much
Front-On Tackle	1	2	3	4	5
Side-On Tackle	1	2	3	4	5
Smother Tackle	1	2	3	4	5
Tackling from behind	1	2	3	4	5
Double tackle	1	2	3	4	5

2. What is important to you when making a tackle during a match?
To indicate your answers make an X in the desired block

	Not all important	Not too important	Undecided	Somewhat important	Very important
Doing what you practiced	1	2	3	4	5
Proper technique	1	2	3	4	5
Bringing down the ball-carrier at all costs	1	2	3	4	5
Your own safety (lowering the risk of getting injured)	1	2	3	4	5
Safety of the ball-carrier (lowering the risk of injuring the ball-carrier)	1	2	3	4	5
Safety of both you and the ball-carrier	1	2	3	4	5
Putting in a 'Big Hit'	1	2	3	4	5
Going for the ball only	1	2	3	4	5
Staying on your feet	1	2	3	4	5
Preventing the ball-carrier from retaining position	1	2	3	4	5
Preventing the ball-carriers team from retaining the ball	1	2	3	4	5

Further Comment (Any additional information regarding this question):

3. Does your answer to question 2 change according…
To indicate your answers make an X in the desired block

As the match progresses	Never	Rarely	Sometimes	Frequently	Always
First 20 min of the 1st half	1	2	3	4	5
Second 20 min of the 1st half	1	2	3	4	5
First 20 min of the 2nd half	1	2	3	4	5
Second 20 min of the 2nd half	1	2	3	4	5
As the score changes					
In your team's favour	1	2	3	4	5
In the opposition's favour	1	2	3	4	5
A small score margin (less than 10 points)	1	2	3	4	5
A large score margin (more than 10 points)	1	2	3	4	5
Position on the field					
Defending on your try-line	1	2	3	4	5
Defending within your 22-M (from your try-line to your 22-M line)	1	2	3	4	5
Defending within the mid-section of the field (from your 22-M line to the opposition 22-M line)	1	2	3	4	5
Defending within the opposition 22-M (from the opposition 22-M line to the opposition try-line)	1	2	3	4	5
Position relative to ruck/maul/scrum/lineout					
If you are close (within 5m) to the ruck/maul/scrum/lineout	1	2	3	4	5
If you are not close (more than 5m away) to the ruck/maul/scrum/lineout	1	2	3	4	5
If you are on the blind-side	1	2	3	4	5
If you are on the open side	1	2	3	4	5
Importance of the game					
Playing for promotion or relegation	1	2	3	4	5
Playing a final	1	2	3	4	5
Playing a local derby	1	2	3	4	5

Further Comment (Any additional information regarding this question):

4. What do you think may help you improve your tackle performance (preventing the ball-carrier from gaining territory and the ball-carriers team from retaining the ball) and lowering your risk of injury in a tackle during a rugby match?
To indicate your answers make an X in the desired block

	Not at all	A little	A fair amount	Much	Very Much
Knowledge of proper technique	1	2	3	4	5
Training proper technique regularly	1	2	3	4	5
Attitude	1	2	3	4	5
Reaction time	1	2	3	4	5
Vision	1	2	3	4	5
Defensive structures	1	2	3	4	5
Motivation	1	2	3	4	5
Determination	1	2	3	4	5
Weather conditions	1	2	3	4	5
The crowd	1	2	3	4	5
Confidence	1	2	3	4	5
Match day preparations	1	2	3	4	5
Personal fitness conditioning (strength, speed, stamina)	1	2	3	4	5
Rest prior to the game	1	2	3	4	5
Stretching prior to the game	1	2	3	4	5
General flexibility	1	2	3	4	5
Using protective gear (shoulder pads, scrumcap)	1	2	3	4	5

Further Comment (Any additional information regarding this question):

Thank You for Your Participation

Reference List

1. Gabbett, T. and Kelly, J., Does fast defensive line speed influence tackling proficiency in collision sport athletes? *International Journal of Sports Science and Coaching*, 2007, 2, (4), 467-472.

2. Noakes TD and Du Plessis M. Rugby without risk. A practical guide to the prevention and treatment of rugby injuries. Pretoria: J.L van Schaik, 1996.

3. International Rugby Board. Law 15 Tackle: Ball carrier brought to the ground. International Rugby Board Playing Charter, 62. 2008.

4. Australian Rugby Union. Key points for the tackler and ball-carrier. Australian Rugby Union SmartRugby: Confidence in Contact. A guide to the SmartRugby program., 18-19. 2008.

5. Quarrie, K. L. and Hopkins, W. G., Tackle injuries in professional Rugby Union. *The American Journal of Sports Medicine*, 2008, 36, (9), 1705-1716.

6. Australian Rugby League Referees' Association, The 2007 ARL Laws of the game and notes on the laws (approved by the Australian Rugby Football League). *http://www arlra org au/pdf-files/International_Laws_2007 pdf*, 2007.

7. Smart, D. J., Gill, N. D., Beaven, C. M., Cook, C. J., and Blazevich, A. J., The relationship between changes in interstitial creatine kinase and game-related impacts in rugby union. *British Journal of Sports Medicine*, 2008, 42, (3), 198-201.

8. Gabbett, T., Kelly, J., and Pezet, T., A comparison of fitness and skill among playing positions in sub-elite rugby league players. *Journal of Science and Medicine in Sport*, 2008, 11, (6), 585-592.

9. Gabbett, T. J., Incidence of injury in junior and senior rugby league players. *Sports Medicine*, 2004, 34, (12), 849-859.

10. Gissane, C., Jennings, D. C., Cumine, A. J., Stephenson, S. E., and White, J. A., Differences in the incidence of injury between rugby league forwards and backs. *Australian Journal of Science and Medicine in Sport*, 1997, 29, (4), 91-94.

11. Sirotic, A. C., Coutts, A. J., Knowles, H., and Catterick, C., A comparison of match demands between elite and semi-elite rugby league competition. *Journal of Sports Sciences*, 2009, 27, (3), 203-211.

12. Gabbett, T. J., Science of rugby league football: a review. *Journal of Sports Sciences*, 2005, 23, (9), 961-976.

13. Fuller, C. W., Ashton, T., Brooks, J. H., Cancea, R. J., Hall, J., and Kemp, S. P., Injury risks associated with tackling in rugby union. *British Journal of Sports Medicine*, 2010, 44, (3), 159-167.

14. Bartlett R. Sports Biomechanics: Reducing injury and improving performance. London: E and FN Spon.Routledge, 1999.

15. Fuller, C. W., Molloy, M. G., Bagate, C., Bahr, R., Brooks, J. H., Donson, H., Kemp, S. P., McCrory, P., McIntosh, A. S., Meeuwisse, W. H., Quarrie, K. L., Raftery, M., and Wiley, P., Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. *British Journal of Sports Medicine*, 2007, 41, (5), 328-331.

16. King, D. A., Gabbett, T. J., Dreyer, C., and Gerrard, D. F., Incidence of injuries in the New Zealand national rugby league sevens tournament. *Journal of Science and Medicine in Sport*, 2006, 9, (1-2), 110-118.

17. Duthie, G., Pyne, D., and Hooper, S., Applied physiology and game analysis of rugby union. *Sports Medicine*, 2003, 33, (13), 973-991.

18. Quarrie, K. L. and Hopkins, W. G., Changes in player characteristics and match activities in Bledisloe Cup rugby union from 1972 to 2004. *Journal of Sports Sciences*, 2007, 25, (8), 895-903.

19. Brooks, J. H. and Kemp, S. P., Recent trends in rugby union injuries. *Clinics in Sports Medicine*, 2008, 27, (1), 51-viii.

20. Garraway, W. M., Lee, A. J., Hutton, S. J., Russell, E. B., and Macleod, D. A., Impact of professionalism on injuries in rugby union. *British Journal of Sports Medicine*, 2000, 34, (5), 348-351.

21. Nicholls, A. R., Holt NL, Polman RCJ, and Bloomfield J, Stressors, coping, and coping effectiveness among professional rugby union players. *The Sport Psychologist*, 2006, 20, (3), 314-329.

22. Potgieter JC, Grobbelaar HW, and Andrew M, Sport psychological skill levels and related psychosocial factors that distinguish between rugby union players of different participation levels. *Journal of Social & Psychological Sciences*, 2008, 1, (1), 43-64.

23. Richard N, Mellalieu S.D, and Hanton S, Psychological skills usage and the competitive anxiety response as a function of skill level in rugby union. *Journal of Sports Science and Medicine*, 2006, 5, 415-423.

24. Cresswell, S. L. and Eklund, R. C., The nature of player burnout in Rugby: key characteristics and attributions. *Journal of Applied Sport Psychology*, 2006, 18, (3), 219-239.

25. Hodge, K., Lonsdale, C., and Ng, J. Y., Burnout in elite rugby: relationships with basic psychological needs fulfilment. *Journal of Sports Sciences*, 2008, 26, (8), 835-844.

26. Cresswell, S. L. and Eklund, R. C., Motivation and burnout in professional rugby players. *Research Quarterly for Exercise and Sport*, 2005, 76, (3), 370-376.

27. Maxwell, J. P. and Visek, A. J., Unsanctioned aggression in rugby union: relationships among aggressiveness, anger, athletic identity, and professionalization. *Aggressive Behavior*, 2009, 35, (3), 237-243.

28. Nicholls, A. R., Backhouse, S. H., Polman, R. C., and McKenna, J., Stressors and affective states among professional rugby union players. *Scandinavian Journal of Medicine and Science in Sports*, 2009, 19, (1), 121-128.

29. Nicholls, A. R., Jones, C. R., Polman, R. C., and Borkoles, E., Acute sport-related stressors, coping, and emotion among professional rugby union players during training and matches. *Scandinavian Journal of Medicine and Science in Sports*, 2009, 19, (1), 113-120.

30. Cresswell, S. L., Possible early signs of athlete burnout: a prospective study. *Journal of Science and Medicine in Sport*, 2009, 12, (3), 393-398.

31. Mellalieu, S. D., Hanton, S., and Shearer, D. A., Hearts in the fire, heads in the fridge: a qualitative investigation into the temporal patterning of the precompetitive psychological response in elite performers. *Journal of Sports Sciences*, 2008, 26, (8), 811-824.

32. Treasure, D. C., Carpenter, P. J., and Power, K. T., Relationship between achievement goal orientations and the perceived purposes of playing rugby union for professional and amateur players. *Journal of Sports Sciences*, 2000, 18, (8), 571-577.

33. Brooks, J. H. and Fuller, C. W., The influence of methodological issues on the results and conclusions from epidemiological studies of sports injuries: illustrative examples. *Sports Medicine*, 2006, 36, (6), 459-472.

34. Holtzhausen, L. J., Schwellnus, M. P., Jakoet, I., and Pretorius, A. L., The incidence and nature of injuries in South African rugby players in the rugby Super 12 competition. *South African Medical Journal*, 2006, 96, (12), 1260-1265.

35. Gabbett, T. J., Influence of fatigue on tackling technique in rugby league players. *Journal of Strength & Conditioning Research*, 2008, 22, (2), 625-632.

36. Takarada, Y., Evaluation of muscle damage after a rugby match with special reference to tackle plays. *British Journal of Sports Medicine*, 2003, 37, (5), 416-419.

37. McIntosh, A. S., Rugby injuries. *Medicine and Sport Science*, 2005, 49, 120-139.

38. Wilson, B. D., Quarrie, K. L., Milburn, P. D., and Chalmers, D. J., The nature and circumstances of tackle injuries in rugby union. *Journal of Science and Medicine in Sport*, 1999, 2, (2), 153-162.

39. Fuller, C. W., Brooks, J. H., Cancea, R. J., Hall, J., and Kemp, S. P., Contact events in rugby union and their propensity to cause injury. *British Journal of Sports Medicine*, 2007, 41, (12), 862-867.

40. Kaplan, K. M., Goodwillie, A., Strauss, E. J., and Rosen, J. E., Rugby injuries - a review of concepts and current literature. *Bulletin of the NYU Hospital for Joint Diseases*, 2008, 66, (2), 86-93.

41. Best, J. P., McIntosh, A. S., and Savage, T. N., Rugby World Cup 2003 injury surveillance project. *British Journal of Sports Medicine*, 2005, 39, (11), 812-817.

42. Fuller, C. W., Laborde, F., Leather, R. J., and Molloy, M. G., International Rugby Board Rugby World Cup 2007 injury surveillance study. *British Journal of Sports Medicine*, 2008, 42, (6), 452-459.

43. Jakoet, I. and Noakes, T. D., A high rate of injury during the 1995 Rugby World Cup. *South African Medical Journal*, 1998, 88, (1), 45-47.

44. Brooks, J. H., Fuller, C. W., Kemp, S. P., and Reddin, D. B., A prospective study of injuries and training amongst the England 2003 Rugby World Cup squad. *British Journal of Sports Medicine*, 2005, 39, (5), 288-293.

45. Bathgate, A., Best, J. P., Craig, G., and Jamieson, M., A prospective study of injuries to elite Australian rugby union players. *British Journal of Sports Medicine*, 2002, 36, (4), 265-269.

46. Targett, S. G., Injuries in professional Rugby Union. *Clinical Journal of Sport Medicine*, 1998, 8, (4), 280-285.

47. Bird, Y. N., Waller, A. E., Marshall, S. W., Alsop, J. C., Chalmers, D. J., and Gerrard, D. F., The New Zealand Rugby Injury and Performance Project: V. Epidemiology of a season of rugby injury. *British Journal of Sports Medicine*, 1998, 32, (4), 319-325.

48. Bottini, E., Poggi, E. J., Luzuriaga, F., and Secin, F. P., Incidence and nature of the most common rugby injuries sustained in Argentina (1991-1997). *British Journal of Sports Medicine*, 2000, 34, (2), 94-97.

49. Schick, D. M., Molloy, M. G., and Wiley, J. P., Injuries during the 2006 Women's Rugby World Cup. *British Journal of Sports Medicine*, 2008, 42, (6), 447-451.

50. Gabbett, T. J., Severity and cost of injuries in amateur rugby league: a case study. *Journal of Sports Sciences*, 2001, 19, (5), 341-347.

51. Stephenson, S., Gissane, C., and Jennings, D., Injury in rugby league: a four year prospective survey. *British Journal of Sports Medicine*, 1996, 30, (4), 331-334.

52. Gissane, C., White, J., Kerr, K., Jennings, S., and Jennings, D., Health and safety implications of injury in professional rugby league football. *Occupational Medicine*, 2003, 53, (8), 512-517.

53. Gabbett, T. J. and Domrow, N., Risk factors for injury in subelite rugby league players. *The American Journal of Sports Medicine*, 2005, 33, (3), 428-434.

54. Gabbett, T. J., Incidence of injury in semi-professional rugby league players. *British Journal of Sports Medicine*, 2003, 37, (1), 36-43.

55. Lee, A. J. and Garraway, W. M., Epidemiological comparison of injuries in school and senior club rugby. *British Journal of Sports Medicine*, 1996, 30, (3), 213-217.

56. Brooks, J. H., Fuller, C. W., Kemp, S. P., and Reddin, D. B., Epidemiology of injuries in English professional rugby union: part 1 match injuries. *British Journal of Sports Medicine*, 2005, 39, (10), 757-766.

57. Garraway, W. M., Lee, A. J., Macleod, D. A., Telfer, J. W., Deary, I. J., and Murray, G. D., Factors influencing tackle injuries in rugby union football. *British Journal of Sports Medicine*, 1999, 33, (1), 37-41.

58. Babic, Z., Misigoj-Durakovic, M., Matasic, H., and Jancic, J., Croatian rugby project. Part II: injuries. *Journal of Sports Medicine and Physical Fitness*, 2001, 41, (3), 392-398.

59. Quarrie, K. L., Cantu, R. C., and Chalmers, D. J., Rugby union injuries to the cervical spine and spinal cord. *Sports Medicine*, 2002, 32, (10), 633-653.

60. Noakes, T. D., Jakoet, I., and Baalbergen, E., An apparent reduction in the incidence and severity of spinal cord injuries in schoolboy rugby players in the western Cape since 1990. *South African Medical Journal*, 1999, 89, (5), 540-545.

61. Gabbett, T. J., Incidence, site, and nature of injuries in amateur rugby league over three consecutive seasons. *British Journal of Sports Medicine*, 2000, 34, (2), 98-103.

62. Gissane, C., Jennings, D., Kerr, K., and White, J. A., A pooled data analysis of injury incidence in rugby league football. *Sports Medicine*, 2002, 32, (3), 211-216.

63. New Zealand Rugby Union. Technique : the key factors in the tackle and taking the ball into contact. RugbySmart 2007: A guide to injury prevention for peak performance,2007, 12-14.

64. New Zealand Rugby Union. Technique : the key factors in the tackle and taking the ball into contact. RugbySmart : good technique is safe technique, 2008, 12-14.

65. Quarrie, K. L., Gianotti, S. M., Hopkins, W. G., and Hume, P. A., Effect of nationwide injury prevention programme on serious spinal injuries in New Zealand rugby union: ecological study. *British Medical Journal*, 2007, 334, (7604), 1150-1153.

66. Gianotti, S. M., Quarrie, K. L., and Hume, P. A., Evaluation of RugbySmart: a rugby union community injury prevention programme. *Journal of Science and Medicine in Sport*, 2009, 12, (3), 371-375.

67. Noakes, T. D. and Draper, C. E., Preventing spinal cord injuries in rugby union. *British Medical Journal*, 2007, 334, (7604), 1122-1123.

68. South African Rugby Union, BokSmart: safe and effective techniques in rugby - practical guidelines. *http://www sarugby co za/boksmart/pdf/BokSmart%20-%20Safe%20Rugby%20Techniques%20Practical%20guidelines pdf*, 2009.

69. South Africa Rugby Union. Tackling techniques. SA Coaches Logbook : the practical and technical guide to a safer game of rugby, 2007, 59.

70. New Zealand Rugby Union, New Zealand Rugby Union Coaching Toolbox.Skills-Tackling. *http://www coachingtoolbox co nz/toolbox/index php?option=com_toolbox&grade_id=grades_27&section_id=13&cat_list=70&grade=Seniors&section=Skills&category=Tackling&stamp=-1#*, 2009.

71. Holcroft B. Futuristic Fifteen Man Rugby: Coaching revelations 2007. Academy of Excellence Series. Victoria: Trafford Publishing, 2007.

72. International Rugby Board. IRB rugby ready. 2008.

73. New Zealand Rugby League, LeagueSmart: Technique. *http://www nzrl co nz/files/leaguesmart/leaguesmart_cycle/technique pdf*, 2009.

74. Hall SJ. Basic biomechanics. Singapore: McGraw-Hill, 2004.

75. Hay JG. The biomechanics of sports techniques. New Jersey: Prentice-Hall, 1993.

76. Gabbett, T. J., Physiological and anthropometric correlates of tackling ability in rugby league players. *The Journal of Strength & Conditioning Research*, 2009, 23, (2), 540-548.

77. Gabbett, T. and Ryan, P., Tackling Technique, Injury Prevention, and Playing Performance in High-Performance Collision Sport Athletes. *International Journal of Sports Science and Coaching*, 2009, 4, (4), 521-533.

78. Lydon J, Tackling Technique - 'Start to stop thinking about it'. *http://www rfu com/pdfs/technical_journal/lydontacklingtechnique pdf*, 2005.

79. Copemen P, Tackling. *http://www community-rugby com/communityrugby/index cfm/fuseaction/Home Download_Counter/downloadId/1109/filename/Tackling%20Coleman2 pdf*, 2006.

80. Carter, A. F. and Muller, R., A survey of injury knowledge and technical needs of junior Rugby Union coaches in Townsville (North Queensland). *Journal of Science and Medicine in Sport*, 2008, 11, (2), 167-173.

81. Boardley ID, Kavussana M, and Ring C, Athletes' perceptions of coaching effectiveness and athlete-related outcomes in rugby union: An investigation based on the coaching efficacy model. *The Sport Psychologist*, 2008, 22, 269-287.

82. Grant, S. J., Oommen, G., McColl, G., Taylor, J., Watkins, L., Friel, N., Watt, I., and McLean, D., The effect of ball carrying method on sprint speed in rugby union football players. *Journal of Sports Sciences*, 2003, 21, (12), 1009-1015.

83. Walsh, M., Young, B., Hill, B., Kittredge, K., and Horn, T., The effect of ball-carrying technique and experience on sprinting in rugby union. *Journal of Sports Sciences*, 2007, 25, (2), 185-192.

84. McKenzie, AD, Holmyard, DJ, and Docherty, D, Quantitative analysis of rugby:factors associated with success in contact. *Journal of Human Movement Sciences*, 1989, 17, 101-113.

85. Sayers, MGL and Washington-King, J, Characteristics of effective ball carries in Super 12 rugby. *International Journal of Performance Analysis in Sport*, 2005, 5, (3), 92-106.

86. Smyth G, O'Donoghue P.G, and Wallace E.S. Notational analysis of contact situations in rugby union. In Hughes M and Tavares F Notational Analysis of Sport: IV World Congress Proceedings, 156-164. Centre for Team Sport Studies, University of Porto, 1998.

87. Wheeler, K. W., Askew, C. D., and Sayers, M. G., Effective attacking strategies in rugby union. *European Journal of Sport Science*, 2010, 10, (4), 237-242.

88. Wheeler, K. and Sayers, M., Contact skills predicting tackle-breaks in rugby union. *International Journal of Sports Science and Coaching*, 2009, 4, (4), 535-544.

89. Wheeler, K. W. and Sayers M.G.L., Rugby union contact skills alter evasive agility performance during attacking ball carries. *International Journal of Sports Science and Coaching*, 2011, 6, (3), 419-432.

90. Jones N.M.P, Mellalieu S.D, James N, and Moise J. Contact area playing styles of Nortern and Southern Hemisphere international rugby union teams. In O' Donoghue P and Hughes M Performance Analysis of Sport VI, 114-199. Centre for Performance, Univeristy of Wales, 2004.

91. Upton, P. A., Roux, C. E., and Noakes, T. D., Inadequate pre-season preparation of schoolboy rugby players--a survey of players at 25 Cape Province high schools. *South African Medical Journal*, 1996, 86, (5), 531-533.

92. Runyan, C. W., Using the Haddon matrix: introducing the third dimension. *Injury Prevention*, 1998, 4, (4), 302-307.

93. Runyan, C. W., Introduction: back to the future-revisiting Haddon's conceptualization of injury epidemiology and prevention. *Epidemiologic Reviews*, 2003, 25, 60-64.

94. Haddon, W., Jr., Options for the prevention of motor vehicle crash injury. *Israel Journal of Medical Sciences*, 1980, 16, (1), 45-65.

95. McKenna, J. and Hammond, C., Perspectives on injuries in snowboarders. *The Journal of the Royal Society for the Promotion of Health*, 2007, 127, (4), 181-189.

96. Rich D, Victorian sports injury prevention program: an overview. *Journal of Science and Medicine in Sport*, 2000, 3, (2), 64-72.

97. Fuller, C. and Drawer, S., The application of risk management in sport. *Sports Medicine*, 2004, 34, (6), 349-356.

98. Timpka, T., Ekstrand, J., and Svanstrom, L., From sports injury prevention to safety promotion in sports. *Sports Medicine*, 2006, 36, (9), 733-745.

99. Chalmers, D. J., Injury prevention in sport: not yet part of the game? *Injury Prevention*, 2002, 8 Suppl 4, IV22-IV25.

100. Timpka, T., Finch, C. F., Goulet, C., Noakes, T., and Yammine, K., Meeting the global demand of sports safety: the intersection of science and policy in sports safety. *Sports Medicine*, 2008, 38, (10), 795-805.

101. Bishop, D., An applied research model for the sport sciences. *Sports Medicine*, 2008, 38, (3), 253-263.

102. Eime, R., Owen, N., and Finch, C., Protective eyewear promotion: applying principles of behaviour change in the design of a squash injury prevention programme. *Sports Medicine*, 2004, 34, (10), 629-638.

103. Van Tiggelen, D., Wickes, S., Stevens, V., Roosen, P., and Witvrouw, E., Effective prevention of sports injuries: a model integrating efficacy, efficiency, compliance and risk-taking behaviour. *British Journal of Sports Medicine*, 2008, 42, (8), 648-652.

104. Finch, C., A new framework for research leading to sports injury prevention. *Journal of Science and Medicine in Sport*, 2006, 9, (1-2), 3-9.

105. Kok, G. and Bouter, L. M., On the importance of planned health education. Prevention of ski injury as an example. *The American Journal of Sports Medicine*, 1990, 18, (6), 600-605.

106. van Mechelen, W., Hlobil, H., and Kemper, H. C., Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. *Sports Medicine*, 1992, 14, (2), 82-99.

107. Epidemiology of sports injuries. Champaign IL: Human Kinetics, 1996.

108. Ford, P., Collins, D., Macnamara, A., Pearce, G., and Toms, M., Participant development in sport and physical activity: The impact of biological maturation. *European Journal of Sport Science*, 2011, Online First.

109. Meeuwisse, W. H., Assessing causation in sport injury: A multifactorial model. *Clinical Journal of Sport Medicine*, 1994, 4, (3), 166-170.

110. Bahr, R. and Krosshaug, T., Understanding injury mechanisms: a key component of preventing injuries in sport. *British Journal of Sports Medicine*, 2005, 39, (6), 324-329.

111. McIntosh, A. S., Risk compensation, motivation, injuries, and biomechanics in competitive sport. *British Journal of Sports Medicine*, 2005, 39, (1), 2-3.

112. Gissane, C., White, J., Kerr, K., and Jennings, D., An operational model to investigate contact sports injuries. *Medicine & Science in Sports & Exercise*, 2001, 33, (12), 1999-2003.

113. McManus, A. and Cross, D. S., Incidence of injury in elite junior rugby union: a prospective descriptive study. *Journal of Science and Medicine in Sport*, 2004, 7, (4), 438-445.

114. Collins, C. L., Micheli, L. J., Yard, E. E., and Comstock, R. D., Injuries sustained by high school rugby players in the United States, 2005-2006. *Archives of Pediatrics & Adolescent Medicine*, 2008, 162, (1), 49-54.

115. McIntosh, A. S., McCrory, P., Finch, C. F., and Wolfe, R., Head, face and neck injury in youth rugby: incidence and risk factors. *British Journal of Sports Medicine*, 2010, 44, (3), 188-193.

116. Junge, A., Cheung, K., Edwards, T., and Dvorak, J., Injuries in youth amateur soccer and rugby players--comparison of incidence and characteristics. *British Journal of Sports Medicine*, 2004, 38, (2), 168-172.

117. Underhill, J., Dostaler, S. M., Brison, R. J., and Pickett, W., Rugby injury in Kingston, Canada: a ten-year study. *Chronic Diseases in Canada*, 2007, 27, (4), 163-170.

118. Hendricks, S. and Lambert, M., Tackling in Rugby: Coaching strategies for effective technique and injury prevention. *International Journal of Sports Science and Coaching*, 2010, 5, (1), 117-135.

119. Osberg, J. S. and Stiles, S. C., Safety behavior of in-line skaters. *Injury Prevention*, 2000, 6, (3), 229-231.

120. Emery, C. A., McKay, C. D., Campbell, T. S., and Peters, A. N., Examining attitudes toward body checking, levels of emotional empathy, and levels of aggression in body checking and non-body checking youth hockey leagues. *Clinical Journal of Sport Medicine*, 2009, 19, (3), 207-215.

121. Finch, C. F., McIntosh, A. S., and McCrory, P., What do under 15 year old schoolboy rugby union players think about protective headgear? *British Journal of Sports Medicine*, 2001, 35, (2), 89-94.

122. Pettersen, J. A., Does rugby headgear prevent concussion? Attitudes of Canadian players and coaches. *British Journal of Sports Medicine*, 2002, 36, (1), 19-22.

123. Finch, C., Donohue, S., and Garnham, A., Safety attitudes and beliefs of junior Australian football players. *Injury Prevention*, 2002, 8, (2), 151-154.

124. Lund J and Aarø L.E., Accident prevention. Presentation of a model placing emphasis on human, structural and cultural factors . *Safety Science*, 2004, 42, (4), 271-324.

125. Collard, D., Singh, A., and Verhagen, E. Sports injury research. In Evert Verhagen and Willem van Mechelen 162. New York: Oxford Univeristy Press, 2010.

126. Chalmers, D. J., Simpson, J. C., and Depree, R., Tackling rugby injury: lessons learned from the implementation of a five-year sports injury prevention program. *Journal of Science and Medicine in Sport*, 2004, 7, (1), 74-84.

127. Fink, A. The Survey Kit 2. How to ask survey questions. London: SAGE Publications, 1995.

128. Czaja, R. and Blair, J. Designing surveys. A guide to decisions and procedures. London: Pine Forge Press, 2005.

129. Babbie, E. The practice of social sciences. Belmont: Thomson Wadsworth, 2004.

130. Salant, P. and Dillman, D. A. How to conduct your own survey. New York: John Wiley and Sons Inc., 1994.

131. Dillman, D. A. Mail and internet surveys. The tailored design method. New Jersey: John Wiley and Sons Inc., 2007.

132. Carifio, J. and Perla, R., Resolving the 50-year debate around using and misusing Likert scales. *Medical Education*, 2008, 42, (12), 1150-1152.

133. Corcoran, G and Bird, S, Preseason strength training for rugby union: the general and specific preparatory phases. *Strength & Conditioning Journal*, 2009, 31, (6), 66-74.

134. Gamble, P, Physical preparation for elite-level rugby union football. *Strength & Conditioning Journal*, 2004, 26, (4), 10-23.

135. Hodges, N. J. and Franks, I. M., Modelling coaching practice: the role of instruction and demonstration. *Journal of Sports Sciences*, 2002, 20, (10), 793-811.

136. Schmidt, R. A. and Wrisberg, C. A. Motor learning and performance. Champaign, IL: Human Kinetics, 2008.

137. McMorris T, Teaching games for understanding: its contribution to the knowledge of skill acquisition from a motor learning perspective. *Physical Education & Sport Pedagogy*, 1998, 3, (1), 65-74.

138. Branta, C., Haubenstricker, J., and Seefeldt, V., Age changes in motor skills during childhood and adolescence. *Exercise and Sport Sciences Reviews*, 1984, 12, 467-520.

139. Abernethy, L. and Bleakley, C., Strategies to prevent injury in adolescent sport: a systematic review. *British Journal of Sports Medicine*, 2007, 41, (10), 627-638.

140. Frankfort -Nachmias, C. and Nachmias, D. Research methods in the social sciences. New York: Worth Publishers, 2007.

141. McIntosh, A. S., Savage, T. N., McCrory, P., Frechede, B. O., and Wolfe, R., Tackle characteristics and injury in a cross section of rugby union football. *Medicine & Science in Sports & Exercise*, 2010, 42, (5), 977-984.

142. Brault, S., Bideau, B., Craig, C., and Kulpa, R., Balancing deceit and disguise: how to successfully fool the defender in a 1 vs. 1 situation in rugby. *Human Movement Science*, 2010, 29, (3), 412-425.

143. Passos, P., Araujo, D., Davids, K., Gouveia, L., Milho, J., and Serpa, S., Information-governing dynamics of attacker-defender interactions in youth rugby union. *Journal of Sports Sciences*, 2008, 26, (13), 1421-1429.

144. Passos, P., Araujo, D., Davids, K., Gouveia, L., Serpa, S., Milho, J., and Fonseca, S., Interpersonal pattern dynamics and adaptive behavior in multiagent neurobiological systems: conceptual model and data. *Journal of Motor Behavior*, 2009, 41, (5), 445-459.

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

146. Passos, P., Araujo, D., Davids, K., Gouveia, L., and Serpa, S., Interpersonal dynamics in sport:the role of artificial neural networks and 3-D analysis. *Behavior Research Methods*, 2006, 38, (4), 683-691.

147. Mouchet, A, Subjectivity in the articulation between strategy and tactics in team sports: an example of rugby. *Italian Journal of Sport Sciences*, 2005, 12, (1), 24-33.

148. Watson, G., Brault, S., Kulpa, R., Bideau, B., Butterfield, J., and Craig, C., Judging the 'passability' of dynamic gaps in a virtual rugby environment. *Human Movement Science*, 2011, 30, (5), 942-956.

149. Sekiguchi, A., Yokoyama, S., Kasahara, S., Yomogida, Y., Takeuchi, H., Ogawa, T., Taki, Y., Niwa, S. I., and Kawashima, R., Neural Bases of a Specific Strategy for Visuospatial Processing In Rugby Players. *Medicine & Science in Sports & Exercise*, 2011, 43(10), 1857-1862.

150. Meir, R, Conditioning the visual system: a practical perspective on visual conditioning in rugby football. *Strength & Conditioning Journal*, 2005, 27, (4), 86-92.

151. Correia, V., Araujo, D., Craig, C., and Passos, P., Prospective information for pass decisional behavior in rugby union. *Human Movement Science*, 2011, 30, (5), 984-997.

152. Hendricks, S., Jordaan, E., and Lambert, M., Attitude and behaviour of junior rugby union players towards tackling during training and match play. *Safety Science*, 2012, 50, 266-284.

153. Duthie, G. M., Pyne, D. B., Marsh, D. J., and Hooper, S. L., Sprint patterns in rugby union players during competition. *Journal of Strength & Conditioning Research*, 2006, 20, (1), 208-214.

154. Pain, M. T., Tsui, F., and Cove, S., In vivo determination of the effect of shoulder pads on tackling forces in rugby. *Journal of Sports Sciences*, 2008, 26, (8), 855-862.

155. Wheeler, K. W. and Sayers, M. G. L., Modification of agility running technique in reaction to a defender in rugby union. *Journal of Sport Science and Medicine*, 2010, 9, 445-451.

156. Edgecomb, S. J. and Norton, K. I., Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian football. *Journal of Science and Medicine in Sport*, 2006, 9, (1-2), 25-32.

157. Barris, S. and Button, C., A review of vision-based motion analysis in sport. *Sports Medicine*, 2008, 38, (12), 1025-1043.

158. Brewin, MA and Kerwin, DG, Accuracy of scaling and DLT reconstruction techniques for planar motion analyses. *Journal of Applied Biomechanics*, 2003, 19, 79-88.

159. Alcock, A., Hunter, A., and Brown, N., Determination of football pitch locations from video footage and official pitch markings. *Sports Biomechanics*, 2009, 8, (2), 129-140.

160. Kwon, Y. H. and Casebolt, J. B., Effects of light refraction on the accuracy of camera calibration and reconstruction in underwater motion analysis. *Sports Biomechanics*, 2006, 5, (1), 95-120.

161. Carling, C., Bloomfield, J., Nelsen, L., and Reilly, T., The role of motion analysis in elite soccer: contemporary performance measurement techniques and work rate data. *Sports Medicine*, 2008, 38, (10), 839-862.

162. Mallo, J., Veiga, S., Lopez de, Subijana C., and Navarro, E., Activity profile of top-class female soccer refereeing in relation to the position of the ball. *Journal of Science and Medicine in Sport*, 2010, 13, (1), 129-132.

163. McIntosh, A. S., McCrory, P., and Comerford, J., The dynamics of concussive head impacts in rugby and Australian rules football. *Medicine & Science in Sports & Exercise*, 2000, 32, (12), 1980-1984.

164. Jennings, D., Cormack, S., Coutts, A. J., Boyd, L., and Aughey, R. J., The validity and reliability of GPS units for measuring distance in team sport specific running patterns. *International Journal of Sports Physiology and Performance*, 2010, 5, (3), 328-341.

165. Nevill, A. M. and Atkinson, G., Assessing agreement between measurements recorded on a ratio scale in sports medicine and sports science. *British Journal of Sports Medicine*, 1997, 31, (4), 314-318.

166. Nevill, A., Validity and measurement agreement in sports performance. *Journal of Sports Sciences*, 1996, 14, (3), 199.

167. Bland, J. M. and Altman, D. G., Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, 1986, 1, (8476), 307-310.

168. Headey, J., Brooks, J. H., and Kemp, S. P., The epidemiology of shoulder injuries in English professional rugby union. *The American Journal of Sports Medicine*, 2007, 35, (9), 1537-1543.

169. King, D. A. and Gissane, C., Injuries in amateur rugby league matches in New Zealand: a comparison between a division 1 and a division 2 premier grade team. *Clinical Journal of Sports Medicine*, 2009, 19, (4), 277-281.

170. Newman, J. A., Beusenberg, M. C., Shewchenko, N., Withnall, C., and Fournier, E., Verification of biomechanical methods employed in a comprehensive study of mild traumatic brain injury and the effectiveness of American football helmets. *Journal of Biomechanics*, 2005, 38, (7), 1469-1481.

171. Pellman, E. J., Viano, D. C., Tucker, A. M., Casson, I. R., and Waeckerle, J. F., Concussion in professional football: reconstruction of game impacts and injuries. *Neurosurgery*, 2003, 53, (4), 799-812.

172. Frechede, B. and McIntosh, A. S., Numerical reconstruction of real-life concussive football impacts. *Medicine and Science in Sports and Exercise*, 2009, 41, (2), 390-398.

173. Pellman, E. J., Viano, D. C., Tucker, A. M., and Casson, I. R., Concussion in professional football: location and direction of helmet impacts-Part 2. *Neurosurgery*, 2003, 53, (6), 1328-1340.

174. Gabbett, T. J., Jenkins, D. G., and Abernethy, B., Physiological and anthropometric correlates of tackling ability in junior elite and subelite rugby league players. *Journal of Strength & Conditioning Research*, 2010, 24, (11), 2989-2995.

175. Austin, D., Gabbett, T., and Jenkins, D., The physical demands of Super 14 rugby union. *Journal of Science and Medicine in Sport*, 2011, 14, (3), 259-263.

176. Deutsch, M. U., Kearney, G. A., and Rehrer, N. J., Time - motion analysis of professional rugby union players during match-play. *Journal of Sports Sciences*, 2007, 25, (4), 461-472.

177. Eaton, C. and George, K., Position specific rehabilitation for rugby union players. Part II: Evidence -based examples. *Physical Therapy in Sport*, 2006,(7), 30-35.

178. Sundaram, A., Bokor, D. J., and Davidson, A. S., Rugby Union on-field position and its relationship to shoulder injury leading to anterior reconstruction for instability. *Journal of Science and Medicine in Sport*, 2011, 14, (2), 111-114.

179. Hendricks, S, Karpul, D, Nicholls, F, and Lambert, M, Velocity and acceleration before the Tackle in Rugby Union. *Journal of Sports Sciences*, 2011, 30 (12), 1215-1224.

180. Usman, J., McIntosh, A. S., and Frechede, B., An investigation of shoulder forces in active shoulder tackles in rugby union football. *Journal of Science and Medicine in Sport*, 2011, 14, (6), 547-552.

181. Burkett, B. Sport mechanics for coaches. Champaign, IL: Human Kinetics, 2010.

182. Blazevich A. Sports Biomechanics: The basics: optimising human performance. London: A&C Black Publishers Ltd, 2007.

183. Good, D. W., Leonard, M., Lui, D., Morris, S., and McElwain, J. P., Acetabular fractures following rugby tackles: a case series. *Journal of Medical Case Reports*, 2011, 5, 505-509.

184. Docherty, D., Wenger, H. A., and Neary, P., Time-motion analysis related to the physiological demands of rugby. *Journal of Human Movement Studies*, 1988, 14, 269-277.

185. Young, W. B., James, R., and Montgomery, I., Is muscle power related to running speed with changes of direction? *Journal of Sports Medicine and Physical Fitness*, 2002, 42, (3), 282-288.

186. Gabbett, T. J., Jenkins, D. G., and Abernethy, B., Correlates of tackling ability in high-performance rugby league players. *The Journal of Strength & Conditioning Research*, 2011, 25, (1), 72-79.

187. Longo, U. G., Huijsmans, P. E., Maffulli, N., Denaro, V., and De Beer, J. F., Video analysis of the mechanisms of shoulder dislocation in four elite rugby players. *Journal of Orthopaedic Science*, 2011, 16, (4), 389-397.

188. Smart, D., Hopkins, W. G., Quarrie, K. L., and Gill, N., The relationship between physical fitness and game behaviours in rugby union players. *European Journal of Sport Science*, 2011, iFirst article, 1-10.

189. Austin, D., Gabbett, T., and Jenkins, D., Repeated high-intensity exercise in professional rugby union. *Journal of Sports Sciences*, 2011, 29, (10), 1105-1112.

190. Lago, C., The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *Journal of Sports Sciences*, 2009, 27, (13), 1463-1469.

191. Taylor, J. B., Mellalieu, S. D., James, N., and Shearer, D. A., The influence of match location, quality of opposition, and match status on technical performance in professional association football. *Journal of Sports Sciences*, 2008, 26, (9), 885-895.

192. Marcelino, R., Mesquita, I., and Sampaio, J., Effects of quality of opposition and match status on technical and tactical performances in elite volleyball. *Journal of Sports Sciences*, 2011, 29, (7), 733-741.

193. Westgate, P, The Principles and Techniques of Defence in Rugby Union. *http://www rfu com/TakingPart/Coach/CoachResourceArchive/TechnicalJournalArchive/~/media/Files/2009 /Coaching/Articles/TechnicalJournal/2007/4thQuarter/5defence20lecturepaulwestgate ashx*, 2007.

194. Gréhaigne, JF, Richard, JF, and Richard, L. Teaching and learning team sports and games. New York: Routledge, 2005.

195. International Rugby Board Game Analysis, statistical review and match analysis 2011 RBS 6 Nations. 2011.

196. International Rugby Board Game Analysis, statistical review and match analysis 2011Tri Nations. 2011.

197. International Rugby Board Game Analysis, Statistical Review and Match Analysis 2011 Rugby World Cup. 2011.

198. Passos, P., Milho, J., Fonseca, S., Borges, J., Araujo, D., and Davids, K., Interpersonal distance regulates functional grouping tendencies of agents in team sports. *Journal of Motor Behavior*, 2011, 43, (2), 155-163.

199. McGarry, T., Anderson, D. I., Wallace, S. A., Hughes, M. D., and Franks, I. M., Sport competition as a dynamical self-organizing system. *Journal of Sports Sciences*, 2002, 20, (10), 771-781.

200. Ortega, E., Villarejo, D., and Palao, J. M., Differences in game statistics between winning and losing rugby teams in the Six Nations Tournament. *Journal of Sport Science and Medicine*, 2009, 8, 523-527.

201. Glazier, P. S., Game, set and match? Substantive issues and future directions in performance analysis. *Sports Medicine*, 2010, 40, (8), 625-634.

202. Vilar, L., Araujo, D., Davids, K., and Button, C., The role of ecological dynamics in analysing performance in team sports. *Sports Medicine*, 2012, 42, (1), 1-10.

203. Gomez, M. A., Lorenzo, A., Ibanez, S. J., Ortega, E., Leite, N., and Sampaio, J., An analysis of defensive strategies used by home and away basketball teams. *Perceptual Motor Skills*, 2010, 110, (1), 159-166.

204. Hughes, M. D. and Bartlett, R. M., The use of performance indicators in performance analysis, *Journal of Sports Sciences*, 2002, 20, (10), 739-754.

205. Jones, N. M., James, N., and Mellalieu, S. D., An objective method for depicting team performance in elite professional rugby union. *Journal of Sports Sciences*, 2008, 26, (7), 691-700.

206. Duthie, G., Pyne, D., and Hooper, S., Time motion analysis of 2001 and 2002 super 12 rugby, *Journal of Sports Sciences*, 2005, 23, (5), 523-530.

207. Roberts, S. P., Trewartha, G., Higgitt, R. J., El-Abd, J., and Stokes, K. A., The physical demands of elite English rugby union. *Journal of Sports Sciences*, 2008, 26, (8), 825-833.

208. Biscombe, T. and Drewett, P. Rugby Steps to Success. Champaign, IL: Human Kinetics, 2010.